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3

Determinants of the Shadow Value of Simultaneous Information Sharing in the Japanese Machine-Tool Manufacturing Industry

Hiroyuki Chuma

3.1 Introduction

As discussed in more detail in the previous chapter, Japan is widely known for its use of participatory employment practices, involving employees in a substantive way in many firm decision-making processes. Information sharing is one such participatory employment practice. Information sharing and collaboration across business components have proved to be important and valuable employment practices in Japanese firms, enabling workers with different core responsibilities to interact more effectively. The value of such information sharing is particularly apparent in the interaction between those who design production processes and those who execute them. This paper is a case study of the value of information sharing to the machine-tool industry, and how information sharing has contributed to the success of the machine-tool industry in recent decades.

Until the mid-1970s, Japanese machine-tool manufacturers lagged far behind their U.S. and German counterparts. The advent of computerized numerical control (CNC) complex lathes or machining centers (MCs)[1] drastically changed this situation (Finegold 1994; Finegold et al. 1994; Fleischer 1997; or Kobayashi and Ohdaka 1995). Indeed, since 1982, Japanese machine-tool manufacturers have led the industry, producing the world's largest (U.S. dollar) amount of machine tools.[2] The following external and technological factors are normally credited with spurring the

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[1] Most of these are flexible, general-purpose machines.

[2] In 1975, Japan occupied the fourth position, just after the former Soviet Union. The United States occupied the first position and the former West Germany the second.

rapid development of the Japanese machine-tool industry since the late 1970s:[3] (a) the extensive expansion of the Japanese automobile industry, represented by Toyota, Nissan, and Honda, which in 1981 surpassed all other countries in unit sales; (b) the "leap-forward" development of Japanese mechatronics manufacturers, represented by Fanuc, Mitsubishi Electric, and Yaskawa Electric, who provided superior numerical control devices and software; (c) the rapid development of precision-parts manufacturers, such as NSK, NTN, or THK, who could supply bearings, ball screws, and linear guideways; and (d) the basic development of foundry engineering technology, represented by automatic control technology for annealing, which effectively removes casting stresses.

Needless to say, each of these factors has played a very important role in the rise of the machine-tool industry. Chuma (1998) shows, however, that there is a very important human-related factor: (e) the existence of a formal simultaneous information-sharing system in which, even in the early stages of fundamental machine design, development and design (D&D) engineers can exchange opinions with production shop managers. Mechanical designers have multitudinous details to bear in mind when designing complex, modern CNC machine tools. Except in very rare cases, keeping track of everything is almost impossible, even for first-rate designers. Introducing a simultaneous information-sharing system linking highly skilled machinists and D&D engineers at early stages of product development will reduce lead time.[4]

The ever-increasing importance of information-sharing systems has generated an increase in the premium paid to broadly skilled production workers (ones with so-called "integrated skills"; Koike 1999). As machines have become more and more complex both mechanically and electrically, problem-solving skills have become more important for shortening lead time in machine development. Here, "problem-solving skills" broadly refers to the ability to anticipate and prevent problems with machines. These skills require logical thinking and abundant experience with machine problems. Without this broad skill base, production workers and engineers could not properly communicate and would therefore be unable to anticipate and improvise solutions to the diversity of problems that invariably arise in newly developed complex machines.[5]

[3] The strong role of the government, especially that played by the Ministry of International Trade and Industry (MITI) could be added to these four factors. However, there are contrasting views on this subject. Thus, we do not consider it. For more on this factor, see Friedman (1988), Holland (1992), Kobayashi and Ohdaka (1995), or Miwa (1998).

[4] A similar point, based on a few case studies of new machine development processes used by German, Italian, Japanese, and U.S. machine-tool manufacturers, can be found in several papers in Jurgens (1999). However, the argument has never been statistically validated. Moreover, the cases profiled are not rich enough to introduce a specific machine development process, as is done in this paper.

[5] In this sense, contrary to Braverman's (1978) naive conjecture, the advent of CNC complex lathes, or MCs, through the mechatronics revolution is apt to induce upskilling rather than deskilling of machine-tool manufacturers.

The main purpose of this paper is to empirically test these conjectures using information from basic field research as well as a statistical analysis of an original survey.

The structure of this paper is as follows. In the next section, an outline of the research method is introduced. In section 3.3, I briefly summarize the external and technological factors that have favored Japanese machine-tool manufacturers since 1970. Sections 3.4 and 3.5 are the main sections of the paper. Section 3.4 introduces the gist of the simultaneous information-sharing system for developing new machines, based on field research. Section 3.5 considers economic rationales for such a system and statistically confirms my conjectures using an original survey. The final section summarizes the results.

3.2 The Research Method

I investigated twelve representative Japanese machine-tool manufacturers from September 1996 to March 2000. Seven of these firms are large-scale manufacturers, with more than 1,000 full-time employees. The other five have less than 500 full-time employees.[6] These firms can be classified into four groups. The first group produces high- or medium-class machines that are mass-produced abroad as well as in Japan. The second group mass-produces high- or medium-class machines that are only domestically produced and are largely exported to the United States or Europe. The third group mass-produces low-cost machines that are only domestically produced and are largely exported to developing countries such as Asian newly industrialized economies. The final group consists of mother-machine-type MCs with extraordinary tolerances that are only domestically produced. Thus, these firms are nicely varied for my research purposes.[7] In selecting these firms, I was advised by an industry specialist who is actively involved in the top-rated machine-tool industry journal in Japan, *Seisan-zai Marketing Shi* (*Capital Goods Marketing Journal*), which is analogous to *American Machinists* in the United States.[8]

In addition to the field research, I also conducted a survey of about 600 machine-tool and related firms in March 1998. These firms constitute the population of firms in the machine-tool industry as identified by the *Almanac of Office Automation,* a publication issued annually by *Seisan-zai Marketing Shi.* This almanac includes nearly all of the machine-tool manufacturers in Japan. I asked a supervisor (such as a foreman) in the as-

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[6] Although the results are not explicitly introduced here, I also visited an NC manufacturer, an LM guideway manufacturer, and three German machine-tool manufacturers.

[7] I visited each shop floor or R&D section at least twice, and each interview lasted approximately two hours excluding time for factory tours. The details of this research are in Chuma (1998).

[8] I was introduced to this expert by a researcher from the Association of the Japanese Machine Tool Industry.

sembly or machining shop of each company to fill out the questionnaire. The response rate was approximately 20 percent.

3.3 External and Technological Factors

In this section, I briefly introduce external and technological factors that have aided the development of the Japanese machine-tool industry since 1970. The human factors emphasized in this paper must be analyzed in the context of these other factors. As illustrated in the statistical analysis that follows, it is the combination of all of these factors that has induced the development (albeit a discontinuous one) of this industry.

One crucial factor has been the rapid development of the Japanese auto industry, represented by Toyota, Nissan, and Honda. About 60 percent of domestic machine tools are demanded by auto and auto parts manufacturers. Moreover, if auto-related molding and electric equipment manufacturers are included, the corresponding percentage is much higher. The link between the machine-tool and auto industries is reflected by the fact that Japanese auto makers produced the world's largest output in their industry in 1981, and Japanese machine-tool manufacturers accomplished the same feat in 1982. Japanese machine-tool manufacturers are also considered expert at making CNC composite lathes, or MCs, whose prices range from $100,000 to $500,000.

Another primary factor has been the development of the Japanese mechatronics industry, represented by Fanuc, Mitsubishi Electric, and Yaskawa Electric. The numerical control (NC) technology owned by these companies has long been considered very sophisticated in world markets, particularly since the early 1980s (for details, see Finegold 1994 or Kobayashi and Ohdaka 1995). Normally, machine-tool manufacturers collaborate with NC manufacturers in order to enhance the motion controllability of their machines. This is one reason Japanese machine-tool manufacturers continue to enjoy a substantial advantage in the advanced controllability of high-speed and high-precision machines. Of course, mechatronics manufacturers must be compensated for their contributions. Indeed, my field research suggests that 30 to 40 percent of total machine-tool costs are spent in order to utilize this high NC technology (including both software and hardware), regardless of whether the technology was developed by the machine-tool manufacturers themselves.[9]

A third important factor has been the development of the Japanese bearing, ball screw, and guideway manufacturing industries, represented by NSK, NTN, and THK. As is the case for NC technology, these high-

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[9] Such heavy reliance on the mechatronics industry has been interpreted by many Japanese machine-tool manufacturers as an industry crisis, and the demand for open NC interfaces has greatly increased.

precision parts are typically specific to individual machine-tool manufacturers. Therefore, a long-term relationship between these parts suppliers and machine-tool manufacturers is again desirable.[10] In other words, having easy access to high-precision parts manufacturers is quite beneficial to machine-tool manufacturers. One of the most influential of the high-precision parts is the linear motion guideway (LM guide), which was invented by THK about twenty-five years ago. Before the LM guide, slide guideways that required highly advanced hand-scraping skills[11] in order to guarantee a micron level of precision were quite common. The LM guide, however, significantly reduced the need for hand scraping without sacrificing the controllability of machines.[12] This is reflected in the fact that most of the machine-tool manufacturers I visited claimed that their payments to parts manufacturers constitute 10 to 20 percent of their total costs.

The fourth factor has been the rapid development of foundry engineering as represented by the automatic control technology for annealing to promptly remove casting stresses. In fact, this technology was invented about twenty years ago. In my field research, many engineers emphasized the fact that high-quality iron castings became cheaper due to the spread of annealing furnaces equipped with advanced automatic process control technology. The modern casting process uses open-arc or annealing furnaces. It requires precision in all aspects of the production process, including time, temperature, and ingredients, and so it must be automatically controlled in order to produce high-quality products. Many Japanese machinery manufacturers have invented very precise controlling technologies. Before these innovations, manufacturers placed iron castings around their factories for (natural) aging. In fact, one reason German and Swiss machine-tool manufacturers of the pre-innovation era were very proud of the stability of their high-precision machines was that they used high-quality iron castings that had undergone long-term aging. Nowadays, similar aging effects can easily be achieved by three to six hours of stress relief annealing inside a furnace of 500 to 550 degrees centigrade (Monma 1997). Many of the research and development (R&D) engineers I interviewed mentioned that the availability of high-quality iron castings is no longer a bottleneck in the production of high-quality machines.

3.4 Simultaneous Information Sharing during the Development Process

In this section we examine the types of simultaneous information sharing that take place in the Japanese machine-tool industry. We use manufacturer

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[10] Several representative machine-tool manufacturers produce their own ball screws.

[11] Hand-scraping skills are among the most difficult craft-type skills, even though the motion is seemingly repetitive and physically demanding.

[12] It is sometimes claimed that slide guideways are still much better than LM guides for maintaining micron or submicron levels of machine precision for heavy-duty jobs (Bates 1999).

B, a leading Japanese machine-tool manufacturer, as an example of how new machine ideas are developed and what kind of information sharing takes place when a firm produces experimental machines in anticipation of commercial production. Similar machine development processes have been introduced in most of the twelve machine-tool manufacturers I investigated.

Before continuing, however, we need to distinguish among three types of drawings: prototype drawings, conceptual drawings, and component drawings. Prototype drawings outline the basic ideas for a potential new machine.[13] Conceptual drawings break the prototype drawings down into elaborately detailed sections. Conceptual drawings are sometimes called "drawings for assembly." After the conceptual drawings are complete, it is possible to make component drawings, which indicate the exact form and size of each part.[14] The recent development of computer-aided design (CAD) makes it possible to use the conceptual figures to calculate such things as the strength of the machine, the frequency of vibrations, and the thermal transformations that occur when the machine is heated up.

3.4.1 Examples of Leading Newly Developed Machines

We use the MC FF63S (not the real name) as an example of a leading machine at manufacturer B. This machine is characterized by a highly respected trade journal as a horizontal machining center "developed based on both the high-speed and high-precision technology that applies to high-level heat-control systems." More concretely, it can rapidly and precisely process medium- or large-sized output; its work-feeding speed reaches 30 meters per minute when special square-angled slide guideways are used. The development designer at manufacturer B, whom I interviewed, said that the main objective of this machine was to reduce total costs by 30 percent over the previous prototype, and that it actually reduces the processing time by 35 percent for certain auto parts manufacturers. This MC has sold well, especially in the United States.

3.4.2 The Process of Machine Development

Manufacturer B uses a rolling five-year development plan that lists each type of machine and its expected year of completion. This plan is closely

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[13] In these drawings, users' needs, competitors' machine specifications, and relevant concepts for strategically important components are clarified. Details are given on the forms and structures of ball screws and guideways, as well as the main spindle, which make it possible to attain the targeted cutting speed and precision. Designers try to simulate the main objectives in these drawings.

[14] In the case of main spindle units, the corresponding conceptual drawings consist of a three-dimensional figure and two-dimensional drawings that indicate the placement of bearings, springs, spacers, and so on. In these drawings, exact sizes, intervals between bearings, torque for screwing, and the like are given. The drawing for each main spindle, bearing, spacer, and so forth is called a component figure. Therefore, whether a drawing is a component or conceptual drawing depends to some extent on the mechanism of each machine.

aligned with the fundamental management plan. It clearly stipulates market conditions based on sales information, user feedback, related literature, newspapers, and other sources. A plan with a concrete timetable is created for each type of machine, such as grinding machines, machining centers, and made-to-order machines. The machines are principally planned by members of the machine-tool planning sections in the machine-tool and mechatronics divisions. Most of these planners were originally in the development and design division. In addition, participants from other departments, such as sales, production planning, machining and assembling, purchasing, quality control, and R&D give input. The FF63S was developed mainly in response to users' feedback.

3.4.3 Information Sharing in the Design Review 1

The development of the machining center FF63S was initiated in December 1994, when the machine was added to the five-year development plan. It was completed in 1995. Usually, a project manager is selected as soon as it is decided that a machine is to be developed. The manager immediately starts to make a commodity design plan, which verifies such strategic details as sales points, main specification comparisons with similar machines made by competitors, sales and profit plans, and users' current and future demands. In the case of FF63S, the project team studied sales information from the previous prototype machine, FF60B. They considered examples of inquiries about FF60B, an analysis of the main reasons why these specific inquiries did or did not lead to actual orders, and feedback from users after the sale. Section or department heads of the aforementioned departments typically join in making the commodity design plan.

After the commodity design plan has been successfully completed, the project manager[15] and his or her subordinates create a product design plan, which usually takes about two months. This plan includes the machine's main development objective, mechanical specifications, costs, expected development time, selling points, expected difficulties, quality target, design quality, method of product maintenance, and so on. In addition, it stipulates previously developed parts that are to be used. For example, a plan might include a comment such as "some parts of the main spindle of the previous machine can be used as they are." Moreover, in going from the commodity design plan to the product design plan, it is quite common to reevaluate the relevance of the users' development requests, which had been submitted early in the commodity design phase. Again, planning participants from various departments, especially department heads, provide input for revisions of the product design plan. For example, representatives from the machinists' division theorize on how they may or may not be able

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[15] I interviewed the project manager of FF63S himself.

to overcome the difficulties specified in the product design plan, and representatives from purchasing comment on the expected costs.

At manufacturer B, the meeting to discuss the product design plan proposed by the project manager is called the DR1 (design review 1). The basic ideas for the drawings (including the prototype drawings) are all decided upon in the DR1, and they are rarely modified thereafter. During the DR1 for the FF63S, the project chief was asked to clarify the precision and efficiency of the machine if used on the special projects of the specific users for whom the FF63S was being produced.

3.4.4 Information Sharing in the Design Review 2

If the product design plan passes the DR1, conceptual drawings are made based on the commodity design plan. The relevance of these drawings is discussed in the design review 2 (DR2). At this stage, even the exterior face of the machine is sketched in detail. In other words, the conceptual drawings are quite complicated and precise. The section managers of the sales, production planning, machining and assembling, purchasing, quality control department, and R&D departments participate in the DR2. For example, representatives from the assembly shop may comment on the feasibility of the tolerances indicated in the drawings.

In order to estimate the total costs of the new machine, the conceptual drawings specify the man-hours needed to build the machine and the corresponding total and unit labor costs. In addition, materials costs, energy costs, and the costs of using the company's facilities are specified. Then, representatives from the machining and assembly shops voice their opinions on the accuracy of the proposed man-hours, and sometimes change the estimates. Of course, it is desirable for assembly workers and machinists to secure sufficient time in which to complete their assigned tasks. Indeed, the man-hours determined in the DR2 become the standard against which actual man-hours are measured in the commercial production phase. However, since management insists on optimal cost-efficiency, the man-hours needed for assembly or machining must be as small as possible. It is in the DR2 that such adjustments are made. I should note that, for most projects, there is a general consensus among the planning participants regarding required man-hours for assembly or machining, based on past job experience or working records. Lastly, when tolerances required by the conceptual drawings exceed the level attainable using existing hardware, representatives from the machining shops are likely to request permission to purchase new hardware.

3.4.5 Information Sharing in the Design Review 3

After the conceptual design is accepted in the DR2, work on various component drawings begins immediately. Only drawings of important parts (e.g., the main spindle) that have been drastically changed from the previous prototype are reviewed in the design review 3 (DR3). The designers in charge decide whether or not a drawing needs to be reviewed. I should note here that reviewers from all departments utilize the same set of drawings during all the design reviews, regardless of affiliation. In other words, representative reviewers from sales, services, and production shops all review every DR3 drawing. Their opinions are also applied to the DR1 and DR2 drawings. For example, in the DR3, representatives from the assembly shop may claim that the assembly tasks depicted in a certain drawing are quite difficult and must be changed. Or representatives from the machining shop may claim that the shape of the machine as depicted in the drawings requires too many man-hours and so ought to be changed. In this way, professionals from various departments exchange opinions about the feasibility and reliability of the proposed machine.

3.4.6 Information Sharing during Experimental Production

After the DR3, experimental production begins. This used to be done by assembly workers and machinists on the shop floor. Recently, however, firms have begun to form special teams on a trial basis that specialize in experimental production. Standard working manuals are also written in this phase. To create these manuals, factory engineers conduct time studies using stopwatches or by interviewing the workers in charge in order to determine the standard working time for each task. However, the factory engineers do not unilaterally determine standard working time. Rather, it is determined by a combination of discussion and this evidence. Work improvement proposals are also written at this stage. In the case of the FF63S, about a year passed between the proposal of the commodity design plan and the completion of the first experimental machine. Five months passed between the beginning of experimental production and the completion of test cutting.

Normally, only one or two experimental machines are produced. After that, about ten commercial machines are produced for specific users. These twelve machines are used in part to uncover and eliminate bugs. For example, if cut chips tend to block efficient cutting, the chip-handling system is redesigned. If some part of the machine is not strong enough, the design flaw will be corrected. In the case of the FF63S, a new technology was used that automatically controls the thermal expansion expected to occur around the main spindle. However, this control system did not work reliably in the experimental production stage, and several technological breakthroughs were needed to fix it.

It is not uncommon for mechanical designers to try to immediately correct machine defects in the assembly shops. They are apt to stay in the shops during the whole of experimental production. Project leaders or chief design managers sometimes instruct their subordinates to work alongside the assembly workers while they are assembling the machine.

The objective is to avoid delays caused by insufficiently detailed drawings, because the ambiguity can be clarified immediately. The project manager of the FF63S explained,

> Without experience, it is very difficult to understand the gist of machine-tool mechanics. It can be quite dangerous to design machines without knowing how each machine is processed and assembled in the shop. To effectively design new machines and machine parts, mechanical designers have to have an understanding of the skill level of the assemblymen and machinists as well as the production capacity and finishing ability of company-owned facilities.

3.5 The Necessity for Simultaneous Information Sharing

3.5.1 Intuition Acquired from Field Research

The simultaneous information-sharing system linking mechanical designers and production workers has been broadly utilized and institutionalized by all of the machine-tool manufacturers we investigated. However, many have begun to criticize it, saying that the Japanese practice of regarding the common consensus as first best is outdated. However, the head of the technology department of manufacturer B pointed out the following very interesting fact:

> It is an established fact that we think highly of simultaneous information sharing among our various departments and divisions. This practice has been well established for about ten years—since the so-called TQC began to be widely practiced. Certainly, people shared a sense of family even before then, and consensus was important in various aspects of our production process. The current, rather egalitarian information-sharing system, however, was established in the 1980s, at which point certain types of sectionalism were almost wiped out and collaboration started to play a more important role. Twenty or thirty years ago, the technology department unilaterally presided over the production department. In a sense, engineers in the technology department encouraged production workers to do a good job in a paternalistic way. Also, they had the arrogance to say that the production workers had only to faithfully follow their instructions in order to produce good machines. However, such a unilateral relationship could not produce good products. As a result, the current design review system was introduced, based on the idea that, because only assembly and machining shops produce actual products, machine drawings must respect the shops' ways of doing things and take into account the various shops' constraints.

Total quality control (TQC) practices were well established by the 1960s in the Japanese automobile and household appliance industries (Udagawa et al. 1995). They have been utilized well into the 1980s, at least for manufacturer B (see the foregoing quotation). If this were true for all other machine-tool manufacturers, we could claim, contrary to the generally accepted notion, that the simultaneous information-sharing system linking production workers and engineers was established only recently. In other words, the system is not indigenous to Japan, but came into existence as the efficient production system of the period of rapid globalization in the 1980s. Indeed, our survey revealed the following: About 62 percent of machine-tool manufacturers[16] with close information sharing between mechanical designers and production workers answered that their system was initiated after 1980. This number increases to 74 percent when we include manufacturers who reported initiating their systems after 1970.

Why was the current egalitarian system of information sharing introduced fairly recently? The following comments from the mechanical designers of one of the largest machine-tool manufacturers in the industry help to answer this question:

> When traditional non-NC lathes or milling machines used to be produced, mechanical designers were very overconfident relative to the current standard. This was because they could theorize much of how these non-NC machines were built. However, their ability to do this gradually diminished as the machines became multifunctional, as in the case of machining centers or complex lathes, and equipped with CNC. This was reinforced by the advent of high-speed and high-precision machines equipped with ATC (auto tool changer) and APC (auto pallet changer). In the case of such complex machines, designers must take many factors into account beforehand in order to design a good machine. However, except in very rare cases, this is almost impossible. This is when the present simultaneous and egalitarian information-sharing system among our departments and divisions started to play an important role. Compared with the skills of machinists, the skills of first-rate assemblymen are primarily based on experience with a large number of fundamental laws. These skills are quite durable, even in the face of rapid technological development. As a result, assembly shops have become increasingly powerful.

Many engineers in the machine-tool manufacturing firms I investigated support the above statements. It is very interesting to note that, in contrast to automobile or household appliance manufacturers, none of the investigated machine-tool manufacturers have production or factory engineering sections (for assembly shops). These sections normally standardize assembling processes, manage production processes, or serve as an interface between production workers and R&D engineers or designers. Their absence underscores the necessity for close and simultaneous information sharing during the development process.[17]

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[16] Only 7 percent say they have no such close information-sharing system.

[17] Only one of the machine-tool manufacturers I visited had such a section. However, upon further investigation, this section was found not to play the same role as an ordinary production engineering section.

Lastly, some people maintain that information sharing between production workers and engineers was practiced even in the prewar period. The following examples support this claim. According to Tokyo Gas Electric (now Hitachi Fine Machinery),

> The first stage of production management is design. In 1933, when we were still in a depression, the company employed 2 to 3 university graduates as designers of milling machines in a particular series. We had established a system in which the designers were responsible for all defects in the machines, so that it was quite troublesome when machines could not be produced as designed. All members of the production team thought hard about any problems that arose, and tried to improve the machines. It was not rare for young designers to take special on-the-job lessons in machining or assembly from skilled workers. Such an environment created excellent designers. (Miyazaki 1997)

According to Seiko,

> Around the last half of the 1920s, university graduates in the engineering section responsible for design who had insufficient knowledge of manufacturing technology were grouped together with assembly workers who had strong project-specific skills but were weak in theoretical understanding. They developed new products together. In this process, new products were revised again and again by both designers and skilled workers. They were put into commercial production only when no more defects could be found by any of the group's members. The close relationship between designers and skilled workers at that time reminds us of the current-style production process. (Odaka 1993, 151)

To be sure, it can be surmised from these statements that a form of mutual understanding between engineers and production workers played an important role in manufacturing even in the prewar period. However, Yamashita (1999) also introduces evidence collected from interviews with several former Tokyo Gas Electric engineers that suggests that even informal communication between production workers and engineers was quite rare in the prewar Tokyo Gas Electric, in direct contradiction to the above example. Thus, it is doubtful that the current type of simultaneous information system existed in the prewar period.[18]

3.5.2 Statistical Analysis

As indicated in the previous section, the advent of CNC complex lathes or MCs increased the need for simultaneous information sharing between production workers and design and development engineers. To show this statistically, we estimate a probit equation (1) allowing for heteroskedas-

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[18] Prewar evidence of informal and rather sporadic information sharing in Nihon Denki (the current NEC), Shibaura Seisaku-sho (the current Toshiba), and Mitsubishi Electric (a part of the former Mitsubishi Heavy Industry) is introduced in Sasaki (1998).

ticity. In this equation, the dependent dummy variable d_sinfo1 takes on a value of one if the firm answered "yes" to the following question: "Does your company (or factory) have a formal design review system in which, even in the early states of machine development, both R&D (or D&D) engineers and production workers simultaneously and directly exchange opinions?"

In the sample of 108 respondents, 67 percent answered "yes." In addition to this dependent variable (d_sinfo1), we also use two other dependent variables: d_sinfo2 and d_sinfo3. The dummy variable d_sinfo2 takes on a value of one if d_sinfo = 1 and the firm introduced this information-sharing system in 1980 or later. The dummy variable d_sinfo3 takes on a value of one if d_sinfo1 = 1 and the system was introduced in 1970 or later. These additional variables are utilized because the field research suggests that information-sharing systems were mainly introduced after 1980. Indeed, 41 percent of firms are in the d_sinfo2 = 1 sample and 50 percent are in the d_sinfo3 = 1 sample, so a large number of manufacturers introduced the system after 1980. Description of the independent variables (X_i) used are provided in the appendix.

$$(1)\quad \text{d\_sinfo1} = 1 \text{ if} \left(\alpha_0 + \sum_{i=1}^{i=n} \alpha_i X_i + \varepsilon \geq 0 \right); = 0 \text{ otherwise for } j = 1, 2, 3$$

where α_i = coefficients, X_i = independent variables ($i = 1, 2, \ldots n$), $\varepsilon \in \phi\,(0, 1)$ (the standard normal distribution).

The estimation results are shown in tables 3.1 through 3.3. Generally speaking, the most favorable results employ the dependent variable d_sinfo2, the next most favorable use d_sinfo3, and the least favorable use d_sinfo1. This indicates that the need for simultaneous information sharing between production workers and design and development engineers has increased, especially since 1980. This is also the period during which Japanese machine-tool manufacturers have consistently maintained the world's largest machine-tool production.

According to table 3.1, d_sinfo1 is positively correlated with the explanatory variables d_integ, d_ptime and d_TQC, all of whose coefficients are significant at the 1 percent level. The dummy variable d_integ takes on a value of one if the manufacturer answered "Yes" to the question: "In training your regular assemblymen, do you basically make them gain broad skills and know-how for both main- and parts-assembling processes?" The dummy variable d_ptime indicates that the sampled manufacturer employs nonregular employees such as part-timers. The dummy variable d_TQC that takes on a value of one if the firm has introduced TQC activities. The negatively correlated variables, significant at the same level, are OVERSEAS and d_pswar. The dummy variable OVERSEAS indicates that the firm has directly produced machines overseas using a production process that is quite different from that used for domestic production. The

Table 3.1 The Effects of Firm Characteristics on the Probability of Adoption of a Simultaneous Information-Sharing Design Review System (d_sinfo1)

					95% Confidence Interval		
d_sinfo1	Coefficient	Standard Error	*z*	$P > \lvert z \rvert$	(1)	(2)	dP/dx
_cons*	–1.42	0.81	–1.75	0.08	–3.01	0.17	—
method	0.47	0.35	1.33	0.19	–0.22	1.16	0.1
d_integ***	**1.14**	**0.42**	**2.73**	**0.01**	**0.32**	**1.95**	**0.4**
d_early**	**0.72**	**0.32**	**2.20**	**0.03**	**0.08**	**1.35**	**0.2**
d_mfunc*	1.41	0.83	1.70	0.09	–0.22	3.04	0.3
d_mfunc2	0.15	0.76	0.20	0.84	–1.34	1.63	0.0
d_scrape**	**1.11**	**0.56**	**1.98**	**0.05**	**0.01**	**2.21**	**0.3**
d_tshoot**	**1.10**	**0.47**	**2.35**	**0.02**	**0.18**	**2.01**	**0.4**
skillrat	–0.14	0.23	–0.61	0.54	–0.58	0.30	(0.0)
d_ptime***	**0.94**	**0.36**	**2.62**	**0.01**	**0.24**	**1.65**	**0.3**
d_TQC***	**0.87**	**0.32**	**2.73**	**0.01**	**0.25**	**1.49**	**0.3**
d_experi	0.41	0.40	1.03	0.30	–0.37	1.18	0.1
overseas***	**–1.69**	**0.47**	**–3.61**	**0.00**	**–2.61**	**–0.78**	**(0.6)**
d_pubedu	0.18	0.39	0.45	0.65	–0.59	0.95	0.1
d_intwar	–0.77	0.56	–1.37	0.17	–1.87	0.33	(0.3)
d_pstwar***	**–1.44**	**0.52**	**–2.76**	**0.01**	**–2.47**	**–0.42**	**(0.4)**
d_lathe	0.07	0.43	0.16	0.87	–0.78	0.91	0.0
d_MC	–0.09	0.42	–0.20	0.84	–0.92	0.75	(0.0)
d_Drill	–0.94	0.75	–1.25	0.21	–2.41	0.53	(0.3)
d_Boring	0.15	0.83	0.18	0.86	–1.49	1.78	0.0
d_GeaGrd*	0.69	0.36	1.92	0.06	–0.02	1.40	0.2
d_IND	–0.04	0.38	–0.10	0.92	–0.78	0.71	(0.0)
d_Misc	–0.33	0.32	–1.03	0.30	–0.96	0.30	(0.1)
d_spoint	–0.55	0.37	–1.50	0.13	–1.27	0.17	(0.2)
d_spoint2	–0.07	0.30	–0.25	0.81	–0.66	0.51	(0.0)
scale100	0.54	0.39	1.39	0.16	–0.22	1.30	0.2
N	108						
Pseudo-R^2	0.32						
Log-likelihood	46.59415						

Notes: Probit estimates of equation (1) with robust standard errors. Obs. *P*(d_sinfo1 = 1) = 0.67; pred. *P*(d_sinfo1 = 1) = 0.75 (at x-bar). Boldface indicates that the variables are statistically significant.

***$P \leq .01$.

**$P \leq .05$.

*$P \leq .10$.

variable d_pswar is a dummy variable that takes on a value of one if the manufacturer was founded after World War II (WWII).

The result that d_integ positively and significantly increases the probability of introducing a simultaneous information-sharing system is expected a priori because, other things being equal, it suggests that assembly workers are broadly skilled. The positive and significant impact of d_TQC

Table 3.2 The Effects of Firm Characteristics on the Probability of Adoption of a Simultaneous Information-Sharing Design Review System since 1980 (d_sinfo2)

					95% Confidence Interval		
d_sinfo2	Coefficient	Standard Error	z	$P > \lvert z \rvert$	(1)	(2)	dP/dx
_cons***	**–3.25**	**1.01**	**–3.23**	**0.00**	**–5.23**	**–1.28**	—
method***	**1.42**	**0.51**	**2.81**	**0.01**	**0.43**	**2.41**	**0.5**
d_integ*	0.94	0.49	1.90	0.06	–0.03	1.90	0.3
d_early**	**0.87**	**0.42**	**2.08**	**0.04**	**0.05**	**1.69**	**0.3**
d_mfunc***	**2.36**	**0.86**	**2.75**	**0.01**	**0.67**	**4.04**	**0.7**
d_mfunc2	0.58	0.82	0.71	0.48	–1.03	2.19	0.2
d_scrape***	**1.94**	**0.64**	**3.03**	**0.00**	**0.68**	**3.19**	**0.6**
d_tshoot***	**1.97**	**0.59**	**3.31**	**0.00**	**0.80**	**3.13**	**0.6**
skillrat	–0.15	0.27	–0.55	0.59	–0.67	0.38	(0.1)
d_ptime***	**1.97**	**0.46**	**4.24**	**0.00**	**1.06**	**2.87**	**0.7**
d_TQC***	**1.07**	**0.41**	**2.62**	**0.01**	**0.27**	**1.87**	**0.4**
d_experi***	**1.40**	**0.51**	**2.77**	**0.01**	**0.41**	**2.39**	**0.4**
overseas***	**–2.65**	**0.72**	**–3.70**	**0.00**	**–4.06**	**–1.25**	**(0.5)**
d_pubedu***	**1.92**	**0.50**	**3.82**	**0.00**	**0.94**	**2.91**	**0.6**
d_intwar***	**–4.24**	**0.83**	**–5.10**	**0.00**	**–5.87**	**–2.61**	**(0.7)**
d_pstwar***	**–2.69**	**0.78**	**–3.46**	**0.00**	**–4.21**	**–1.16**	**(0.8)**
d_lathe***	**1.52**	**0.53**	**2.86**	**0.00**	**0.48**	**2.56**	**0.6**
d_MC*	1.22	0.70	1.74	0.08	–0.16	2.61	0.5
d_Drill**	**–2.08**	**0.85**	**–2.45**	**0.02**	**–3.76**	**–0.41**	**(0.5)**
d_Boring	–1.22	0.79	–1.54	0.13	–2.77	0.34	(0.3)
d_GeaGrd	0.48	0.49	0.98	0.33	–0.47	1.43	0.2
d_IND	0.46	0.49	0.95	0.34	–0.49	1.42	0.2
d_Misc***	**–2.00**	**0.45**	**–4.43**	**0.00**	**–2.88**	**–1.11**	**(0.6)**
d_spoint***	**–1.35**	**0.45**	**–3.02**	**0.00**	**–2.22**	**–0.47**	**(0.4)**
d_spoint2	–0.46	0.38	–1.21	0.23	–1.20	0.28	(0.2)
scale100***	**1.50**	**0.52**	**2.91**	**0.00**	**0.49**	**2.52**	**0.5**
N	108						
Pseudo-R^2	0.56						
Log-likelihood	32.03						

Notes: Probit estimates of equation (1) with robust standard errors. Obs. P(d_sinfo1 = 1) = 0.41; pred. P(d_sinfo1 = 1) = 0.37 (at x-bar). Boldface indicates that the variables are statistically significant.

***$P \leq .01$.

**$P \leq .05$.

*$P \leq .10$.

is also consistent with my conjectures. As for the OVERSEAS dummy, my field research suggests that most machine-tool manufacturers involved in overseas production (12 percent of the sample) mass-produce machine-tools based on expected demand. Compared with user-specific machines, mass-produced machines are less demanding of assembling and machining skills. Thus, OVERSEAS has a negative and significant impact. In addi-

Table 3.3 **The Effects of Firm Characteristics on the Probability of Adoption of a Simultaneous Information-Sharing Design Review System since 1970 (d_sinfo3)**

					95% Confidence Interval		
d_sinfo3	Coefficient	Standard Error	z	$P > \lvert z \rvert$	(1)	(2)	dP/dx
_cons*	–1.43	0.85	–1.68	0.09	–3.09	0.24	—
method	0.47	0.37	1.26	0.21	–0.26	1.20	0.2
d_integ***	**1.28**	**0.48**	**2.68**	**0.01**	**0.35**	**2.22**	**0.5**
d_early**	**0.84**	**0.37**	**2.28**	**0.02**	**0.12**	**1.56**	**0.3**
d_mfunc	0.48	0.60	0.81	0.42	–0.68	1.65	0.2
d_mfunc2	0.09	0.75	0.12	0.90	–1.37	1.56	0.0
d_scrape***	**1.10**	**0.57**	**1.93**	**0.05**	**–0.02**	**2.22**	**0.4**
d_tshoot	0.29	0.50	0.58	0.56	–0.68	1.26	0.1
skillrat	–0.14	0.22	–0.63	0.53	–0.58	0.30	(0.1)
d_ptime***	**1.58**	**0.40**	**3.94**	**0.00**	**0.80**	**2.37**	**0.6**
d_TQC**	**0.74**	**0.36**	**2.08**	**0.04**	**0.04**	**1.44**	**0.3**
d_experi*	0.69	0.38	1.80	0.07	–0.06	1.44	0.3
overseas***	**–1.84**	**0.49**	**–3.75**	**0.00**	**–2.81**	**–0.88**	**(0.6)**
d_pubedu***	**1.29**	**0.46**	**2.78**	**0.01**	**0.38**	**2.19**	**0.4**
d_intwar***	**–3.07**	**0.73**	**–4.20**	**0.00**	**–4.51**	**–1.64**	**(0.8)**
d_pstwar***	**–2.07**	**0.65**	**–3.20**	**0.00**	**–3.34**	**–0.80**	**(0.7)**
d_lathe**	**1.06**	**0.47**	**2.25**	**0.02**	**0.14**	**1.98**	**0.4**
d_MC**	**1.11**	**0.50**	**2.24**	**0.03**	**0.14**	**2.09**	**0.4**
d_Drill	–1.17	0.79	–1.47	0.14	–2.72	0.39	(0.4)
d_Boring**	**–1.45**	**0.74**	**–1.96**	**0.05**	**–2.91**	**0.00**	**(0.5)**
d_GeaGrd	0.10	0.37	0.26	0.79	–0.62	0.81	0.0
d_IND	0.47	0.37	1.25	0.21	–0.27	1.20	0.2
d_Misc***	**–1.05**	**0.35**	**–3.03**	**0.00**	**–1.73**	**–0.37**	**(0.4)**
d_spoint	–0.64	0.42	–1.51	0.13	–1.47	0.19	(0.3)
d_spoint2	–0.35	0.33	–1.04	0.30	–1.00	0.31	(0.1)
scale100***	**1.35**	**0.44**	**3.06**	**0.00**	**0.48**	**2.22**	**0.5**
N	108						
Pseudo-R^2	0.46						
Log-likelihood	–40.16						

Notes: Probit estimates of equation (1) with robust standard errors. Obs. P(d_sinfo1 = 1) = 0.50; pred. P(d_sinfo1 = 1) = 0.56 (at x-bar). Boldface indicates that the variables are statistically significant.

***$P \leq .01$.

**$P \leq .05$.

*$P \leq .10$.

tion, firms founded after WWII are more apt to specialize in mass-produced machines than are the more established firms. This is why d_pswar has as significant and negative an impact as OVERSEAS. I do now know why d_ptime has a significant, positive impact. However, my field research yields no definitive evidence that mass-producers use more nonregular workers. Accordingly, it is possible for d_ptime to a priori have either a positive or negative impact.

There are additional variables in table 3.1 that are significant at the 5 percent level. These are d_early, d_scrape, and d_tshoot. The dummy variable d_early takes on a value of one if the firm answered "yes" to the following question: "In order to foster your prospective leaders, are you concerned about putting talented assemblymen in charge of a wider range of work beginning in the early stages of their careers, so that they can gain integrated skills?" The dummy variable d_scrape implies that the most advanced job for assemblyworkers in the firm is hand scraping, which is required to attain the static or dynamic precision called for by the drawings. The dummy variable d_tshoot indicates that the most advanced job for assemblyworkers in the firm is that of troubleshooting in the shops (diagnosing and correcting both new and previously encountered bugs). All three of these variables indicate that the assemblyworkers in the firm are highly skilled. They significantly enhance the need for simultaneous information sharing between production workers and design and development engineers.

We note here that there are two or three other variables that are significant at the 10 percent level. Their significance, however, is highly dependent on the total sample size, so it is dangerous to draw conclusions based on these data alone. The highly significant coefficients are also significant in tables 3.2 and 3.3, whereas the less significant coefficients are not always robust to changes in the dependent variable.

As previously mentioned, the field research suggests that the need for simultaneous information sharing between production workers and design and development engineers has increased since the late 1970s. The fact that the number of significant (at the 1 percent or 5 percent level) variables jumps appreciably in tables 3.2 and 3.3 supports this suggestion.[19] It is especially apparent in table 3.2 for the dependent variable d_sinfo2, which takes on a value of 1 if d_sinfo1 = 1 and the system was introduced in 1980 or later. Additional variables with positive and significant coefficients in tables 3.2 and 3.3 are d_method, d_mfunc, d_experi, d_pubedu, d_lathe, d_MC, and scale100. The variables d_intwar, d_Drill, d_Misc, and d_spoint all have negative and significant coefficients.

The dummy variable d_method takes on a value of 1 if the total assembly method of high-speed/high-accuracy machines differs significantly from that of other machines. The dummy variable d_mfunc indicates that the firm tries to make its machinists multifunctional, since being responsible for many machines at once might allow them to troubleshoot more effectively. The variable d_experi indicates that, compared to machining skills, assembling skills in a firm are apt to withstand rapid technological innovation.[20] The dummy variable d_pubedu indicates that the firm requires

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[19] The significance of d_integ drops a little, but it is still significant at the 6 percent level.

[20] Actually, about 80 percent of the manufacturers interviewed for my survey reported that assembling skills are more likely to be internalized in a specific person than machining skills. Moreover, compared with machining skills, assembling skills are more dependent on many experienced laws.

public trade skill licenses for promotion. If the firm produces (CNC) lathes, the dummy variable d_lathe takes on a value of 1. If the firm produces machining centers, drilling machines, or miscellaneous machines, the dummy variables d_MC, d_Drill, and d_Misc respectively take on a value of 1. The dummy variable scale100 indicates that the firm has more than 100 full-time employees. The dummy variable d_intwar indicates that the firm was founded during the interwar period. Finally, the dummy variable d_spoint indicates that the firm's sales point is "low price."

The variable d_method is a proxy for whether the firm has highly skilled assemblyworkers; if the firm produces high-speed and high-precision machines, such workers are necessary. Thus, the positive and significant coefficient on d_method is consistent with a priori expectations. The variable d_mfunc implies that the machinists have broad skills. Hence, its significant and positive impact is also acceptable. The same interpretation is applicable to the coefficient on the variable d_experi because assembling skills rely heavily on rules of thumb. Insights from the field research are helpful in interpreting the significant positive impact of the variable d_pubedu. Machine-tool manufacturers that recommend acquiring public trade skill licenses also make the licenses mandatory for promotion in order to cope with fierce competition among production workers and to maintain the objectivity of promotion criteria. Hence, the significant positive result is comprehensible to some extent. The positive, significant impact of d_lathe or d_MC is also quite understandable because most of these lathes and MCs are the complex CNC machine types, through which Japanese machine-tool manufacturers attained their current leading position in the world market in the early 1980s.[21] The variable d_Drill indicates that the firm is still producing traditional drilling machines, so the significant negative impact can be given the opposite interpretation of d_lathe and d_MC. Only innovative manufacturers that maintained a certain firm scale could effectively survive the cutthroat competition among rival producers of high-speed and high-precision complex machines. Therefore, the positive and significant coefficient on scale100 is reasonable. Lastly, the negative and significant coefficient on d_spoint is quite natural, given that d_spoint represents a "low price" sales point.

Finally, the last columns in tables 3.1 through 3.3 show each variable's impact on the probability that simultaneous information sharing is introduced. Except for the constant (cons) and the skillrat variable, all the independent variables are dummies, so the impact is actually equivalent to the elasticity. In table 3.1, only d_integ and d_tshoot have a large, positive elasticity. Still, the impact of these variables is at most 0.4. In table 3.2, however, the number of variables with a large positive impact is much higher. Furthermore, the magnitudes are far greater than in table 3.1. Indeed, the following variables have an elasticity greater than 0.5: d_method,

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[21] Note that both d_lathe and d_MC are significant and positive even in table 2.3.

d_mfunc, d_scrape, d_tshoot, d_ptime, d_pubedu, d_lathe, d_MC, and scale100. These results suggest that simultaneous information-sharing systems are more likely to be introduced by machine-tool manufacturers that retain highly skilled assemblyworkers and machinists, produce (CNC) lathes or MCs, or have more than 100 full-time workers.

3.6 Summary and Conclusion

The Japanese machine-tool industry attained the position of world output leader in 1982 and has maintained this status ever since. This paper analyzes the factors that enabled this success. In this analysis, I assert the importance of human-related factors in addition to such popular technological factors as the extensive development of Japanese automakers, the "leap-forward" development of Japanese mechatronics manufacturers, the rapid development of precision-parts manufacturers, and the basic development of foundry engineering technology. I pay special attention to the existence of simultaneous and formal information-sharing systems between production workers and design and development engineers.

My analysis utilizes both field research and survey results. The field research reveals that the machine-tool industry employs a simultaneous and rather egalitarian information-sharing system linking production workers and design and development engineers. It is typically asserted that this kind of system is indigenous to Japan. However, the field research indicates that these systems have largely been implemented since 1980. I also investigate why the system was introduced so recently. One promising reason is that current CNC machines are so complex that, without close collaboration among the various professionals, mechanical designers could not effectively design machines to the last detail and keep lead times short. This last conjecture is statistically confirmed by the survey data. Indeed, the statistical analysis predicts that simultaneous information-sharing systems are more likely to be implemented by machine-tool manufacturers that retain highly skilled assemblyworkers and machinists, produce (CNC) lathes or MCs, and have more than 100 full-time workers.

Appendix

Legend

d_sinfo1	A dummy variable that takes on a value of one if the firm answered "yes" to the following question: "Does your company (or factory) have a formal design review system in which, even in early stages of machine development, both R&D (or D&D) engineers and production workers simultaneously and directly exchange opinions?"

d_sinfo2	A dummy variable that takes on a value of one if d_sinfo1 = 1 and the firm introduced this information-sharing system in 1980 or later
d_sinfo3	A dummy variable that takes on a value of one if d_sinfo1 = 1 and the system was introduced in 1970 or later
method	A dummy variable that takes on a value of one if the total assembly method of high-speed/high-accuracy machines differs significantly from that of other machines
d_integ	A dummy variable that takes on a value of one if the maker answered "yes" to the question: "In training your regular assemblymen, do you basically make them gain broad skills and know-how for both main- and parts-assembling processes?"
d_early	A dummy variable that takes on a value of one if the firm answered "yes" to the following question: "In order to foster your prospective leaders, are you concerned about putting talented assemblymen in charge of a wider range of work beginning in the early stages of their careers, so that they can gain integrated skills?"
d_mfunc	A dummy variable that takes on a value of one if the firm tries to make its machinists multifunctional because this might allow the machinists to understand the interaction between the machine tools and the parts they process
d_mfunc2	A dummy variable that takes on a value of one if the firm tries to make its machinists multifunctional because this might allow the machinists to troubleshoot more effectively
d_scrape	A dummy variable that takes on a value of one if the most advanced job for assemblyworkers in the firm is hand scraping
d_tshoot	A dummy variable that takes on a variable of one if the most advanced job for assemblyworkers in the firm is troubleshooting in the shops
skillrat	The percentage of (full-time) assemblyworkers that could fully manage all of the advanced jobs indicated in the question
d_ptime	A dummy variable that takes on a value of one if the manufacturer employs nonregular employees such as part-timers
d_TQC	A dummy variable that takes on a value of one if the firm conducts TQC activities and expects these to lead to a simultaneous information-sharing system
d_experi	A dummy variable that takes on a value of one if, compared to machining skills, assembling skills are apt to withstand rapid technological innovation

overseas	A dummy variable that takes on a value of one if the sampled firm has directly produced machines overseas using a production process that is quite different from that used for domestic production
d_intwar	A dummy variable that takes on a value of one if the firm was founded during the interwar period
d_pswar	A dummy variable that takes on a value of one if the maker was founded after WWII
d_pubedu	A dummy variable that takes on a value of one if the firm requires public trade skill licenses for promotion
d_lathe	A dummy variable that takes on a value of one if the firm produces (CNC) lathes
d_MC	A dummy variable that takes on a value of one if the firm produces MCs
d_Drill	A dummy variable that takes on a value of one if the firm produces drilling machines
d_Boring	A dummy variable that takes on a value of one if the firm produces boring machines
d_GeaGrd	A dummy variable that takes on a value of one if the firm produces gear-cutting machines or grinders
d_IND	A dummy variable that takes on a value of one if the firm produces industry machines
d_Misc	A dummy variable that takes on a value of one if the firm produces miscellaneous machines
d_spoint	A dummy variable that takes on a value of one if the firm's sales point is "low price"
d_spoint2	A dummy variable that takes on a value of one if the firm's sales point is "high-speed and high-precision machines"
scale100	A dummy variable that takes on a value of one if the firm has more than 100 full-time employees

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