An Empirical Analysis of Industrial Transformation in the Japanese Machine Tool Industry

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Abstract We attempt to analyze empirically how industrial transformation took place in the Japanese machine tool industry. For estimation, the following variables are selected: (a) automobile production; (b) exports; (c) investment; and (d) GDP. We then select meaningful variables according to Akaike's Information Criterion. After this procedure, we use the method of Seemingly Unrelated Regression. By this method, we can specify the exact demand functions for machine tools.

1. INTRODUCTION

Since the bursting of the bubble economy, Japan has been suffering its longest recession of the post-war period. We are beginning to see the myth once surrounding the Japanese economy start to fade away; namely, its well-known industries such as those related to automobiles, household electric appliances, semiconductors, shipbuilding, and steel have been losing their predominant share in the world market. One reason for this is U.S. industries are once again productive, and another is because the Asian "four dragons" have been catching up with Japan. There is, however, still one industry that continues to retain its position with a market size that is relatively small but no less important among the above industries -- the machine tool industry. It is no doubt an important industry, since products today are manufactured by the use of parts, equipment, and machines, and these are all products of machine tools. In this sense, a machine tool is referred to as a "mother machine". The quality of the products are entirely dependent on such tools. The Japanese machine tool industry possesses an overwhelmingly high level of technology, and it is believed that it will be able to enjoy a major share of the market for an additional five to ten years.

In this paper, we attempt to analyze empirically how industrial transformation took place in the machine tool industry: namely, what kind of factors in the demand for machine tools made it possible. By following the conclusion obtained by Tsuji and Ishikawa [1994], which discussed the same issues by using annual data and making use of an estimation method, the stepwise-Chow test, we fix the timing of industrial transformation in 1976. Then, we use more rigorous methods such as Akaike's Information Criterion (AIC) and Seemingly Unrelated Regression (SUR) to estimate the demand functions in the period before and after industrial transformation.[1)]

This paper consists of the following five sections. In section two, an explanation is provided on the growth and industrial transformation of the machine tool industry from the viewpoint of its production as well as industrial structure, namely, the upheaval of individual firms. In the third section, the specification of the model and the method of estimation are provided. Then, in the fourth section, the results of the estimation of the demand functions are presented. Concluding remarks are provided in the final section.

2. INDUSTRIAL TRANSFORMATION OF THE MACHINE TOOL INDUSTRY

Table 1 indicates the growth of the Japanese machine tool industry since 1961 in terms of production, exports, and imports. It reached the highest level of production during the bubble economy, but current production is approximately half that amount, and it has yet to restore its peak level. As for exports, they increased sharply after the oil crises of the 1970s, which was due to the success of numerically-controlled (NC) machine tools. During this period, as seen in the aforementioned table, exports exceeded imports. This shows that the quality (in terms of price) of Japanese machine tools had become compatible with that of Western countries. Due to NC machine tools, Japan was able to increase its exports, and this made the industry heavily dependent on exports that recently amounted to approximately 80% of the total products.

Since the late 1970s, Japanese assembling and processing industries have achieved a high level of international competitive power and their products have been exported abroad. The reason for their high competitiveness was their high quality and low prices. It was NC machine tools that made this possible. The NC ratio, which implies the ratio of NC machine tools to total production, has shown an increase since the period of the oil crises (see table 1).

Industrial transformation took place in the domestic market of the machine tool industry. Here, we will discuss the domestic competition and its aftermath, namely, how the success or failure of the development of NC machine tools affected the rank order of individual firms in terms of amount of production. Figure 1 indicates that prior to 1977, companies with a long tradition in manufacturing machine tools which included Ikegai, Okuma, Toshiba Machine Tools, Hitachi Precision Works, and Toyoda Machine Works, were called the "Big 5," and had occupied the largest market share in the machine tool industry. They had a long tradition in producing machine tools, especially Ikegai which was one of the oldest companies in this industry.

There was another category of firms, namely, that of Okuma, Yamazaki, and Mori Precision Machinery. The size of this group was not very big at its origins. As shown in figure 1, after 1977, the rank order of the firms in this industry changed entirely. The aforementioned firms increased their market share tremendously, and Yamazaki, Okuma, and Mori are presently still the biggest companies. Due to this, these firms are referred to as the "Big 3". The most well-known firm in this industry, Ikegai, suffered a drastic loss in its market share. This drastic change in rank order of market share, as stated above, stems from the success or failure to develop new technology, i.e., NC machine tools, computerized numerically-controlled (CNC) machine tools more precisely. The difference came from their philosophy towards development of new technology such as NC or CNC machine tools.[2)]

3. SPECIFICATION OF THE MODEL

In this paper we make an estimate of the demand function for machine tools, and attempt to determine the precise time of industrial transformation of the machine tool industry.

As stated previously, that are two kinds of demand for machine tools: namely, NC and non-NC machine tools, and they are estimated separately. There is a demand for machine tools from the following industries: (a) industrial machinery such as construction machinery and electric machinery; (b) transporting machinery such as automobiles; (c) metal works; and (d) other machinery and equipment. In addition to these, other macroeconomic variables such as GDP, investment, government expenditure, and exports influence the demand for machine tools. It can be expected, however, that all these variables are correlated with each other, and this raises the problem of collinearity.[3)] Therefore, we select the following variables, namely: (a) the volume of automobile production (CAR), since the automobile industry is one of the largest demanders of machine tools; (b) exports (EXT) which signifies the demand from abroad; (c) investment (IOP) which reflects the demand from other manufacturing industries, and also shows the cyclical movement of the demand; and (d) GDP which represents overall demand from the economy. Variables in terms of monetary unit are divided by suitable price index, and they are all expressed in real terms. In addition to these variables, since the main purpose of the paper is to analyze the industrial transformation of the machine tool industry, we use dummy variables (DUM_i) to indicate the structural change in the demand function.

3.1 Unit Root Tests

Here all variables are quarterly data, and in order to eliminate seasonal relation, they are converted to last year's ratios. It might, however, be possible for the variables to have a unit root. Thus, we adopt the unit root tests to examine how stationary the variables are. By making use of the Augmented Dickey-Fuller test, we find that the four variables MT, NC, IOP, and GDP do have unit roots. We cannot abandon the null hypothesis that they have unit roots. According to the usual procedure, we take the first order difference of these four variables, then apply the unit root tests again. This time the existence of the unit root is rejected.

3.2 Method of Estimation

Thus, we use the following model to make an estimate of demand functions for NC and non-NC machine tools, which are indicated as NC_t, and MT_t, respectively.

$$\begin{aligned}\triangle NC_t = {} & \alpha_0 + \alpha_1{*}DUM_i + \alpha_2{*}DUM_{OIL} \\ & + \Sigma(\beta_{0j} + \beta_{1j}{*}DUM_i){*}CAR_{t-j} \\ & + \Sigma(\gamma_{0j} + \gamma_{1j}{*}DUM_i){*}EXT_{t-j} \\ & + \Sigma(\delta_{0j} + \delta_{1j}{*}DUM_i){*}\triangle IOP_{t-j} \\ & + \Sigma(\varepsilon_{0j} + \varepsilon_{1j}{*}DUM_i){*}\triangle GDP_{t-j} \\ & + u_t \qquad (1)\end{aligned}$$

$$\begin{aligned}\triangle MT_t = {} & \alpha'_0 + \alpha'_1{*}DUM_i + \alpha'_2{*}DUM_{OIL} \\ & + \Sigma(\beta'_{0j} + \beta'_{1j}{*}DUM_i){*}CAR_{t-j} \\ & + \Sigma(\gamma'_{0j} + \gamma'_{1j}{*}DUM_i){*}EXT_{t-j} \\ & + \Sigma(\delta'_{0j} + \delta'_{1j}{*}DUM_i){*}\triangle IOP_{t-j} \\ & + \Sigma(\varepsilon'_{0j} + \varepsilon'_{1j}{*}DUM_i){*}\triangle GDP_{t-j} \\ & + u_t \qquad (2)\end{aligned}$$

where DUM_i stands for a dummy variable which takes 1 after the second quarter of 1976 and zero before this time, that is, it indicates the time when industrial transformation is supposed to take place. DUM_{OIL} indicates the period of the oil crises.

After estimation of (1) and (2), from each equation of the model, we select meaningful variables according to Akaike's Information Criterion (AIC) and erase other meaningless variables from the models. The model consisting of only meaningful variables is referred to as the "AIC model" in this paper. After this procedure, we use the method of Seemingly Unrelated Regression (SUR).

4. RESULTS OF ESTIMATION OF THE MODELS

Following the above procedure, we calculate (1) and (2). Tables 2, 3, 4, 5 indicate the results of the estimation. Tables 2 and 3 are estimations of the AIC model. When comparing NC and non-NC machine tools, the former is found to have better estimators than the latter. As seen from table 1, NC machine tools have dominated the machine tool market, and non-NC machine tools have been losing their share. This caused the difference in the estimation.

The implication of tables 2 and 3 is rather difficult to determine, even if the variables are at a significant level for t-statistics. The reason is that lags appear on the right hand side of the equations, which are caused by the use of the first order difference of variables as NC, MT, IOP, and GDP, with the remaining variables, CAR and EXT, being last year's ratios. Two kinds of variables show up in the models, then the AIC chooses the one-quarter lag to all variables.[4] In addition, the signs of the estimated coefficients of all variables, excluding CAR and GDP, are opposite. Negative signs might appear in the estimation, since we take the first order difference for the aforementioned variables. That the same variables with or without a lag have opposite signs indicates that quite extensive structural shifts took place before and after industrial transformation.

Due to these reasons, while taking the first order difference of all variables, we again estimate the AIC model, and the results are shown in tables 4 and 5. The variables with suffix T indicates coefficients throughout the sample period, while those with suffix 76 are coefficients after the second quarter of 1976. As for NC machine tools, the coefficients CAR_{76}, EXT_T, and IOP_T are significant in terms of t-statistics. Following the second quarter of 1976, automobile production increased its effectiveness; on the other hand, exports as well as investment lost their influence after industrial transformation, although the export coefficient is significant throughout the sample period. Thus, we can say that the demand for NC machine tools had been promoted by domestic investment before the second quarter of 1976; after that period it was automobile production that most influenced the demand for NC machine tools.

As for non-NC machine tools, only two variables, EXT_T and IOP_T, are significant and throughout the period, exports and investment influenced the demand for non-NC machine tools. After industrial transformation, however, no variables had any significant influence. This seems to coincide with the data that indicates the production of non-NC machine tools eventually showing a drastic decrease.

5. CONCLUDING REMARKS

By using a rigorous estimation method, we can specify the exact time of industrial transformation as well as the demand functions for NC and non-NC machine tools. Estimators obtained by SUR and AIC are rather difficult to interpret, and this is due to the definition of the variables. Since the time series of the data such as those related to NC and non-NC machine tools, IOP, and GDP cannot meet unit root tests, we have to convert these data to a different form. We have to consider which kind of data to use for the estimation.

Because of collinearity, we do not use all the variables which affect the demand for machine tools. Miyahara and Tsuji [1995] attempted to avoid this by using the Ridge estimation. This method is, however, not suitable for the analysis of industrial transformation. An estimation method which can analyze both collinearity and industrial transformation is required.

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Notes

1) As pointed out by Tsuji and Ishikawa [1994], the Chow test is not restrictive. For the wide range of the probable period, the test meets the condition of the F-test. We selected the time that took the highest F value, but another time could also meet the criteria of the F-test. The same point is discussed, for instance, by Morimune [1983], pp. 57-61.

2) For a more detailed discussion of the competition for innovation of NC machine tools, see Tsuji *et al.* [1996].

3) For an estimation with additional variables, such as industrial machinery, using the Ridge estimation method to avoid the problem of collinearity, see Miyahara and Tsuji [1995].

4) That a one-quarter lag appears in the result is acceptable. The machine tool industry has been experiencing a wide fluctuation in its business cycle. Changes occurred prior to a business cycle, since machine tools are capital goods. Thus, lags in the model are consistent with the fact that the production of machine tools fluctuates almost instantaneously to changes in demand factors.

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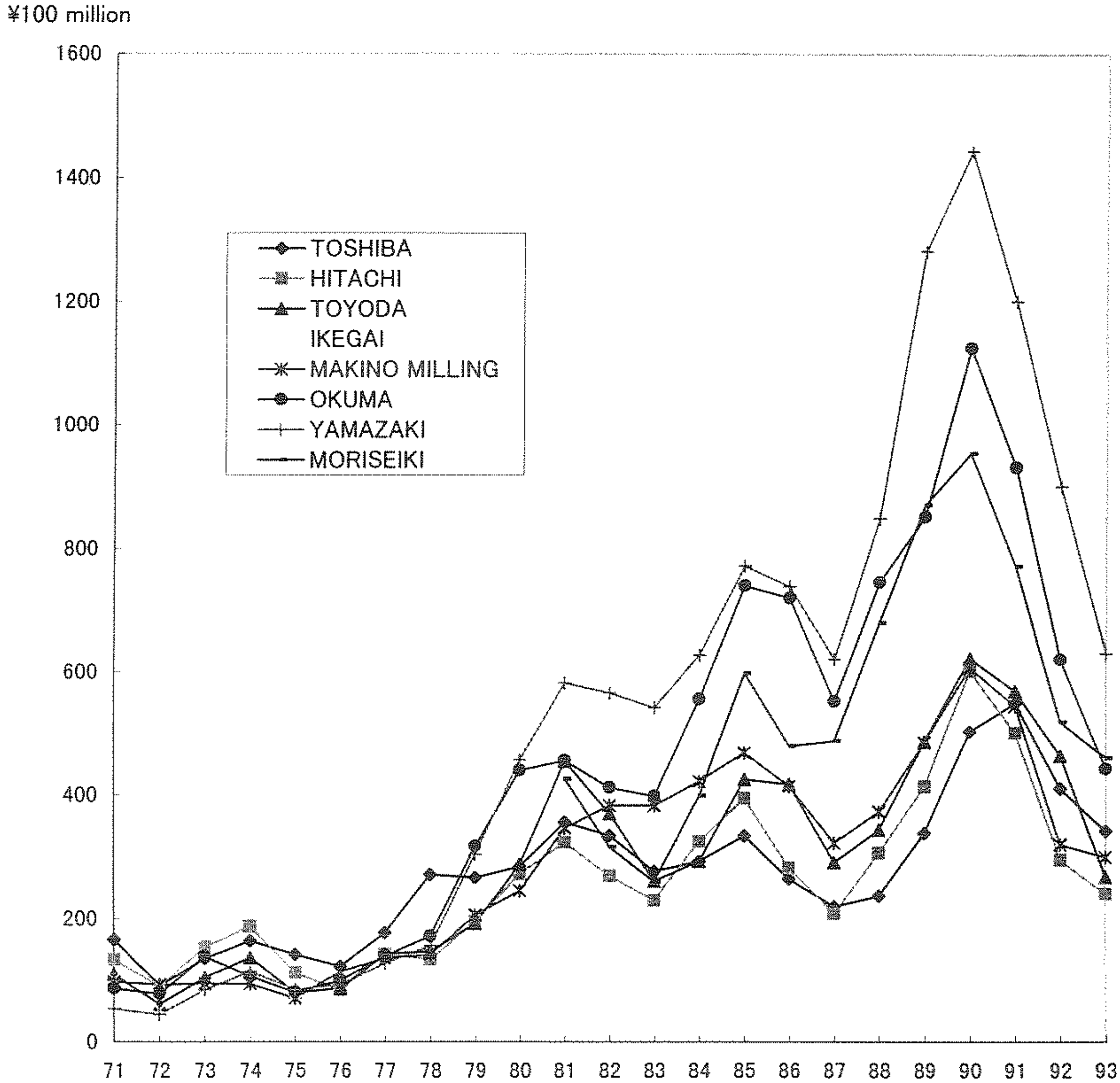

Figure 1. Upheaval in the Machine Tool Industry

¥ million, %

Year	Value of Production		Exports		Ratio of Export		Imports		Dependency of Imports
	(A) Production	NC ratio	(B) Exports	NC ratio	B/A	b/a NC	(C) Imports	NC ratio	C/D
1961	81,882	…	2,434	…	3.0	…	38,899	…	32.9
1962	100,892	…	2,588	…	2.6	…	47,582	…	32.6
1963	95,132	…	4,295	…	4.5	…	22,796	…	20.1
1964	90,906	…	6,509	…	7.2	…	21,320	…	20.2
1965	70,349	…	8,943	…	12.7	…	13,963	…	18.5
1966	76,453	…	14,611	…	19.1	…	7,586	…	10.9
1967	126,041	…	17,642	…	14.0	…	12,839	…	10.6
1968	175,986	…	18,583	…	10.6	…	34,176	…	17.8
1969	239,988	…	21,742	…	9.1	…	34,485	…	13.6
1970	312,349	7.8	24,088	2.5	7.7	2.4	44,162	8.3	13.3
1971	264,405	9.5	28,044	3.5	10.6	3.9	39,763	8.0	14.4
1972	205,180	12.0	27,408	5.9	13.4	6.5	22,366	7.8	11.2
1973	305,223	15.6	35,237	5.0	11.5	3.7	21,332	4.9	7.3
1974	358,610	16.3	57,664	9.3	16.1	9.2	37,211	6.4	11.0
1975	230,739	17.3	61,611	13.1	26.7	20.2	21,575	6.8	11.3
1976	228,604	22.4	76,073	23.8	33.3	35.3	13,867	4.2	8.3
1977	312,844	25.7	115,493	31.5	36.9	45.2	15,720	7.7	7.4
1978	365,525	29.4	162,138	38.7	44.4	58.3	19,638	15.0	8.8
1979	484,132	42.4	206,643	48.2	42.7	48.5	26,214	10.4	8.6
1980	682,102	49.8	269,577	64.1	39.5	50.9	38,221	11.8	8.5
1981	851,312	51.0	310,763	70.5	36.5	50.4	38,623	11.2	6.7
1982	782,776	53.9	247,576	65.6	31.6	38.5	43,585	19.5	7.5
1983	702,287	60.7	237,445	65.5	33.8	36.4	32,517	18.1	6.5
1984	881,485	66.9	315,132	71.7	35.8	38.3	29,259	24.0	4.9
1985	1,051,128	67.0	395,040	72.1	37.6	40.5	35,186	32.5	5.1
1986	899,402	67.9	363,606	71.8	40.4	42.8	33,241	42.2	5.8
1987	688,779	70.7	296,374	69.3	43.0	42.2	22,073	46.3	5.3
1988	881,070	70.4	321,488	79.7	36.5	41.3	36,726	39.3	6.2
1989	1,139,205	73.0	428,591	81.3	37.6	41.9	50,494	38.1	6.6
1990	1,303,442	75.7	455,809	81.6	35.0	37.7	68,645	42.8	7.5
1991	1,265,587	72.5	411,948	78.7	32.5	35.3	58,496	43.1	6.4
1992	831,087	72.5	330,291	80.1	39.7	43.9	41,027	51.5	7.6
1993	592,727	77.3	306,094	78.5	51.6	52.4	25,230	46.1	8.1
1994	554,080	79.2	328,786	78.6	59.3	58.9	25,226	33.6	10.1
1995	699,351	82.3	478,054	77.6	68.4	64.5	41,032	33.4	15.6

Source: JMTBA.   D: Domestic demand,   D = (A) + (C) − (B)

Table 1.   Statistics of the Japanese Machine Tool Industry

Variables	estimated coefficients	t-statistics
Const	−0.531	−0.169
CAR_T	1.318	2.869**
CAR_{76}	—	—
$CAR_T(-1)$	2.183	3.569**
$CAR_{76}(-1)$	−3.240	−4.301**
EXT_T	3.774	4.986**
EXT_{76}	−3.612	−3.773*
$EXT_T(-1)$	−4.233	−5.363**
$EXT_{76}(-1)$	3.988	4.076**
IOP_T	−6.750	−3.962**
IOP_{76}	8.539	4.511**
$IOP_T(-1)$	−3.542	−1.731
$IOP_{76}(-1)$	5.088	2.214*
GDP_T	—	—
GDP_{76}	—	—
$GDP_T(-1)$	12.150	4.975**
$GDP_{76}(-1)$	−17.764	−4.441**
DUM_{76}	—	—
DUMOIL	—	—
Adj-R^2	0.544	
D.W.	2.470	

*indicates 5% of significant level, ** that of 1%

Table 2 Demand Function of NC Machine Tools (AIC model)

Variables	Estimated Coefficients	t-statistics
Const	−11.559	−2.112*
CAR_T	—	—
CAR_{76}	−0.394	−1.425
$CAR_T(-1)$	1.459	5.616**
$CAR_{76}(-1)$	−1.459	−3.859**
EXT_T	1.949	4.035**
EXT_{76}	−1.344	−2.343*
$EXT_T(-1)$	−1.305	−3.908**
$EXT_{76}(-1)$	1.151	2.535*
IOP_T	—	—
IOP_{76}	2.407	5.028**
$IOP_T(-1)$	—	—
$IOP_{76}(-1)$	—	—
GDP_T	—	—
GDP_{76}	—	—
$GDP_T(-1)$	−2.370	−1.864
$GDP_{76}(-1)$	4.686	2.476*
DUM_{76}	9.728	1.697
DUMOIL	35.357	2.735**
Adj-R^2	0.534	
D.W.	1.902	

*indicates 5% of significant level, ** that of 1%

Table 3 Demand Function of Non-NC Machine Tools (AIC model)

Variables	Estimated Coefficients	t-statistics
Const	—	—
CAR_T	—	—
CAR_{76}	0.999	1.944*
EXT_T	1.925	3.166**
EXT_{76}	−1.672	−1.936
IOP_T	2.463	3.483**
IOP_{76}	—	—
GDP_T	—	—
GDP_{76}	—	—
DUM_{76}	—	—
DUMOIL	−43.090	−2.047**
Adj-R^2	0.244	
D.W.	2.295	

*indicates 5% of significant level, ** that of 1%

Table 4 Adjusted Estimation of Demand Function (NC Machine Tools)

Variables	Estimated Coefficients	t-statistics
Const	-	-
CAR_T	0.202	1.015
CAR_{76}	−0.324	−1.052
EXT_T	0.899	2.976**
EXT_{76}	−0.598	−1.450
IOP_T	2.119	
IOP_{76}	-	6.544**
GDP_T	-	-
GDP_{76}	-	-
DUM_{76}	-	-
DUMOIL	18.873	1.958*
Adj-R^2	0.356	
D.W.	1.888	

*indicates 5% of significant level, ** that of 1%

Table 5 Adjusted Estimation of Demand Function (NC Machine Tools)