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# SOURCES OF MACHINE-TOOL INDUSTRY LEADERSHIP IN THE 1990s: OVERLOOKED INTRAFIRM FACTORS

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# Sources of Machine-tool Industry Leadership in the 1990s: Overlooked Intrafirm Factors

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## Abstract

Through the use of extensive field research and an original international questionnaire, the main sources of the leapfrogging development of the Japanese machine-tool industry in the past 19 years were investigated. Past studies have emphasized the strategic R&D alliance with superlative computerized numerical control (CNC) makers, the extensive use of outsourcing from excellent precision parts' suppliers, and the extraordinary development of automakers. This paper critically considered these factors and verified their inadequacy in explaining the further development of this industry in the 1990s. Hence, attention was paid to the significant roles of "intrafirm factors" such as: (a) the simultaneous and cross-functional information sharing system at an early stage of new product development processes; (b) the positive and early participation of frontline skilled workers in assembly or machining shops; and (c) the existence of highly skilled assemblymen or machinists. The significant roles of these intrafirm factors were robustly validated by the statistical analysis of the questionnaire survey as well as by the results of our field research. The results showed striking similarities between the Japanese and the German machine-tool makers and notable dissimilarities between the two and the US makers.

Keywords: Machine-tool, Product Development Process, Information Sharing
JEL classification: L10, L22, L64

## 1. Introduction

Until the mid 1970s, the Japanese machine-tool industry had lagged behind its U.S. and German counterparts. Indeed, in 1975, Japan was the fourth largest producer behind the (former) Soviet Union. First was the U.S., followed by (formerly) West Germany. The advent of CNC[1] complex lathes and machining centers (MC), however, drastically changed the situation. In 1982, the Japanese machine-tool industry produced the largest amount (US dollars) of machine tools in the world and has maintained this leading position for 19 years.

Most of the past studies which observed this leapfrogging development (e.g. Finegold et. al. (1994a and 1994b), Fleischer (1997), Kobayashi and Ohdaka (1995), and Mazzoleni (1999)) have emphasized the following “interfirm factors:” a) the strategic R&D alliance with superlative CNC makers such as Fanuc, Mitsubishi Electric, and Yasukawa Electric that provide optimal control software as well as CNC devices or servo motors; b) the extensive use of outsourcing from excellent precision part's suppliers of bearings, ballscrews[2] or linear guideways, for example NSK, NTN, and THK; and c) the extraordinary development of the auto industry[3], represented by Toyota, Nissan, and Honda and the huge induced demand from these “demanding and knowledgeable” users.[4] In particular, the collaboration with CNC producers is the universally repeated and emphasized factor.

These factors have certainly played very important roles. As clarified in this paper, however, these interfirm factors do not sufficiently explain the further development of this industry during the 1990s. Markets for CNC and precision parts have been so globalized that stable and prompt key-part procurement could no longer be a crucial constraint for foreign competitors. Moreover, although the export ratio of Japanese machine-tools was 30 - 40% (30-40%) until the early 1990s, it exceeded 65% in 1995 and reached about 75% in 1999. In this regard, an increase in demand came mostly from foreign manufacturers.

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[1] Computerized Numerical Control.

[2] Special screws that change rotative movement into linear movement.

[3] The Japanese auto industry became the world’s largest producer in 1981.

[4] In addition to these three factors, some may maintain that the strong governmental roles, especially as played by the MITI, should be included. There are, however, contrasting views on this point and thus, we do not consider this factor. For more details on this point, see Friedman (1988), Holland (1989), Kobayashi and Ohdaka (1995), and Miwa (1998).

In this paper, we will emphasize the role of the overlooked “intrafirm factors” on the development of the Japanese machine-tool industry in the 1990s: (a) the existence of a simultaneous and cross-functional information sharing system conducted at an early stage of the new product development processes; (b) the positive and early participation of frontline skilled assemblymen or machinists in such a process; and (c) the existence of highly skilled assemblymen or machinists who could troubleshoot their unknown problems in a prompt and proper manner.[5]

As is well known, modern CNC machine-tools have become much more complex, both mechanically and electrically. Even at the system design phase where targeted market needs are conceptualized, mechanical designers have to bear in mind the various kinds of interference problems among key unit parts. Except for very rare cases, however, it becomes almost impossible even for first-rate designers to do this. Thus, to reduce the development lead-time for new machines or to not frequently return to previous development stages, a simultaneous and cross-functional information sharing system becomes very essential.

The main purpose of this paper is to validate these conjectures based on both careful and comprehensive field research and a statistical analysis of our original questionnaire survey simultaneously conducted among Japanese, US and German machine-tool makers. Despite its importance, there are only a few studies that have tried to investigate this subject in a comprehensive manner. There are several papers included in Jurgens (2000)[6] where a similar point was considered based on a few case studies of German, Italian, Japanese, and US machine-tool makers.[7] All of these papers, however, only paid attention to a specific country,

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[5] We note here that most of these skilled workers are not conventional “craft-types” but “problem-solving-types” of people. Based on relevant systematic as well as experimental knowledge, the problem-solving types can promptly discover the causes and effects of various kinds of actual and potential machine troubles and properly prevent or alleviate them. A detailed description of problem-solving types of skills in the auto or auto-parts industry is provided in Koike, Chuma, and Ohta (2001).

[6] Lippert (2000), Rolfo (2000) and Kobayashi (2000).

[7] Finegold, et. al. (1994a, 1994b) tried exhaustively to figure out why the US machine-tool makers had declined so much in the 1980s. Their research is based on a large number of hearings from various people and on macro data analyses. They, however, did not directly take into account the new product development processes *per se* or statistically test their numerous

the German-US difference or to new product development processes *per se,* and did not clarify the crucial reasons for why such an international difference came into being. Moreover, although each paper's subject varied, only two cases per country were discussed at best. Lastly, the conjectures proposed in each paper were not statistically tested.

The structure of this paper is as follows. In the next section, the outline of the research method will be introduced. In Section 3, we will critically review the three interfirm factors. Section 4 will be the main part of this paper. In the first half of this section, the importance of the overlooked intrafirm factors will be discussed based mainly on field research and the questionnaire survey. In the second half of this section, the importance of these intrafirm factors will be statistically confirmed. The final section summarizes the results.

## 2. The Research Method

### 2.1. About the Field Research

We have investigated twelve Japanese machine-tool makers, two CNC makers, and one precision parts' maker. Three German machine-tool makers were also examined, whereas, regrettably, US producers were not considered. Among Japanese machine-tool makers, seven were large-scale producers with more than 1000 full-time employees and the others had fewer than 500 full-time employees.

The field research was conducted from the end of September 1996 to the end of March 2000. For each company, we interviewed foremen from assembly shops, chief designers or engineers in Design and Development (D&D) sections, and chief officers in the personnel department. Interviews normally took two hours and were conducted at least twice for each person. This rule did not apply to German makers or one of the CNC makers.

### 2.2. Questionnaire Survey

In addition to field research, between February and April of 2000 we also conducted a questionnaire survey for the Japanese, German and US machine-tool makers. Japanese samples included all establishments (1750) that were included in the of Census of Manufacturers (MITI) list in 1997. More concretely, they belong to the metal-cutting machine industry, the metal forming machine industry, or the machine-tool related parts, attachments or cutting-tool industries. Mainly due to the budget constraint, samples for the first two industries were

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conjectures based on micro data. Moreover, they only considered the situation in the 1980s.

limited to those with more than five full-time workers, while the third industry was limited to those with more than twenty full-time workers.

The US samples consist of all machine-tool makers (366) that belong to the AMT (Association of Manufacturing Technology) and machine-tool related makers ( 517) that belong to the NTMA (National Tooling and Machining Association). The list of names that we used was compiled from the home page of each association.

The German samples included all machine-tool makers ( 273) that belong to VDW (Verein Deutscher Werkzeugmash Cinenfabriken e.V.) or VDMA (Verband Deutscher Maschinen und Anlagenbau e.V.) and are listed in the Red Book CD-ROM issued by these organizations.

The questionnaire was to be filled out by supervisory personnel in assembly and/or machining shops. In reality, however, most interviewees who were identifiable were division or section chiefs of production sections. The response rate for each country is as follows: 30% in Japan, 22% in the US, and 12% in Germany.

## 3. “Interfirm Factors” for Leapfrogging Development: Critical Assessment

### 3.1. Strategic R&D Alliances with CNC Makers

It is well known that the development of the Japanese machine-tool industry was attained by using general-purpose CNC lathes and MCs (Kobayashi and Ohdaka (1995)). Among them, machines ranging from $200,000 to $500,000 are currently competitive in the world market. Most of the CNC and servo motors with which these machines are equipped are produced by Fanuc, Mitsubishi Electric, or Yasukawa Electric. The domestic and world market share of Fanuc is 70% or 50% respectively.[8]

The contribution of these CNC makers to the machine-tool industry is considerable. This point can be partially confirmed by the cost ratio of CNC-related parts or software to the total cost of machine-tool building. It sometimes amounts to even 30- 40%.[9]

To equip their new machines with CNC and control software, machine-tool makers normally need to have close technological collaboration with CNC makers. This is mainly because to optimally achieve the motion control of their machines, knowledge of both machine characteristics and CNC units becomes essential. To differentiate their machines, machine-tool

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[8] The data is based on Kaisha-Shiki-Ho (Quarterly Financial Reports on Listed Companies) by Toyokeizai Shinpo-sha.

[9] The number is based on our field research.

makers are also quite eager to add their unique optional (software) functions to the existing ready-made functions.[10] Moreover, CNC makers eventually earn proprietorship of the interface between the mechanical parts of machines and CNC devices. Therefore, the relationship between machine-tool makers and CNC producers tends to be exclusive and long-term.

For example, in the case of Makers A and B that are competing for the number one position in Japan, each maker has its own CNC division within the Nagoya Works of Mitsubishi Electric and obtains specific CNC supplies. Mitsubishi's engineers also frequently visit Makers A and B independently, especially during the new machine development processes. Furthermore, Maker C, that has a very powerful R&D control division, has had quite a long-term relationship with Fanuc and has retained the proprietary and extensive Fanuc-CNC interfaces.

The machine-tool division chief of Maker D made the following comments concerning this point. Maker D produces Swiss-type automatic NC turret lathes that have unique multi-axes & a multi-functional optimal control system.

> CNC makers derive most of their profits, not from selling CNC devices themselves, but from developing the corresponding made-to-order software. In fact, it is quite common for Fanuc to collaborate with various machine-tool makers to develop and fine-tune their software. As a result of this collaboration, substantial knowledge has been transferred from machine-tool makers to CNC makers. In addition, Fanuc and Mitsubishi retain Gulliver's share so that the best-practiced technology of competitive machine-tool makers shall effectively spill over to machine-tool makers that are relatively weak in having motion control of their machines.

Even during the 1990s, was the close collaboration between machine-tool and CNC makers prevalent only in Japan? To be sure, Mozzoleni (1999) and Finegold et. al. (1994) ascribe one of the main weaknesses of the US machine-tool makers in the 1970s or 1980s to the arm's-length relationship between machine-tool and CNC makers.[11] Since around 1989,

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[10] This point is based on our field research

[11] The same thing is applicable to the German machine-tool industry (Englmannn et. al. (1994) and Mazzoleni (1999)).

however, Fanuc has run a joint venture with GE in the US and Siemens in Germany.[12] Furthermore, as a result of Fanuc and Mitsubishi's foreign direct investment, their superior CNC devices and related control software have become more accessible globally.[13]

Reflecting the situation, for example, in the famous Chicago machine-tool show in September 1999, 33% of exhibited machines were equipped with GE's (hence Fanuc's) CNC, 14% with Fanuc's, 9% with Siemens's, and 6% with Mitsubishi's. In the Paris show in May 1999, the corresponding number was Fanuc: 35%, Siemens: 18%, Heidenhein: 10%, and Mitsubishi: 5%. In contrast, in the Tokyo show in October 2000, Fanuc's share was 72%, while Mitsubishi's was 10%, and Ohkuma's 4%.[14]

Although the existence of powerful CNC makers in Japan contributes to the competitiveness of the Japanese machine-tool makers, it becomes very difficult from these facts to maintain an argument that their strategic R&D alliance with CNC makers has been the major source of Japanese machine-tool industry leadership even in the 1990s.

Lippert (2000) also reported that, except for the German maker of standard low-cost MCs,[15] the lead-time for machine development[16] was 24 months for the US maker of standard low-cost MCs, 30 months for the US maker of customized high-tech CNC milling machines and 33 months for the German maker of customized high-tech CNC lathes. In contrast, according to our field research of 12 machine-tool makers, the corresponding lead-time for their top machines was 10 to 12 months without exception.[17] Such a huge difference is hard to explain

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[12] Siemens, however, had cancelled this joint venture later.

[13] This is one of the strong reasons why Taiwanese machine-tool makers have become very competitive in relatively low-cost machine-tools. The same logic must be applied to the Korean machine-tool industry. Korean makers, however, are much less competitive than the Taiwanese. Jeong (1996) indicates, as one of the main reasons for such a weakness, a qualitative skills deficiency due to low investment in skill development. We also note here that Korea banned imports of Japanese machine-tools until 2000.

[14] All data come from Nikkei Shimbun.

[15] The development lead time for this maker was 16 months.

[16] The lead-time for machine development consists of the following four phases: Concept Phase, Product Engineering Phase, Process Engineering Phase, and Production Phase. For details, see Lippert (2000).

[17] Kobayashi (2000) also reports similar facts.

using only collaboration of machine-tool makers with CNC producers.

### 3.2. Extensive use of outsourcing from excellent precision part's suppliers

In addition to CNC and servomotors, machine-tools consist of parts such as main spindles and bearings and high-speed motors for them, guideways and ballscrews or linear motors, and cast iron products such as beds, columns, or saddles. The precision of machines and their production lead-time crucially depend on the performance of these parts as well as their prompt and stable distribution. Technological innovations embodied in these parts also directly enhance the performance of machine-tools. Additionally, the high quality of cast iron significantly influences the precision durability of machines.

It is definitely true that Japanese machine-tool makers have obtained a considerable advantage by depending on outsourcing from top-rated Japanese precision parts' makers. Most of the bearings come from NSK or NTN, ballscrews from NSK, Tsubaki-Nakajima, or Kuroda Seiko, and linear-motion guideways from THK or NSK.[18] Reflecting this situation, most of the machine-tool makers we visited claimed that their payments to these precision parts' makers took 10 to 20% of their total machine-building costs.

These precision parts' makers, however, were globalized in the 1990s. For example, in the case of NSK, the ratio of overseas production, overseas sales and foreign workers was 30%, 70% and 40% respectively. THK also sold 25- 30% of its products abroad. In this sense, the extensive use of outsourcing from top-rated precision parts' makers still could not explain the wide gap of machine development lead-time indicated in the previous section.

### 3.3. Extraordinary development of the auto industry

The impact of the auto industry on the machine-tool industry is enormous. Indeed, domestic auto or autoparts' makers directly create about 30-40% of the induced domestic demand for machine-tools. This number adds up to about 60- 70% if the auto industry related demand from the general machinery industry (e.g., die-making industry) and the electrical machinery

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[18] The world's largest producer of bearings is SKF (whose share is 20%) in Sweden. NSK follows closely in second place. This is especially true about bearings for general machines except for automobiles: SKF 21% and NSK 21% in 1999. NSK has the largest share (30%) of the ballscrew market in the world. THK's share of the linear-motion guideway production in the world is 60%, while NSK's is 9%.

industry is considered.[19] This point is well reflected by the fact that the Japanese machine-tool industry was the largest producer in the world one year after the Japanese became the world's largest automakers (1981).

As is indicated in Rosenberg (1963), the growth stage of manufacturing industries tends to be properly projected on the growth of capital goods industries like the machine-tool industry. Hence, it was quite probable that the "demanding and knowledgeable" Japanese automakers helped greatly to increase the competitiveness of the Japanese machine-tool makers.

The observation of the past development process of the machine-tool industry, however, uncovers a slightly different story. A large amount of the demand for Japanese machine-tools came, especially during the late 1970s and the early 1980s, from the US auto and aircraft industries. The export ratio of Japanese machine-tools was just 10% in 1970, but it exceeded 40% in 1978 and oscillated between 30 and 40 % during the 1980s. Eighty percent of machine-tools newly consumed in the US were American in 1975, whereas this number dropped to 50% in 1985. Most of them were replaced by Japanese machine-tools (Finegold, et. al. (1994)).

The above structure has since not changed very much. Indeed, the preference for Japanese machine-tools has grown. The export ratio of Japanese machine-tools in 1991 was 30%. Reflecting the severe drop in domestic demand, it became 68% in 1995 and 74% in 1999.[20] Moreover, 60% of machine-tools imported to the US in 1999 were made in Japan.[21] In this sense, the Japanese machine-tool industry tends to reflect not the domestic but the world manufacturing industries.

Lastly, some researchers (e.g., Graham (1993), Boultinghouse (1994), and Forrant (1997)) have emphasized the role of the "Keiretsu" *a la* Toyota in the Japanese machinetool industry. For examples, Boultinghouse (1994) states as follows:

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[19] The data comes from the Japan Association of Machine-tool Builders and from our field research.

[20] The machine-tool import restriction by the USA via VRA (Voluntary Restraint Agreements) started in 1987 and ended in 1993.

[21] The data comes from the VDW Annual Report and the Japan Association of Machine-tool Builders. In 2000, 47% of Japanese machine-tools were exported to the US, 30% to Europe, and 22% to Asia.

> Several machine-tool builders are tied to both users and suppliers through both cross holdings of equity and long-established trading relationships. For example, Toyoda Machinery... Another example is Toshiba Machinery ... (p.17)

Such a statement, however, is a little misleading. Since the early 1980s, the Japanese machine-tool industry has been led not by these “Keiretsu”-type makers but by independent ones such as Yamazaki Mazak, Mori Machinery, Ohkuma, and Makino Milling Machines.[22] For example, as far as CNC lathes are concerned, the “Big Three” (Yamazaki Mazak, Mori Machinery, and Ohkuma) occupied about 50% of the domestic shares even in 1981. This trend has grown stronger in recent years.[23] It is also true that many of the “Keiretsu”-related makers suffered from a chronic economic depression in the 1990s mainly because they tend to specialize in high-class customer-specific machines equipped with their original and proprietary CNC.

## 4. Overlooked Intrafirm Factors for Explaining Leapfrogging Development

### 4.1. The Necessity for Simultaneous and Cross-functional Information Sharing

The innovation process is characterized by cutting-edge activities to achieve market success. Such activities are initiated by novel and promising ideas and are realized as concrete product specifications, conceptual or accurate drawings, and then as final commercial products. Many important players take part in this process. Their methods of active participation, however, are inclined to be concurrent or simultaneous rather than sequential. Indeed, to have efficient innovations, it is inevitable to promptly and properly resolve various unknown problems along with contradicting cross-functional interests created in the process as early as possible. Moreover, to avert the evils of local maximization, global maximization must always be given first priority.

The appearance of high-speed and high-precision CNC complex lathes or MCs in the 1980s or 1990s has remarkably increased the necessity for such a global maximization. This is mainly because, as the importance of so-called “mechatronics” is drastically increased, even first-rate mechanical designers can not foresee various kinds of interference problems among key parts at the system design phase.

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[22] For details, see Miwa (1998).

[23] The data are derived from the Japan Association of Machine-tool Builders.

Concerning this point, the following statement by a mechanical designer is quite informative. He played an important role in designing various premier products of a large machine-tool maker with a proud history:

> During the time when traditional non-NC lathes or milling machines were produced, machine designers were overconfident of the current standard. This might be mainly because the effective way of building these non-NC machines could be theorized to a considerable extent by designers. However, as the machines have become equipped with CNC and multi-functions as shown in complex CNC lathes or MCs, their theorizing power gradually weakened. This tendency has been intensified by the advent of high-speed and high-precision machines equipped with ATC (Auto Tool Changers) or APC (Auto Pallet Changers). When the machines became complex, designers then had to consider various mechanical and electrical factors before the actual building process. This is why the present simultaneous and cross-functional information sharing system has begun to play an important role. Because the skills of a first-rate assemblyman are more durable than those of a machinist, especially during rapid technological change, the power of assembling shops has become greater than before.

The questionnaire survey validates the relevance of the above statement. In the survey, the interviewee was asked to agree or disagree with the following statement: "CNC machines have become so complex that, without close collaboration with assemblymen and/or machinists during the early stages of machine development, D&D engineers can no longer effectively develop and design new machines to the finest detail." Fifty percent of the Japanese[24] and 59% of the German makers answered "yes." The corresponding number for the American makers was 37%.[25] The percentage increases if makers are limited to those who have introduced a formal concurrent design review (DR) process between the D&D engineers and the representatives of the production shops: 64% for Japan, 45% for the US, and 61% for Germany.

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[24] The Japanese survey was done based on establishments. Among the responding samples, only two or three belonged to the same companies.

[25] The number includes makers that did not answer this question. If non-responses are excluded, the numbers become 65%, 63%, and 42% respectively. In what follows, every number will incorporate these non-responded makers.

If the necessity for simultaneous and cross-functional information sharing developed with the advent of high-speed and high-precision CNC complex lathes or MCs, the above formal DR process must have also been introduced around the late 1980s or the early 1990s. In relation to this point, the head of the technology division of Maker E, a world-famous CNC grinding machine producer, pointed out the following supporting fact:

> It is an established fact that we highly honor the simultaneous and cross-functional information sharing among various departments and divisions. Such a practice was fully established just about ten years ago (around 1987) when the so-called TQC became widely practiced. Certainly, even before then, people shared a sense of family, and consensus was emphasized in various aspects. Nonetheless, the current style of the rather egalitarian information sharing system was set up only in the late 1980s. After that, the previous sectionalism was really gone, and the cooperative atmosphere was nurtured. Indeed about 20 to 30 years ago, the technology department had the power to unilaterally lead the production department. At that time engineers in the technology department had production workers carry out their assigned tasks in a paternalistic way. They also had the arrogance to state that one only had to faithfully follow their instructions to produce good machines. Such a domineering relationship could not have produced any good products. As a result, the current design review system has been introduced based on the idea that only assembly and machining shops produce actual products; it is here that the drawings must be made by taking into account the various constraints of the shops.

What the head of the technological division mentioned above was also confirmed by the questionnaire survey. The percentage of makers who have introduced the above formal concurrent DR process was 49% in Japan, 60% in the US, and 72% in Germany. Moreover, among these makers whose DR processes start even at an early stage, 59% of Japanese makers have introduced such a system since 1990. This number adds up to 78% if makers that started the DR process since 1980 are included. The corresponding numbers were 48% and 59% for US makers and 60% and 67% for German makers.

Lastly we note the qualitative differences of the above formal DR processes among the Japanese, German, and US makers. As indicated above, the US makers were more likely to introduce the process than the Japanese: 60% vs. 49%.[26] The difference becomes more salient when DR processes start even at an early stage where fundamental machine specs are determined: 53% vs. 26%. These numbers, however, do not take into account the frequency of meetings between the D&D engineers and the production workers.

Concerning this point, the survey asked another question: With which in-house department do your D&D engineers tend to meet most frequently? Hence, a cross- tabulation between the previous question and this question leads to the desired information. The result is striking. Among the US makers that have DR processes even at a very early stage, only 26% of them answered “Assembly shops” and 4% “Machining shops.” The “Sales department” was the most frequent: 44%. In contrast, the corresponding numbers were 72%, 51%, and 52% respectively for the Japanese makers, and 73%, 53%, and 53% for the Germans. American DR processes are quite different from those of the Japanese or the Germans.

### 4.2. Statistical Analysis

In the previous section, we mentioned that the advent of high-speed and high-precision CNC complex lathes or MCs necessitated a simultaneous and cross-functional new product development process in the 1990s. The main reasons were also articulated. Based on statistical analysis, this section will validate the conjecture and further clarify the causes and effects of the processes.

Two dependent variables are introduced: the degree of reduction in the development lead-time during the past decade and the degree of decrease in the past decade in the number of claims during the 6 months after the start of commercial production. In the answer, the degrees are indicated as: “1. Almost no change, 2. Reduced (or Decreased) about 10-20%, 3. Reduced 30-40%, 4. Reduced about 50%, 5. Reduced over 50%, 6. I do not know.” In the statistical analysis, we defined the two new dummy variables of d_TimeToMarket10 and d_TimeToMarket30, which takes a unit value if the development lead-time was reduced more than 10-30%, and zero in all other cases. The dummy variable d_NumClaim10 and d_NumClaim30 are similarly defined, but for a number of claims. In estimating the effect on these variables, the PROBIT estimation method was applied to both the mixed data and the singlecountry data.[27]

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[26] For German makers, the former was72%, while the latter was 47%.

[27] In the case of the mixed data, we used the “sysprobit” command in Stata 7 where the response

The independent variables included: (1) differences in countries; (2) methods of training assemblymen and machinists; (3) methods of new product development processes; (4) departments with which the D&D engineers most frequently meet; (5) overseas production facilities; (6) the role of publicly provided off-the-job training; (7) firm size; and (8) differences in produced machine-tools. The precise definitions of these variables and their basic statistics are provided in Appendix 1.

### A. The Estimation Results for the Development Lead-Time

Table 1 shows the estimation results for the development lead-time in the mixed data. The second column indicates the result for d_TimeToMarket10 while the third column is for d_TimeToMarket30. The result of the singlecountry data is provided in Table 2-1 for d_TimeToMarket10 and in Table 2-2 for d_TimeToMarket30.

In Table 1, irrespective of the degree of reducing the development lead-time, the US dummy (d_US) is positively significant at the 4% level. In contrast, the German dummy (d_Germany) is not significant for d_TimeToMarket10, but positively significant at the 1% level for d_TimeToMarket30. Hence, both the American and the German makers have succeeded in catching up with the Japanese in the 1990s. This confirms the report made by Lippert (1999).

The dummy variable d_AsmblyIntegrated takes a unit value whenever a maker has a basic company policy to train its assemblymen with both major assembly and parts assembly skills. In Table 1, this variable is positively significant at the 1% level for d_TimeToMarket10. One of the main reasons[28] why a maker trains them in this style is that “such assemblymen could promptly troubleshoot new and unusual problems occurring in assembly shops.” This was the US makers’ top reason (55%). Although the top reason for the Japanese (72%) and the German (73%) makers was to keep up with technological innovations, 52% of the Japanese and 53% of the German makers still selected the first reason. Hence, the significantly positive effect of d_Asmbly Integrated is justified.

As shown in Table 2-1, the above result, however, is applicable only to the Japanese makers. Variable d_AsmblyIntegrated is no longer significant in Table 2-2 and the third column in Table 1. These results contrast starkly with those variables related to the new product

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rates were utilized as weights. In the case of single country data, the usual “probit” command with a robust option was employed.

[28] Multiple answers are permitted.

development processes. In other words, as far as the development lead-time is concerned, the ways of producing new products are likely to play a more important role than the ways of training assemblymen.

It is said that handscraping is always one of the most difficult craft-type assembly skills. The dummy variable d_HandScraping takes a unit value whenever a maker agrees with this statement. In the third column of Table 1, this variable gives a significantly negative effect. As indicated in Tables 2-1 and 2-2, such a negatively significant result is only applicable to the Japanese makers. In the present, there are a limited number of assemblymen who are very skilled at handscraping. This is mainly because the revolutionary guideways originally invented by THK have drastically reduced the necessity for handscraping. The high-class heavy-duty machines for powerful cutting, however, are still likely to use the conventional slide-type guideways that inevitably require advanced handscraping skills. Thus, the negative significance is acceptable.

The dummy variable d_MultiSkilled takes a unit value whenever a maker answers yes to the following question: “Do your machinists tend to be multifunctional-- responsible for different types of machines.” This variable is not significant in any tables. As was said about the variable d_AsmblyIntegrated, the ways of producing new products might play a more important role than the way the machinists were trained.

The difference in information-sharing methods is expressed by the dummy variable d_EarliestDRPat that takes a unit value whenever a maker has introduced the formal simultaneous design review (DR) process between D&D engineers and representatives of the production shops and also whenever such DR processes start at an early stage where fundamental machine specs are determined. In Table 1, irrespective of the degree of reducing the development lead-time, this variable is positively significant at the 1% level. Shown in Table 2-1 for d_TimeToMarket10, this result is limited to the US makers. This result is seemingly contradictory to the argument in the previous section. In Table 2, however, d_TimeToMarket30 becomes positively significant for both the US and the Japanese makers. In other words, for the Japanese makers, the larger the reduction in the development lead-time, the more significant the role of d_EarliestDRPat. This is quite understandable.

As for the departments with which the D&D engineers most frequently meet, both variables d_MostMachining and d_MostMarketing are positively significant in Table 1. The former implies machining shops and the latter the sales departments. In contrast, d_MostAssembly, the variable that pertains to assembly shops, is not significant. These results, however, become very different when the estimation is done for each country. As shown in Table 2-1 and Table 2-2, for both d_TimeToMarket10 and d_TimeToMarket30, the variable d_MostAssembly is quite positively significant for the Japanese makers, whereas not at all for the US makers. Moreover, for d_TimeToMarket30, only d_MostAssembly is significant among the three variables.[29] Hence, assembly shops play a very critical role with the Japanese makers during the new machine development processes.

The dummy variable d_TQCorTQM takes a unit value whenever TQC or TQM is introduced by a maker. TQC or TQM is a company-wide activity that tries to effectively obtain product and/or process innovations through full employer-employee participation. Hence, if it is properly institutionalized, the effect should be positive. As predicted in Table 1, this variable becomes significantly positive at the 1% level for d_TimeToMarket30. This result strongly reflects the characteristics of the Japanese makers. In both Tables 2-1 and 2-2, d_TQCorTQM is quite significant for the Japanese makers, whereas not at all for the US makers. The result indicates that TQC or TQM activities might be quite different between the Japanese and the US makers.

The dummy variable d_OverseaProduct takes a unit value whenever a maker has production facilities overseas. In Table 1, this variable is quite significant for both d_TimeToMarket10 and d_TimeToMarket30. As indicated in Table 2-1 and Table 2-2, however, this is only applicable to the US makers. This result is difficult to explain. Like Gleason and Ingesol, US makers that operate overseas production tend to be more competitive. The statistic might reflect this fact.

Whenever a maker is using public training facilities to train its workers off-the-job, the dummy variable d_UsePublicOffJT takes a unit value. This variable is not significant in any tables. Troubleshooting abilities of skilled workers are normally accumulated by in-house OJT. The analysis reconfirms this fact.

The variable FirmEmpScale considers several discreet values of full-time employees with each maker. The larger the values, the greater the firm-scale. This variable is not significant in the second or third columns in Table2. In Table 2-1, it becomes positively significant only for the Japanese makers, but this significance disappears in Table 2-2. In this sense, the speed of innovation normally does not depend on the size of machine-tool makers.

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[29] In Table 2-1 and Table 2-2, variable d_MostMachining is dropped because only a few of the US makers meet most frequently with the representatives of machining shops during new machine development processes.

In Table 1, the dummy variables from d_Lathe to d_OtherMachine indicate the type of machine-tools produced by each maker. When a maker produces several types of machines, the corresponding variables take a unit value. Moreover, CNC and non-CNC machines are treated identically even within the same type of machine. Hence, the variables do not fully portray each maker.

Despite such a constraint, in the second column of Table 1 variables such as d_Machining, d_DrillBroaching, d_OtherMetalCut, and d_SpindSlide are positively significant for d_TimeToMarket10. Functions of the recent drilling or broaching machines tend to be incorporated into MCs. Hence, the positive significance of both the MCs and the drilling or broaching machines is understandable. We should note, however, that none of these variables are significant for the US makers (see Table 2-1 and Table 2-2). Moreover, even for the Japanese makers, only d_Grinding (grinding machines) is positively significant. According to these results, the difference in types of machines does not have a significant impact. Lastly we note that grinding machines were effectively equipped with CNC in the 1990s and that many horning or lapping machines (d_HornLapping) are still not equipped with CNC. Thus, the positive significance of the former and the negative significance of the latter are comprehensible to some extent.

### B. The Estimation Results for The Number of Claims

The estimation results for the degree of decrease in the number of claims during the 6 months after the start of commercial production are shown in Table 3 for the mixed data and Table 4-1 and Table 4-2 for each country.

Initially, the US dummy variable (d_US) is significantly negative at the 1% level in both the second and the third columns in Table 1. In contrast, the German dummy (d_Germany) is not significant in either case. This result indicates that, even during the 1990s, US makers did not catch up with the Japanese, while the Germans were comparable to the Japanese.

In Table 1, regarding other independent variables, the significant variables are almost the same for both the above 10% and 30% cases except for types of machine variables. The significant variables are the following: d_AsmblyIntegrated, d_MultiSkilled, d_EarliestDRPat, d_MostMachining, and d_TQCorTQM. This result means that the number of claims tends to be significantly decreased in machine-tool makers where: (a) both assemblymen and machinists are broadly trained; (b) TQC or TQM is actively introduced; (c) the early participation of production workers in DR processes are attained; and (d) D&D engineers frequently meet with representatives from machining shops during the new machine development processes.

Once again, however, in Table 4-1 and Table 4-2, the above results are only applicable to Japanese makers. Indeed, in both tables the only commonly significant variable for the US makers is d_AsmblyIntegrated. In contrast, for the Japanese makers, d_AsmblyIntegrated, d_EarliestDRPat, d_TQCorTQM, and d_MostMarketing are positively significant in Table 4-1, while d_EarliestDRPat and d_TQCorTQM are significant in Table 4-2. In these ways, the decrease in the number of claims for the Japanese makers is attained mainly through simultaneous and cross-functional information sharing and TQC activities through full employer-employee participation. On the other hand, US makers still tend to depend solely on the troubleshooting abilities of skilled assemblymen.

## 5. Summary and Conclusion

Through extensive field research and an original international questionnaire, the main sources of the leapfrogging development of the Japanese machine-tool industry in the past 19 years were investigated. Past studies have emphasized the following "interfirm factors": the strategic R&D alliance with superlative CNC makers; the extensive use of outsourcing from excellent precision parts' suppliers; and the extraordinary development of automakers. This paper critically considered these factors and reconfirmed that, although Japanese machine-tool makers were very weak until the early 1970s, they overcame such weakness by both R&D collaboration with powerful CNC makers and extensive outsourcing from excellent precision parts' makers.

At the same time, however, the paper also verified the inadequacy of these factors in explaining the further development of this industry in the 1990s. Hence, attention was paid to the significant roles of "intrafirm factors" such as: (a) the simultaneous and cross-functional information-sharing system at an early stage of the new product development processes; (b) the positive and early participation of frontline skilled workers in assembly or machining shops; and (c) the existence of highly skilled assemblymen or machinists. The significant roles of these intrafirm factors were robustly validated by the statistical analysis of the questionnaire survey as well as by the results of our field research. The result showed striking similarities between the Japanese and the German machine-tool makers and notable dissimilarities between the two and the US makers.

In the statistical analysis, two dependent variables were introduced: the degree of decrease in the development lead-time and the number of claims during the 6 months after the start of commercial production in the past decade. The estimation results clarified that, for both the development lead-time and the number of claims, methods of developing new products are likely to play a more significant role than the ways in which assemblymen or machinists are trained. Such a tendency was more prominent in Japan than in the US.

Similarly, regarding the development lead-time, both the active participation of assembly shops in new product development processes and TQC or TQM activities played a very critical role for the Japanese makers. Instead, for the US makers these group-oriented factors did not have any significance at all. The decrease in the number of claims for the Japanese makers was mainly earned through simultaneous and cross-functional information sharing and TQC or TQM activities. The US makers, on the other hand, still tended to solely depend on the troubleshooting abilities of individual skilled assemblymen and machinists.

## References

Bates, C. (1999),"Applications show the way," *American Machinist*, January, pp.50-56.

Boultinghouse, B.(1994), "The Japanese Machine-tool Industry," in Finegold, D.(ed.) *The Decline of the U.S. Machine-tool Industry and Prospects for Its Sustainable Recovery*, Vol.2, Rand, MR-479/2-OSTP-V.2.

Englmann, F., C. Heyd, D. Kostler, P. Paustian (1994), "The German Machine-tool Industry," in Finegold, D. (1994b) (ed.) *The Decline of the U.S. Machine-tool Industry and Prospects for Its Sustainable Recovery*, Vol.2, Rand, MR-479/2-OSTP-V.2.

Finegold, D., K.W. Brendley, R. Lempert, D.Henrry, P. Cannon, B. Boultinghouse, M. Nelson (1994a) *The Decline of the U.S. Machine-tool Industry and Prospects for Its Sustainable Recovery*, Vol.1, Rand, MR-479/1-OSTP.

Finegold, D. (1994b) (ed.) *The Decline of the U.S. Machine-tool Industry and Prospects for Its Sustainable Recovery*, Vol.2, Rand, MR-479/2-OSTP-V.2.

Fleischer, M (1997), *The Inefficiency Trap: Strategy Failure in the German Machine-tool Industry*, Edition Sigma, 1997.

Fleischer, M (1997), *The Inefficiency Trap: Strategy Failure in the German Machine-tool Industry*, Edition Sigma.

Forrant, Robert (1997), "The Cutting-Edge Dulled: The Post-Second World War Decline of the United States Machine-tool Industry," in *International Contributions to Labour Studies*; 7(0), 1997, pages 37-58.

Forrant, Robert (1997), "The Cutting-Edge Dulled: The Post-Second World War Decline of the United States Machine-tool Industry," in *International-Contributions-to-Labour-Studies*; 7(0), 1997, pages 37-58.

Friedman, D.(1988) *The Misunderstood Miracle: Industrial development and political change in Japan*, Cornell Studies in Political Economy series, Ithaca and London: Cornell University Press.

Fujimoto, T. and K. Clark (1993), *Seihin Kaihatsu Ryoku* (Power of New Product Development), Diamond-Syuppan.

Graham,-Julie (1993), "Trading industries, trading regions: International trade, American industry, and regional economic development," in Noponen,-Helzi; Graham,-Julie; Markusen,-Ann-R., eds. *Perspectives on Economic Change series,* New York and London: Guilford Press.

Holland, M. (1992), *When the Machine Stopped*, Harvard Business School Press. (This book is translated into Japanese as *Tuieta Yabo: Naze Bergmaster-sha ha Kietaka?* by Diamond-sha in 1992.)

Jeong, J (1996), "Two Types of Labor Shortage: The Case of the Korean Machine-tool Industry," Journal-of-Industry-Studies; 3(1), June 1996, pages 71-85.

Jurgens, U. (2000), *New Product Development and Production Networks*, Springer.

Kobayashi, M. and Ohdaka Y. (1995) "Kosaku-kikai Sangyo," in *Sengo Nihon Sangyo-shi*, ed. By Sangyo Gakkai, Toyokeizai Shinpo-sha, 1995, pp.382-412.

Kobayashi, M. (2000), "Changing Strategies and Processes in the Japanese Machine-tool Product Development," in ed. by Jurgens, U., *New Product Development and Production Networks*, Springer.

Koike, K., H. Chuma, S. Ohta (2001), *Monozukuri no Ginou: Jidosha-sangyo no Shokukba de* (Skills for Production: In the Autoindustry Workshop), Toyokeizai Shuppansha.

Koike, K. (1999) *Shigoto no Keizaigaku*, Toyokeizai-Shinpo-sha.

Lippert, Inger (1999), "Reorganizing Process Chains in the German and American Machine-tool Industry," in Jurgens(1999) ed. *New Product Development and Production Networks*, Springer, pp.149-180.

Mazzoleni, Roberto (1999), "Innovation in the Machine-tool Industry: A Historical Perspective on the Dynamics of Comparative Advantage," in *Sources of Industrial Leadership: Studies of Seven Industrie*s, ed. by David C. Mowery and Richard R. Nelson, Cambridge University Press.

Miwa, Y. (1998), *Seifu no Noryoku, Yuhikaku.*

Przybylinski, S., "Case Study: Computer Numerical Controllers," in Finegold, D. (1994b) (ed.) *The Decline of the U.S. Machine-tool Industry and Prospects for Its Sustainable Recovery*, Vol.2, Rand, MR-479/2-OSTP-V.2.

Yamashita, M. (1999), *Nihon no Sangyo Hatten to Shokusyu-kan Bungyo*, Ph.D. thesis in Waseda University.

Rolfo, S. (2000), "The Italian Machine-tool Industry toward Product Development Networks," in ed. by Jurgens, U., *New Product Development and Production Networks*, Springer.

**Table 1: Probit Estimation about Development Lead-Time**

Number of obs = 655

| Dependent Variables | d_TimeToMarket10 | | | d_TimeToMarket30 | | |
|---|---|---|---|---|---|---|
| Explanatory Variables | Coef. | Std. Err. | P>\|t\| | Coef. | Std. Err. | P>\|t\| |
| **d_US** | **0.330** | **0.159** | **0.04** | **0.340** | **0.169** | **0.04** |
| **d_Germany** | -0.155 | 0.269 | 0.57 | **0.672** | **0.255** | **0.01** |
| **d_HandScraping** | -0.037 | 0.139 | 0.79 | **-0.390** | **0.145** | **0.01** |
| **d_AsmblyIntegrated** | **0.346** | **0.139** | **0.01** | 0.015 | 0.149 | 0.92 |
| d_MultiSkilled | 0.181 | 0.131 | 0.17 | 0.150 | 0.138 | 0.28 |
| **d_EarliestDRPat** | **0.526** | **0.132** | **0.00** | **0.617** | **0.128** | **0.00** |
| d_MostAssembly | 0.130 | 0.128 | 0.31 | 0.009 | 0.135 | 0.95 |
| **d_MostMachining** | **0.442** | **0.145** | **0.00** | **0.382** | **0.142** | **0.01** |
| **d_MostMarketing** | **0.432** | **0.118** | **0.00** | **0.258** | **0.121** | **0.03** |
| **d_TQCorTQM** | 0.141 | 0.118 | 0.23 | **0.349** | **0.118** | **0.00** |
| **d_OverseaProduct** | **0.506** | **0.212** | **0.02** | **0.547** | **0.183** | **0.00** |
| d_UsePublicOffJT | 0.056 | 0.123 | 0.65 | -0.138 | 0.128 | 0.28 |
| FirmEmpScale | 0.064 | 0.048 | 0.18 | 0.042 | 0.047 | 0.37 |
| d_Lathes | -0.179 | 0.178 | 0.31 | -0.129 | 0.179 | 0.47 |
| **d_Machining** | **0.315** | **0.192** | **0.10** | 0.182 | 0.186 | 0.33 |
| **d_DrilBroaching** | **0.525** | **0.226** | **0.02** | -0.036 | 0.256 | 0.89 |
| **d_Grinding** | -0.045 | 0.187 | 0.81 | **0.384** | **0.192** | **0.05** |
| **d_HornLapping** | -0.365 | 0.315 | 0.25 | **-1.000** | **0.377** | **0.01** |
| d_EDM | -0.236 | 0.338 | 0.49 | 0.238 | 0.385 | 0.54 |
| d_Boring | -0.159 | 0.298 | 0.59 | 0.181 | 0.307 | 0.56 |
| **d_OtherMetalCut** | **0.382** | **0.189** | **0.04** | 0.277 | 0.183 | 0.13 |
| **d_SpindSlide** | **0.306** | **0.158** | **0.05** | 0.174 | 0.165 | 0.29 |
| **d_PuchShear** | **-0.588** | **0.300** | **0.05** | -0.225 | 0.349 | 0.52 |
| d_MetalForming | 0.184 | 0.152 | 0.23 | 0.123 | 0.160 | 0.44 |
| d_OtherMachine | 0.069 | 0.133 | 0.60 | 0.164 | 0.142 | 0.25 |
| **constant** | **-1.244** | **0.224** | **0.00** | **-1.646** | **0.241** | **0.00** |

**Table 2-1: Probit Estimation about Development Lead-Time**
**<Japanese & American Machine-tool makers: above 10% >**

| | Number of obs = 464 | | | Number of obs = 157 | | |
|---|---|---|---|---|---|---|
| | Japanese Makers | | | US Makers | | |
| Dependent Variables | d_TimeToMarket10 | | | d_TimeToMarket10 | | |
| Explanatory Variables | Coef. | Std. Err. | P>\|z\| | Coef. | Std. Err. | P>\|z\| |
| d_HandScraping | 0.064 | 0.148 | 0.67 | 0.112 | 0.369 | 0.76 |
| **d_AsmblyIntegrated** | **0.467** | **0.178** | **0.01** | 0.069 | 0.268 | 0.80 |
| d_MultiSkilled | 0.149 | 0.141 | 0.29 | 0.122 | 0.294 | 0.68 |
| **d_EarliestDRPat** | 0.092 | 0.158 | 0.56 | **0.825** | **0.274** | **0.00** |
| **d_MostAssembly** | **0.395** | **0.141** | **0.01** | 0.138 | 0.373 | 0.71 |
| **d_MostMachining** | **0.318** | **0.141** | **0.03** | | | |
| **d_MostMarketing** | **0.401** | **0.131** | **0.00** | **0.603** | **0.297** | **0.04** |
| **d_TQCorTQM** | **0.291** | **0.135** | **0.03** | 0.027 | 0.240 | 0.91 |
| **d_OverseaProduct** | 0.349 | 0.244 | 0.15 | **1.674** | **0.496** | **0.00** |
| d_UsePublicOffJT | 0.087 | 0.150 | 0.56 | 0.289 | 0.256 | 0.26 |
| **FirmEmpScale** | **0.091** | **0.053** | **0.09** | 0.032 | 0.122 | 0.79 |
| d_Lathes | -0.141 | 0.203 | 0.49 | -0.579 | 0.635 | 0.36 |
| **d_Machining** | **0.404** | **0.227** | **0.08** | 0.397 | 0.594 | 0.50 |
| **d_DrilBroaching** | **0.679** | **0.272** | **0.01** | 0.179 | 0.423 | 0.67 |
| d_Grinding | 0.101 | 0.213 | 0.64 | 0.015 | 0.414 | 0.97 |
| d_HornLapping | -0.567 | 0.409 | 0.17 | 0.652 | 0.573 | 0.26 |
| d_EDM | -0.377 | 0.348 | 0.28 | -0.854 | 0.796 | 0.28 |
| d_Boring | 0.086 | 0.344 | 0.80 | -0.168 | 0.461 | 0.72 |
| **d_OtherMetalCut** | **0.390** | **0.202** | **0.05** | **0.704** | **0.419** | **0.09** |
| **d_SpindSlide** | **0.390** | **0.179** | **0.03** | -0.029 | 0.393 | 0.94 |
| d_PuchShear | -0.231 | 0.328 | 0.48 | -0.791 | 0.733 | 0.28 |
| d_MetalForming | 0.244 | 0.162 | 0.13 | 0.477 | 0.499 | 0.34 |
| d_OtherMachine | 0.217 | 0.151 | 0.15 | -0.314 | 0.347 | 0.36 |
| **constant** | **-1.558** | **0.272** | **0.00** | **-0.949** | **0.460** | **0.04** |

**Table 2-2: Probit Estimation about Development Lead-Time**
**<Japanese & American Machine-tool makers: above 30% >**

| | Number of obs = 464 | | | Number of obs = 157 | | |
|---|---|---|---|---|---|---|
| | Japanese Makers | | | US Makers | | |
| Dependent Variables | d_TimeToMarket30 | | | d_TimeToMarket30 | | |
| Explanatory Variables | Coef. | Std. Err. | P>\|z\| | Coef. | Std. Err. | P>\|z\| |
| **d_HandScraping** | **-0.423** | **0.152** | **0.01** | -0.396 | 0.379 | 0.30 |
| d_AsmblyIntegrated | -0.260 | 0.188 | 0.17 | 0.055 | 0.271 | 0.84 |
| d_MultiSkilled | 0.166 | 0.154 | 0.28 | -0.011 | 0.315 | 0.97 |
| **d_EarliestDRPat** | **0.300** | **0.157** | **0.06** | **0.774** | **0.269** | **0.00** |
| **d_MostAssembly** | **0.254** | **0.153** | **0.10** | 0.404 | 0.335 | 0.23 |
| d_MostMachining | 0.168 | 0.148 | 0.26 | | | |
| **d_MostMarketing** | 0.119 | 0.136 | 0.38 | **0.745** | **0.268** | **0.01** |
| **d_TQCorTQM** | **0.476** | **0.138** | **0.00** | 0.079 | 0.248 | 0.75 |
| **d_OverseaProduct** | **0.420** | **0.222** | **0.06** | **1.370** | **0.388** | **0.00** |
| d_UsePublicOffJT | -0.142 | 0.158 | 0.37 | 0.079 | 0.258 | 0.76 |
| FirmEmpScale | 0.054 | 0.050 | 0.28 | 0.062 | 0.123 | 0.62 |
| d_Lathes | -0.338 | 0.219 | 0.12 | 0.018 | 0.484 | 0.97 |
| d_Machining | -0.006 | 0.224 | 0.98 | 0.151 | 0.472 | 0.75 |
| d_DrilBroaching | -0.220 | 0.326 | 0.50 | -0.059 | 0.452 | 0.90 |
| **d_Grinding** | **0.523** | **0.217** | **0.02** | **0.791** | **0.390** | **0.04** |
| **d_HornLapping** | **-0.876** | **0.423** | **0.04** | -0.706 | 0.711 | 0.32 |
| d_EDM | -0.220 | 0.472 | 0.64 | -0.328 | 0.907 | 0.72 |
| d_Boring | 0.488 | 0.366 | 0.18 | 0.255 | 0.521 | 0.62 |
| **d_OtherMetalCut** | **0.413** | **0.195** | **0.03** | 0.155 | 0.378 | 0.68 |
| d_SpindSlide | 0.268 | 0.179 | 0.14 | -0.568 | 0.401 | 0.16 |
| d_PuchShear | 0.002 | 0.412 | 1.00 | -0.230 | 0.715 | 0.75 |
| **d_MetalForming** | -0.028 | 0.176 | 0.88 | **0.766** | **0.422** | **0.07** |
| d_OtherMachine | 0.115 | 0.159 | 0.47 | 0.283 | 0.397 | 0.48 |
| **constant** | **-1.302** | **0.269** | **0.00** | **-1.816** | **0.470** | **0.00** |

**Table 3: Probit Estimation about the Number of Claims during the First 6 Months**

Number of obs = 655

| Dependent Variables | d_NumClaim10 | | | d_NumClaim30 | | |
|---|---|---|---|---|---|---|
| Explanatory Variables | Coef. | Std. Err. | P>\|t\| | Coef. | Std. Err. | P>\|t\| |
| **d_US** | **-0.946** | **0.172** | **0.00** | **-0.618** | **0.195** | **0.00** |
| d_Germany | -0.396 | 0.261 | 0.13 | -0.120 | 0.278 | 0.67 |
| d_HandScraping | -0.020 | 0.129 | 0.88 | -0.225 | 0.138 | 0.11 |
| **d_AsmblyIntegrated** | **0.471** | **0.147** | **0.00** | **0.410** | **0.161** | **0.01** |
| **d_MultiSkilled** | 0.205 | 0.127 | 0.11 | **0.248** | **0.134** | **0.07** |
| **d_EarliestDRPat** | **0.382** | **0.134** | **0.00** | **0.269** | **0.134** | **0.05** |
| d_MostAssembly | -0.120 | 0.127 | 0.35 | -0.178 | 0.133 | 0.18 |
| **d_MostMachining** | **0.379** | **0.133** | **0.01** | **0.363** | **0.135** | **0.01** |
| d_MostMarketing | 0.100 | 0.117 | 0.39 | 0.124 | 0.122 | 0.31 |
| **d_TQCorTQM** | **0.492** | **0.116** | **0.00** | **0.377** | **0.120** | **0.00** |
| d_OverseaProduct | -0.035 | 0.196 | 0.86 | 0.221 | 0.200 | 0.27 |
| d_UsePublicOffJT | 0.039 | 0.125 | 0.76 | -0.186 | 0.131 | 0.16 |
| FirmEmpScale | -0.068 | 0.048 | 0.16 | -0.079 | 0.052 | 0.13 |
| d_Lathes | 0.036 | 0.177 | 0.84 | 0.028 | 0.188 | 0.88 |
| d_Machining | 0.067 | 0.186 | 0.72 | 0.238 | 0.196 | 0.23 |
| d_DrilBroaching | -0.041 | 0.243 | 0.87 | -0.431 | 0.297 | 0.15 |
| **d_Grinding** | 0.239 | 0.183 | 0.19 | **0.424** | **0.194** | **0.03** |
| **d_HornLapping** | -0.235 | 0.327 | 0.47 | **-0.750** | **0.359** | **0.04** |
| d_EDM | -0.133 | 0.304 | 0.66 | 0.380 | 0.326 | 0.24 |
| d_Boring | 0.256 | 0.278 | 0.36 | 0.373 | 0.312 | 0.23 |
| d_OtherMetalCut | 0.259 | 0.171 | 0.13 | 0.106 | 0.175 | 0.55 |
| d_SpindSlide | 0.015 | 0.153 | 0.92 | -0.091 | 0.175 | 0.60 |
| d_PuchShear | -0.010 | 0.318 | 0.98 | -0.038 | 0.355 | 0.91 |
| **d_MetalForming** | 0.154 | 0.149 | 0.30 | **0.301** | **0.160** | **0.06** |
| d_OtherMachine | 0.048 | 0.130 | 0.71 | 0.114 | 0.132 | 0.39 |
| **constant** | **-0.686** | **0.222** | **0.00** | **-1.257** | **0.242** | **0.00** |

**Table 4-1: Probit Estimation about the Number of Claims during the First 6 Months**
**<Japanese & American Machine-tool makers: above 10% >**

Number of obs = 464    Number of obs = 157

| | Japanese Makers | | | US Makers | | |
|---|---|---|---|---|---|---|
| Dependent Variables | d_NumClaim10 | | | d_NumClaim10 | | |
| Explanatory Variables | Coef. | Std. Err. | P>\|z\| | Coef. | Std. Err. | P>\|z\| |
| d_HandScraping | 0.085 | 0.144 | 0.56 | -0.395 | 0.402 | 0.33 |
| **d_AsmblyIntegrated** | **0.478** | **0.177** | **0.01** | **0.645** | **0.266** | **0.02** |
| d_MultiSkilled | 0.069 | 0.139 | 0.62 | -0.021 | 0.309 | 0.95 |
| **d_EarliestDRPat** | **0.401** | **0.154** | **0.01** | 0.192 | 0.279 | 0.49 |
| d_MostAssembly | 0.076 | 0.141 | 0.59 | -0.308 | 0.369 | 0.40 |
| d_MostMachining | 0.202 | 0.137 | 0.14 | -0.216 | 0.629 | 0.73 |
| **d_MostMarketing** | **0.248** | **0.129** | **0.05** | 0.409 | 0.300 | 0.17 |
| **d_TQCorTQM** | **0.479** | **0.133** | **0.00** | 0.342 | 0.258 | 0.19 |
| d_OverseaProduct | -0.267 | 0.214 | 0.21 | 0.216 | 0.388 | 0.58 |
| d_UsePublicOffJT | 0.211 | 0.147 | 0.15 | -0.085 | 0.285 | 0.76 |
| FirmEmpScale | -0.061 | 0.051 | 0.23 | 0.025 | 0.124 | 0.84 |
| d_Lathes | 0.030 | 0.198 | 0.88 | 0.233 | 0.483 | 0.63 |
| d_Machining | 0.332 | 0.216 | 0.12 | -0.531 | 0.478 | 0.27 |
| d_DrilBroaching | -0.126 | 0.291 | 0.67 | 0.010 | 0.434 | 0.98 |
| **d_Grinding** | -0.085 | 0.203 | 0.68 | **0.796** | **0.348** | **0.02** |
| d_HornLapping | -0.222 | 0.398 | 0.58 | -0.397 | 0.762 | 0.60 |
| d_EDM | 0.603 | 0.441 | 0.17 | | | |
| d_Boring | 0.403 | 0.360 | 0.26 | 0.558 | 0.569 | 0.33 |
| **d_OtherMetalCut** | 0.168 | 0.184 | 0.36 | **0.768** | **0.441** | **0.08** |
| d_SpindSlide | -0.016 | 0.174 | 0.93 | -0.072 | 0.402 | 0.86 |
| d_PuchShear | 0.457 | 0.402 | 0.26 | -0.576 | 0.707 | 0.42 |
| d_MetalForming | 0.048 | 0.157 | 0.76 | 0.529 | 0.388 | 0.17 |
| d_OtherMachine | 0.076 | 0.145 | 0.60 | -0.493 | 0.512 | 0.34 |
| **constant** | **-0.746** | **0.252** | **0.00** | **-1.602** | **0.450** | **0.00** |

### Table 4-2: Probit Estimation about the Number of Claims during the First 6 Months
### <Japanese & American Machine-tool makers: above 30% >

| | Number of obs = 464 | | | Number of obs = 157 | | |
|---|---|---|---|---|---|---|
| | Japanese Makers | | | US Makers | | |
| Dependent Variables | d_NumClaim30 | | | d_NumClaim30 | | |
| Explanatory Variables | Coef. | Std. Err. | P>\|z\| | Coef. | Std. Err. | P>\|z\| |
| **d_HandScraping** | -0.019 | 0.144 | 0.89 | **-1.071** | **0.607** | **0.08** |
| **d_AsmblyIntegrated** | 0.311 | 0.193 | 0.11 | **1.271** | **0.370** | **0.00** |
| d_MultiSkilled | 0.059 | 0.148 | 0.69 | 0.051 | 0.417 | 0.90 |
| **d_EarliestDRPat** | **0.415** | **0.150** | **0.01** | -0.109 | 0.374 | 0.77 |
| **d_MostAssembly** | 0.015 | 0.143 | 0.92 | **-0.807** | **0.426** | **0.06** |
| d_MostMachining | 0.124 | 0.142 | 0.38 | 0.722 | 0.637 | 0.26 |
| **d_MostMarketing** | 0.188 | 0.132 | 0.16 | **0.908** | **0.406** | **0.03** |
| **d_TQCorTQM** | **0.464** | **0.133** | **0.00** | 0.207 | 0.346 | 0.55 |
| d_OverseaProduct | -0.026 | 0.220 | 0.90 | 0.601 | 0.605 | 0.32 |
| d_UsePublicOffJT | -0.076 | 0.150 | 0.61 | -0.344 | 0.411 | 0.40 |
| FirmEmpScale | -0.066 | 0.052 | 0.20 | -0.153 | 0.152 | 0.32 |
| d_Lathes | -0.001 | 0.203 | 1.00 | 0.180 | 0.527 | 0.73 |
| d_Machining | 0.138 | 0.229 | 0.55 | 0.629 | 0.626 | 0.32 |
| **d_DrilBroaching** | **-0.706** | **0.329** | **0.03** | -0.123 | 0.621 | 0.84 |
| **d_Grinding** | -0.076 | 0.204 | 0.71 | **1.187** | **0.494** | **0.02** |
| d_HornLapping | -0.308 | 0.432 | 0.48 | | | |
| **d_EDM** | **1.012** | **0.418** | **0.02** | | | |
| d_Boring | 0.620 | 0.387 | 0.11 | 0.710 | 0.782 | 0.36 |
| d_OtherMetalCut | 0.132 | 0.185 | 0.48 | 0.413 | 0.646 | 0.52 |
| d_SpindSlide | -0.036 | 0.184 | 0.84 | -0.159 | 0.903 | 0.86 |
| d_PuchShear | 0.025 | 0.389 | 0.95 | -0.654 | 1.053 | 0.54 |
| **d_MetalForming** | 0.026 | 0.167 | 0.88 | **1.381** | **0.494** | **0.01** |
| d_OtherMachine | 0.164 | 0.151 | 0.28 | | | |
| **constant** | **-1.153** | **0.265** | **0.00** | **-2.323** | **0.683** | **0.00** |

Appendix 1• Basic Statistics and Definition of Variables

| **Variable** | **Mean** | **S.D.** | **Variable Definition** |
|---|---|---|---|
| **d_TimeToMarket10** | 0.54 | 0.50 | Development lead time decreased more than 10% in 10 years |
| **d_TimeToMarket30** | 0.28 | 0.45 | Development leadtime decreased more than 30% in 10 years |
| **d_NumClaim10** | 0.44 | 0.50 | Number of claims during the first 6 months decreased more than 10% in 10 years |
| **d_NumClaim30** | 0.24 | 0.42 | Number of claims during the first 6 months decreased more than 30% in 10 years |
| **d_Protype10** | 0.58 | 0.49 | Period for prototype-making decreased more than 10% in 10 years |
| **d_Protype30** | 0.34 | 0.47 | Period for prototype-making decreased more than 30% in 10 years |
| **d_US** | 0.22 | 0.42 | US Dummy Variable |
| **d_Germany** | 0.04 | 0.21 | Germany Dummy Variable |
| **d_HandScraping** | 0.21 | 0.41 | (Difficult) Handscraping is necessary for assemblymen |
| **d_AsmblyIntegrated** | 0.69 | 0.46 | Normally assemblymen are trained for both major and parts assembly |
| **d_MultiSkilled** | 0.67 | 0.47 | Try to make machinists multiskilled |
| **d_EarliestDRPat** | 0.33 | 0.47 | D&D people simultaneously meet with production workers |
| **d_MostAssembly** | 0.36 | 0.48 | Design & Development(D&D) people most frequently meet assemblymen in the Design Review (DR) |
| **d_MostMachining** | 0.25 | 0.43 | D&D people most frequently meet machinists in the DR |
| **d_MostMarketing** | 0.37 | 0.48 | D&D people most frequently meet marketing or sales people in the DR |
| **d_TQCorTQM** | 0.39 | 0.49 | TQC or TQM is introduced |
| **d_OverseaProduct** | 0.11 | 0.31 | Overseas production is conducted |
| **d_UsePublicOffJT** | 0.34 | 0.47 | Using publicly provided Off-the-job training opportunities |
| **FirmEmpScale** | 3.05 | 1.38 | Firm scale by Fulltimers |
| **d_Lathes** | 0.16 | 0.37 | Making lathes |
| **d_Machining** | 0.15 | 0.36 | Making machining centers |
| **d_DrilBroaching** | 0.07 | 0.25 | Making drilling or broaching machines |
| **d_Grinding** | 0.12 | 0.33 | Making grinding machines |
| **d_HornLapping** | 0.03 | 0.18 | Making horning or lapping machines |
| **d_EDM** | 0.03 | 0.16 | Making EDM (electric discharge machines) |
| **d_Boring** | 0.04 | 0.19 | Making boring machines |
| **d_OtherMetalCut** | 0.13 | 0.33 | Making other metal cutting machines |
| **d_SpindSlide** | 0.13 | 0.34 | Making spindles or slides ( guideways) |
| **d_PuchShear** | 0.03 | 0.17 | Making punching machines or shears |
| **d_MetalForming** | 0.20 | 0.40 | Making metal forming machines |
| **d_OtherMachine** | 0.30 | 0.46 | Making other types of machines |