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Saturation Level of NC Machine-Tool Diffusion

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FOREWORD

Analysis and forecasting of NC machine diffusion constitute one of the main activities of the IIASA Project "Computer Integrated Manufacturing" (CIM). Numerical Control (NC) machine-tools are regarded as a basic component of flexible manufacturing systems (FMS).

This paper is the second paper at IIASA relating to the diffusion of NC machines. The first paper, entitled "CIM Diffusion: The case of NC-machines in the U.S. Metalworking industry", was written by I. Tchijov [Tchijov, 1987].

The author, A. Tani, has improved the method of forecasting the saturation level of NC machines in this paper by establishing a bridge between two kinds of data -- consumption and installation data -- for both cases, the USA and Japan.

The saturation level of the NC share estimated in this paper is about five times higher than in the previous estimation. The result seems more realistic and reliable.

Subsequent work in this direction will also provide a method to make forecasting of the diffusion of FMS and CIM more reliable.

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1. INTRODUCTION

Investigation on the diffusion of NC (numerical control) machine-tools is one of the fundamental and important tasks of the CIM (Computer Integrated Manufacturing) Project at IIASA. NC machines-tools are regarded as basic components of the FMS (flexible manufacturing system), which takes a central part in the CIM system.

The populations of NC machine-tools in several countries are summarized as follows:

Country	Year	Population of NC machine-tools	Source
USA	1983	103,308 units	[AM, 1983]
Japan	1987	70,255 units[1]	[MITI, 1988]
FRG	1985	50,000 units	[Fix-Sterz & Lay, 1986]
France	1985	35,000 units	[Margirier, 1987]

Tchijov analyzed the past development trends of the US MWI (metalworking industry) from the viewpoint of NC machine-tools and estimated the saturation level of NC machine-tools diffusion as a fraction of the total number of machine-tools installed by applying the logistic curve method to the past trend data of the NC share for five time-points (1963, 1968, 1973, 1977 and 1983) [Tchijov, 1987].

According to his paper, the NC share in total machine-tools of the US MWI will saturate in the 1990's and reach a level of 5.8-8.0%.

This estimation is considered to be quite low, because a recent survey on machine-tools in the Japanese machine industry shows that the NC share had reached already 9.2% by the end of September 1987, even in case of including metal-forming machines.

It is very difficult to make a reliable estimate of the saturation level by logistic curve methods based only on data of the early stage of diffusion.

In the foreword of the paper Ayres suggested the necessity of establishing a bridge between two kinds of data -- production

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[1] The survey was carried out for all establishments of more than 50 employees in the machine industry.

and installation data -- to make the forecasts of the NC share more reliable.

It would be more correct to use the term "consumption" rather than "production".

A similar logistic curve method was also applied to the forecasts of FMS in the world [Tchijov & Sheinin, 1988]. Ranta commented on the results as shown below [Ranta, 1988]: "The simple estimate gives above 1800-2000 systems for the year 2000, which is also the saturation level of the diffusion. Although there are a lot of barriers for the diffusion, the saturation level seems to be extremely low -- this poses a question concerning the validity of logistic methods."

As mentioned above, simple logistic curve methods should be revised to improve the reliability of forecasts.

Therefore, this paper proposes a method to establish a bridge between two kinds of data -- consumption and installation data -- to make the forecasts of the NC share more reliable, and especially the forecasts of the saturation levels.

In addition, this paper analyzes the past and recent trends of NC machine-tool diffusion in the USA and Japan, and applies the proposed method to the forecasts of the saturation level of NC shares.

The results concerning NC machine-tools in this paper show that the saturation level will be about five times higher than the previous estimates.

As mentioned before, recent statistical data support such a tendency.

2. TWO KINDS OF NC SHARES IN MACHINE-TOOLS: THEORETICAL CONSIDERATIONS

2.1 Definitions and Assumptions

In order to forecast the diffusion of NC machine-tools, the following three steps are usually taken:

1) to forecast the share of NC machine-tools in total machine-tools (NC share);
2) to forecast the number of total machine-tools in the future;
3) to forecast the number of NC machine-tools by multiplying the NC share to total machine-tools.

The first step, the forecast of the NC share, can be regarded as the most important task among the above three steps.

Therefore, we focus on the forecast of the NC share in this paper.

Definitions

As stated before, two kinds of data concerning the NC shares are theoretically available for the forecasts, namely "NC share in installation" and "NC share in consumption".

a) NC share in installation of machine-tools: $g(t)$

$$g(t) \equiv u(t)/U(t) \qquad (1)$$

where $u(t)$ and $U(t)$ denote the number of NC machine-tools (population) and the number of total machine-tools installed at the end of year t, respectively.

This share can be called a "stock-type variable" in the terminology of system dynamics.

b) NC share in consumption of machine-tools: $f(t)$

$$f(t) \equiv x(t)/X(t) \qquad (2)$$

where $x(t)$ and $X(t)$ denote the number of NC machine-tools and total machine-tools consumed in year t, respectively.

This share can be called a "flow-type variable".

Assumptions

The purpose of this chapter is to develop a method of more reliable forecasting by using the two kinds of NC share data, $g(t)$ and $f(t)$.

There is some relationship between stock-type variable $g(t)$ and flow-type variable $f(t)$. In order to clarify the relationship, we introduce the following assumptions on the pattern of replacement of machine-tools in this paper.

<Assumption I>

Replacement time = constant (m years)

In real cases, the replacement time of machine-tools can be regarded to be probabilistic. However, it may be said that the above assumption does not cause a significant forecasting error when we focus on the long-term trends of diffusion.

According to the above assumption and the definitions of U(t), u(t), X(t) and x(t), the following relationships can be obtained between the stock-type and flow-type variables.

$$\frac{dU}{dt} = X(t) - X(t-m) \tag{3}$$

or

$$U(t) = \int_{t-m}^{t} X(t')dt' \tag{3'}$$

$$\frac{du}{dt} = x(t) - x(t-m) \tag{4}$$

or

$$u(t) = \int_{t-m}^{t} x(t')dt' \tag{4'}$$

The above equations mean that the population at time t is equal to the accumulated number consumed (introduced) from t-m up to t.

<Assumption II>

$$1 \geq f(t) \geq 0 \tag{5}$$

$$\frac{df}{dt} \geq 0 \tag{6}$$

$$\lim_{t \to -\infty} f(t) = 0 \tag{7}$$

$$\lim_{t \to +\infty} f(t) = f_{\infty} \leq 1 \tag{8}$$

These assumptions on the function f(t), the NC share in consumption, mean that f(t) increases monotonously from zero and saturates at the level of f_{∞}, which is a constant of less than 1. I.e., f(t) is assumed to be a growth curve. Condition (6) is considered to be the most severe among the above assumptions. However, it can be said that this condition is satisfied in most cases if short-term fluctuations of f(t) are eliminated.

<Assumption III>

$$X(t) \geq 0 \tag{9}$$

The last assumption shown above is very obvious. This means that the consumption of machine-tools is non-negative.

2.2 Relationship Between the Two Kinds of NC Shares

In this section the characteristics of function g(t) are discussed, based upon the assumptions explained in the previous section.

(1) Value range of g(t)

Function g(t) can be expressed below in terms of f(t) and X(t) by substituting equations (2), (3') and (4') into equation (1).

$$g(t) = \frac{\int_{t-m}^{t} f(t')X(t')dt'}{\int_{t-m}^{t} X(t')dt'} \tag{10}$$

By applying the well-known "mean value theorem for integrals[2]" to the numerator in the above equation, it can be derived that there exists at least one c in [t-m,t] so that

$$\int_{t-m}^{t} f(t')X(t')dt' = f(c) \int_{t-m}^{t} X(t')dt' \tag{11}$$

where

$$t \geq c \geq t-m \tag{12}$$

The conditions where the mean value theorem is applicable are $f(t) \geq 0$ and $X(t) \geq 0$. Both conditions are satisfied in this case due to assumptions (5) and (9).

It can be derived that g(t) is equal to f(t) by substituting equation (11) into (10).

$$g(t) = f(c) \tag{13}$$

On the other hand, condition (6) and inequality (12) give us the following inequality:

$$f(t) \geq f(c) \geq f(t-m) \tag{14}$$

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[2]Mean value theorem for integrals:

If f and X are continuous for [a,b] and X never changes sign in [a,b], then there exists at least one c in [a,b] such that

$$\int_{a}^{b} f(t)\cdot X(t)dt = f(c) \int_{a}^{b} X(t)dt$$

With respect to this theorem, see [Pearson, 1974].

By substituting equation (13) into (14), the value range of g(t) is determined as shown below.

$$f(t) \geq g(t) \geq f(t-m) \tag{15}$$

The limitation values of g(t) can be obtained by applying equations (7) and (8) to (15).

$$\lim_{t \to -\infty} g(t) = 0 \tag{16}$$

$$\lim_{t \to +\infty} g(t) = f_\infty \tag{17}$$

In other words, the limitations of g(t) are equal to those of f(t).

Moreover, the derivative of g(t), dg/dt, is expressed as follows:

$$\frac{dg}{dt} = \frac{1}{U} \{(f(t) - g(t)) \cdot X(t) + (g(t) - f(t-m)) \cdot X(t-m)\} \tag{18}$$

Inequalities (9), (15) and U(t) > 0 show that dg/dt is non-negative. Therefore g(t) is also a monotonously increasing function as is f(t).

To summarize, g(t) has the same characteristics as f(t), which satisfy conditions (5) to (8).

In order to clarify the relationship between g(t) and f(t), we suppose that f(t) saturates at time T.

$$f(t) = f_\infty \text{ when } t \geq T \tag{19}$$

In such a case, by using inequality (15) at time t = T+m, it can be proved that g(T+m) is equal to f_∞.

$$f(T+m) = f_\infty \geq g(T+m) \geq f_\infty = f(T) \tag{20}$$

In other words, the NC share in installation g(t) saturates at least m years after the NC share in consumption f(t) saturates. I.e., f(t) can be regarded as leading series of g(t).

Supposing that the number of machine-tools consumed [X(t)] is approximately constant, g(t) can be expressed as follows:

$$g(t) = \frac{1}{m}\int_{t-m}^{t} f(t')dt' = F\left(t - \frac{m}{2}\right) \qquad (21)$$

where F(t) denotes the moving average of function f within the range [t - m/2, t + m/2].

Figure 1 illustrates an example of the relationship between the diffusion curves g(t) and f(t).

The results of this chapter might be summarized as follows:

- The NC share in consumption f(t) is a leading index of the NC share in installation g(t).
- The diffusion curve g(t) can be forecasted by using future f(t) and consumption of machine-tools X(t).
- The saturation level of the NC share in installation is equal to that in consumption, whereas the saturation time of g(t) lags some years behind that of f(t).

The above results show the possibility that we can estimate the saturation level in installation $g(\infty)$ more reliably by applying logistic curve methods -- not to g(t), but to f(t).

In most cases, forecasting is needed at the early stage of the diffusion level when the diffusion in stock-base is very low. In addition, there are only few data available at such a stage, because a stock-type survey is usually carried out about every five years. Therefore it is very difficult to make a reliable estimate of the saturation level.

On the other hand, flow-type data are available in most cases for each year.[a] There are a lot of sample points for

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[a]Strictly speaking, it is difficult to get the consumption data (user side). However, we can use the production data (supplier side) instead of the consumption data, because production-based data are available in most cases. In case of using production-based data, the data may have to be modified by export/import data.

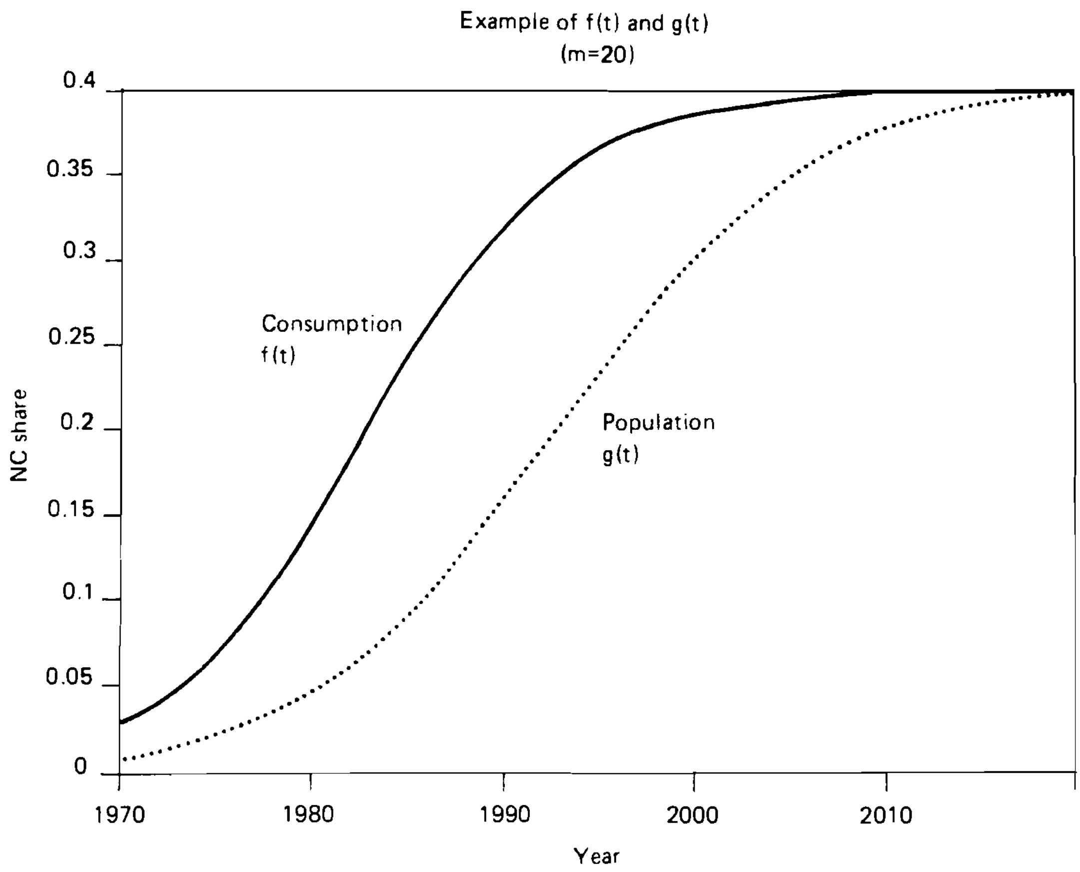

Figure 1. Example of relationship between f(t) and g(t).

statistical analysis. Moreover, the diffusion level in consumption shows to be much higher than in installation. The latest tendencies can be furthermore be included in the analysis.

Therefore it is strongly recommended to use the past data f(t) instead of g(t) for forecasting the NC share in installation.

3. ESTIMATION OF THE SATURATION LEVEL

3.1 The Case of the USA

Data on the machine-tool population are available as a survey on the inventory of metal working equipment for every five years (1963, 1968, 1973, 1977/78 and 1983) in the US MWI (metal working industry) [AM, 1983]. As the data after 1983 are not available, we cannot take into account any recent tendencies.

According to the surveys, the share of NC machine-tools in total machine-tools (metal cutting and metal forming) in the US MWI increased from 0.1% in 1963 to 4.7% in 1983.

Figure 2 shows the results of forecasting by the logistic curve method which is applied to these past trends [Tchijov, 1987]. The saturation level of the NC share in installation, percentage measured on a unit-base, is estimated to be 5.8%.

Table 1 summarizes the results of forecasting the NC share in installation by major types of machines, including the estimates of the saturation level and the NC shares of machines consumed during the period from 1979 to 1983.

In case of turning machines, the NC share in consumption reached 37.1% in the above period, which already exceeded the estimated saturation level of the NC share in installation (16.2%) as shown in Table 1.

Similar gaps can also be observed in the cases of boring machines, milling machines, machining centers and total machine-tools. For instance, the NC share of total machine-tools in consumption was 17.3%, while the saturation level of the NC share in installation was estimated to be only 5.8% from the present level, 4.7% in 1983.

The 13th survey on the inventory of metal working equipment gives us the shares of NC machine-tools by year of installation, which can be used as consumption data (Table 2).

NCMWI

1958	0.01
1963	0.10
1968	0.49
1973	0.93
1977	2.01
1983	4.71

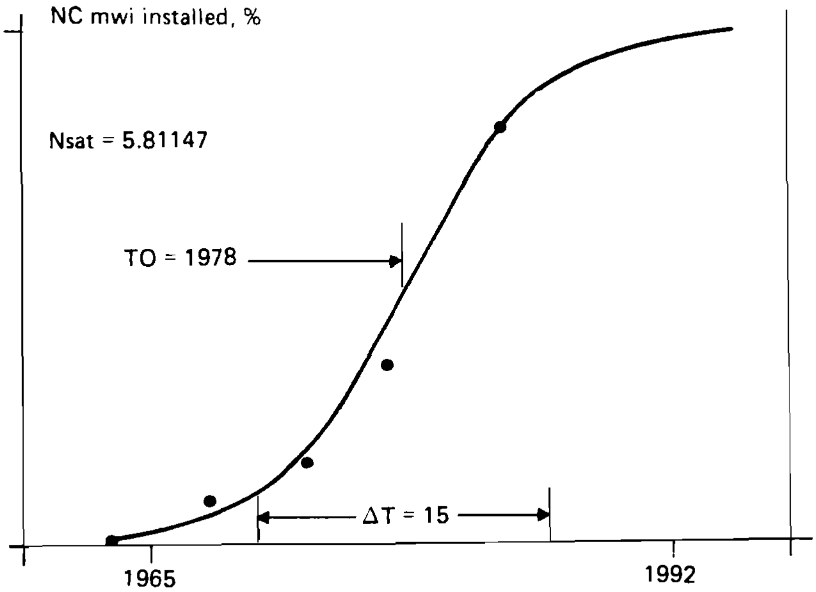

Figure 2. Logistic diffusion of NC-machines installed in US MWI, percentage measured on unit base. [Tchijov, 1987].

Table 1. NC shares of machine-tools in the US MWI (NC share in installation).

	NC share in installation		
	1983	Estimated saturation level**	(NC share in consumption 1979–1983)
Turning machines	9.1%	16.2%	(37.1%)
Boring machines	11.1%	14.4%	(30.7%)
Drilling machines	2.8%	4%***	(5.6%)
Milling machines	6.8%	10.4%	(20.7%)
Grinding machines	0.6%	2%***	(2.1%)
Machining centers*	4.2%	–	(20.3%)
Total metal cutting	5.5%	–	(19.2%)
Total metal forming	1.9%	–	(7.4%)
Total machine-tools	4.7%	5.8%	(17.3%)

* In sum of drilling, milling and boring machines.

** [Tchijov, 1987]

*** The logistic curves were not fitted for these two cases.

Table 2. NC shares of machine-tools in the US MWI (NC share in consumption).

	Year of installation**			
	-1963	1964-1973	1974-1978	1979-1983
Turning machines	0.6%	3.2%	15.5%	37.1%
Boring machines	4.3%	10.9%	19.4%	30.7%
Drilling machines	0.6%	3.3%	4.2%	5.6%
Milling machines	1.4%	4.4%	9.1%	20.7%
Grinding machines	0.1%	0.4%	0.6%	2.1%
Machining centers*	0.1%	1.8%	5.7%	20.3%
Total metal cutting	1.0%	3.0%	7.3%	19.2%
Total metal forming	0.5%	1.4%	3.0%	7.4%
Total machine tools	0.8%	2.6%	6.4%	17.3%

* In sum of drilling, milling and boring machines.

** Year of installation corresponds to the following generation of machine-tools:

Generation at 1983	Year of installation
0-4 years	1979-1983
5-9 years	1974-1978
10-19 years	1964-1973
more than 20 years	-1963

As shown in Figure 3, the NC share in consumption has increased rapidly year by year. In addition, the big gaps between consumption-base and installation-base can be seen for each year of installation.

According to the results of the previous chapter, the NC share in installation saturates at the same level as the NC share in consumption, with some time-lag.

By applying the above relationship to the case of the USA, the saturation levels of the NC share in installation are estimated to be at least higher than the following levels.

Machine type	Saturation level of NC share
total metal cutting	> 19.2%[4]
total metal forming	> 7.4%[4]
total machine-tools	> 17.3[4]

Figure 3 shows us that the NC share in consumption continues to increase even after 1983. Therefore, the real saturation levels are considered to be much higher than the above values.

3.2 The Case of Japan

Data on the machine-tool population are available for the years 1973, 1981 and 1987 in the Japanese machine industry as a survey on machine-tools installation by MITI [MITI, 1988].

According to this survey, the NC shares in installation are summarized in Table 3. The NC share of metal machine-tools (metal cutting) has increased very rapidly from 0.86% in 1973 to 11.3% at the end of September 1987. In the case of the secondary metal working machinery (metal forming), the NC share has also increased from 0.08% in 1973 to 2.2% in 1987, although the absolute value is even now very low.

On the other hand, as shown in Table 3, the NC shares in consumption, namely the shares of an NC type in recent installations, show much higher values than those in installation, as was also observed for the case of the USA.

According to the relationship between consumption-base and installation-base in the previous chapter, the saturation levels

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[4]NC share of machines consumed from 1979 to 1983.

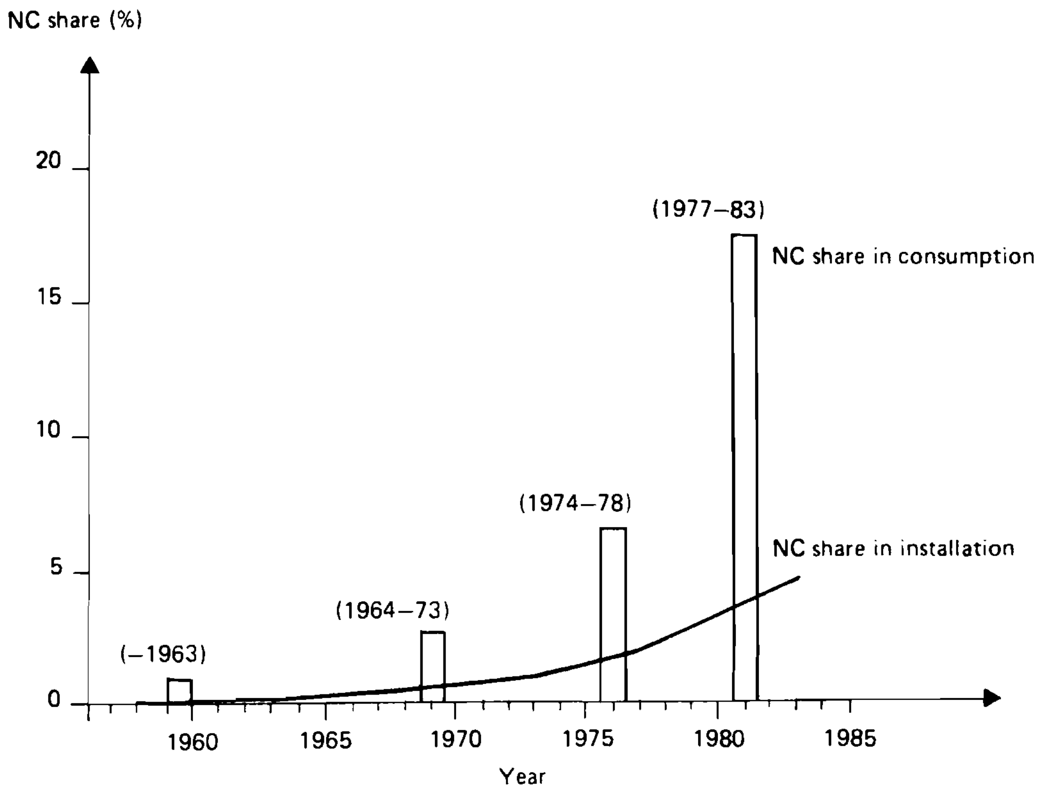

Figure 3. Trends of NC shares in the US MWI.

Table 3. Trends of NC shares in Japan.

	1973	1981	1987
Shares of NC type in machine-tools population			
{ Metal machine tools	0.86%	3.6%	→11.3%
{ Secondary metal working machinery	0.08%	0.8%	→2.2%
Total NC machine-tools	0.67%	2.9%	9.2%
Shares of NC type in recent installation			
{ Metal machine tools		12.1%*	33.2%**
{ Secondary metal working machinery		2.2%*	5.2%**

* Installation year: 1979–1981

** Installation year: 1985–1987

The above data are based upon the survey on Machine Tools Installation by MITI in Japan. The survey was carried out for all establishments of more than 50 employees in machine industry. The coverage of this survey by major sectors in 1987 are shown below in terms of employment.

SIC	Coverage
34	14.2%
35	42.4%
36	56.2%
37	64.8%
38	48.4%

of the NC share in installation are estimated to be at least higher than the following levels.

Machine type	Saturation level of NC share
Metal working machines	> 33.2%
Secondary metal machines	> 5.2%

Table 4 shows us that the NC share in consumption continues to increase even after 1987. This means that the real saturation levels of the NC share in installation are much higher than the above values.

The NC shares of machine-tools in production show a similar trends to those in consumption [MITI, 1970-1986]. Table 5 summarizes the trends of NC shares in production by type of machines. The NC share of the turning machine production already reached 62.8% in 1986. In the case of total metal cutting machines, the NC share in production exceeded 28% in 1986 and showed further diffusion.

In order to forecast the diffusion curve of the NC share, a logistic curve method is applied to the NC shares in production of total metal cutting machines as shown in Table 6.

The saturation level of the NC share in production is estimated to be 34.0%. In other words, 34% of the metal cutting machines will be of the NC type in future production.

By applying this logistic curve $f(t)$ to equation (21) in the previous chapter, the NC share in installation $g(t)$ can be obtained as shown in Table 7. In this estimation the annual production of total machines $X(t)$ is, for reasons of simplicity, assumed to be constant. In addition, three cases are set with respect to the replacement years (m), namely, 12, 15 and 18. Among the three cases the last one ($m = 18$) is considered to be most realistic.

According to this estimation it can be said that the NC share in installation $g(t)$ will show the biggest increase from 1985 to 1995 and approach the saturation level after 2000 in any of the cases, as shown in Figure 4. Moreover, it might be concluded that NC machine-tools will occupy about 30% of the total metal cutting machines in the year 2000.

Table 4. NC shares in machines installed by industrial sectors at the end of September 1987 in Japan.

	[1981]	TOTAL [1987]	By installation year 85–87	83–84	78–82	–77
Metal working machines:						
General machines	4.57%	12.17%	36.32%	28.80%	19.09%	3.08%
Electrical	3.64%	13.46%	34.86%	27.92%	17.20%	2.60%
Transport	2.56%	9.80%	31.21%	20.01%	9.26%	1.66%
Precision	3.12%	9.15%	24.80%	21.84%	14.53%	2.02%
Machine industry	3.57%	11.26%	33.19%	24.90%	14.23%	2.44%
Production data		9.54*%	26.81%	20.59%	11.67%	1.58%**
Secondary metal machines:						
General machines	1.04%	3.28%	10.59%	7.96%	4.58%	0.85%
Electrical	1.19%	2.60%	4.39%	4.27%	4.02%	0.82%
Transport	0.42%	1.51%	4.08%	2.84%	1.35%	0.36%
Precision	0.22%	1.30%	4.98%	2.33%	1.18%	0.33%
Machine industry	0.81%	2.22%	5.18%	4.21%	2.75%	0.62%

* 1970–1986

** 1970–1977

Table 5. NC share in production for each type of machine-tools in Japan (in terms of units).

Year	Lathes	Drilling	Boring	Milling	Grinding	MC/CBM*	Total**
1970	0.93%	0.12%	2.63%	1.22%	0.16%	0.27%	0.57%
1971	1.42%	0.15%	2.24%	1.79%	0.14%	0.37%	0.75%
1972	1.57%	0.25%	2.88%	1.71%	0.15%	0.48%	0.82%
1973	2.94%	0.36%	3.66%	2.31%	0.29%	0.64%	1.30%
1974	3.92%	0.46%	2.35%	3.29%	0.29%	0.80%	1.80%
1975	7.07%	0.40%	2.25%	4.62%	0.19%	1.26%	2.48%
1976	9.66%	0.33%	1.69%	5.35%	0.33%	1.12%	2.78%
1977	16.19%	0.65%	2.29%	5.52%	0.67%	1.88%	4.14%
1978	21.80%	0.66%	2.78%	7.16%	0.26%	3.12%	5.37%
1979	28.85%	0.35%	2.45%	10.61%	1.00%	5.55%	8.72%
1980	34.72%	0.62%	4.14%	14.00%	1.39%	9.81%	12.33%
1981	36.74%	0.87%	4.88%	20.24%	1.99%	15.09%	15.63%
1982	41.74%	0.61%	6.05%	21.93%	2.62%	15.12%	16.47%
1983	45.93%	1.70%	6.67%	25.41%	3.51%	18.85%	18.85%
1984	52.63%	1.60%	12.31%	25.88%	4.99%	19.74%	22.00%
1985	56.92%	1.82%	8.19%	23.37%	7.34%	27.68%	25.66%
1986	62.84%	5.07%	13.32%	27.24%	9.97%	30.82%	28.27%

* Machining centers in sum of drilling, milling and boring machines.

** Including other machine-tools.

Table 6. Logistic curve fitting to NC share in production of machine-tools in Japan.

f=1/(a+b*EXP(−c*t))
PARAMETERS(IT=8)

a = .0294022
b = 2.35723
c = .364993

SD of a (1) = (2.04186E–03)
SD of a (2) = (.592942)
SD of a (3) = (.0277865)

*R2 = .992445
R S S = 9.57137
D.W. = 1.10768

	Estimated(%)	Observed(%)
1970	.418999	.57
1971	.600309	.75
1972	.85807	.82
1973	1.22246	1.3
1974	1.7335	1.8
1975	2.44227	2.48
1976	3.41021	2.78
1977	4.70461	4.14
1978	6.38776	5.37
1979	8.49847	8.72
1980	11.0282	12.33
1981	13.9007	15.63
1982	16.9689	16.47
1983	20.0396	18.85
1984	22.9188	22
1985	25.4579	25.66
1986	27.579	28.27

Table 7. Forecasts of NC share in Japan.

Year	NC share (%) in production f(t)	NC share (%) in installation m=12 g(t)	m=15 g(t)	m=18 g(t)
1970	0.42	0.11	0.09	0.08
1971	0.60	0.16	0.13	0.11
1972	0.86	0.23	0.19	0.16
1973	1.22	0.33	0.27	0.23
1974	1.73	0.48	0.38	0.32
1975	2.44	0.68	0.55	0.46
1976	3.41	0.95	0.77	0.65
1977	4.70	1.34	1.08	0.91
1978	6.39	1.87	1.51	1.26
1979	8.50	2.56	2.07	1.73
1980	11.03	3.47	2.80	2.34
1981	13.90	4.60	3.72	3.11 (3.6%)*
1982	16.97	5.98	4.84	4.05
1983	20.04	7.60	6.17	5.16
1984	22.92	9.44	7.68	6.43
1985	25.46	11.46	9.34	7.84
1986	27.58	13.61	11.14	9.36
1987	29.27	15.85	13.04	10.97 (11.3%)*
1988	30.57	18.11	14.99	12.64
1989	31.55	20.35	16.98	14.36
1990	32.26	22.50	18.97	16.11
1991	32.77	24.53	20.93	17.86
1992	33.14	26.37	22.82	19.60
1993	33.40	27.99	24.62	21.32
1994	33.58	29.38	26.30	23.00
1995	33.71	30.52	27.81	24.61
1996	33.80	31.42	29.13	26.14
1997	33.86	32.12	30.26	27.54
1998	33.91	32.65	31.19	28.82
1999	33.94	33.04	31.92	29.93
2000	33.96	33.32	32.49	30.87

* Observed data for the establishments of more than 50 employees in mechanical industry at the end of September.

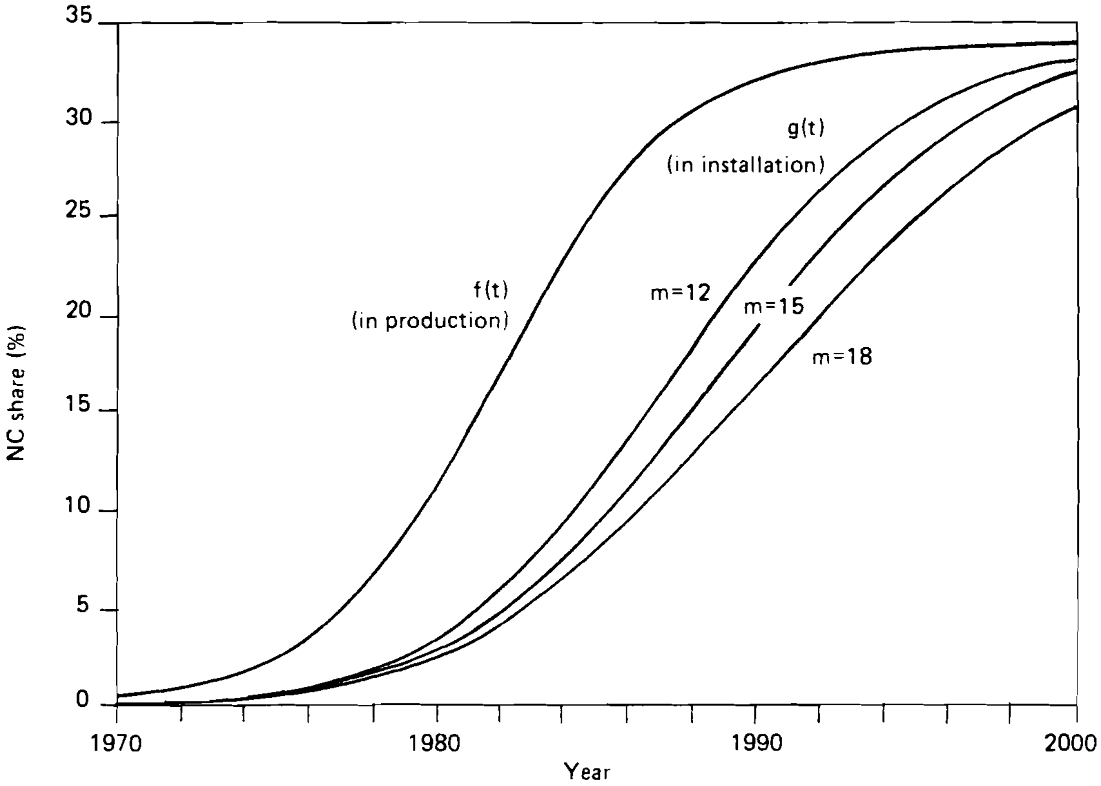

Figure 4. Forecasts of NC share in Japan.

If we focus on large establishments of more than 50 employees, the NC share in installation was already 33.2% in 1987 and will be about 40% in 2000.[5]

4. CONCLUSIONS

(1) Comparisons between the USA and Japan

The comparisons of the past trends of NC shares of machine-tools between the USA and Japan are summarized in Figures 5 and 6. The NC shares by sectors are described in Appendix B.

Figure 5 shows the past trends of the NC share in the population of total machine-tools (metal cutting & metal forming) in the USA and Japan, and Figure 6 shows these trends in the consumption of metal cutting machines.

In both cases similar trends can be observed in the USA and in Japan.

The NC shares in installation and in consumption are considered to be about 10% and about 30% at present in both countries.

The gap between the two kinds of NC shares implies the further diffusion of NC machine-tools in terms of installation-base.

(2) Method to estimate the saturation level of diffusion

As explained in the previous chapters, it is very difficult to estimate a reliable saturation level of diffusion in installation-base by a simple logistic curve model. However, there is some relationship between the diffusion in installation-base and that in consumption-base, as described in Chapter 2, if the diffusion of an advanced type is mainly due to the replacement of conventional types such as NC machine-tools. In such a case the diffusion in consumption can be regarded as a leading index of installation-based diffusion.

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[5]The NC shares in production show lower values than those in consumption. For instance, the NC share in production is 28.3% in 1986, while that in recent installations (1985-1987) is 33.2%. The main reason for this gap is as follows. The data in consumption do not cover small establishments of less than 50 employees. The NC shares in small establishments are considered to be lower than those in large establishments as observed in the case of industrial robots.

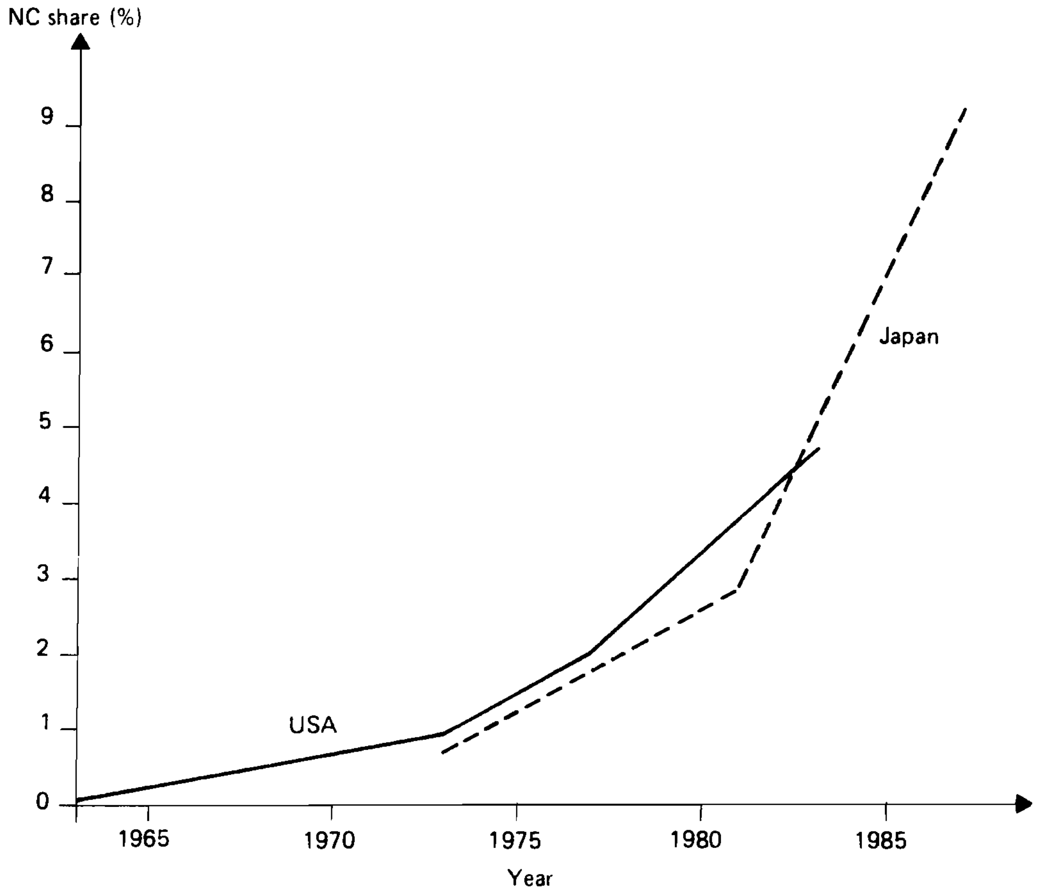

Figure 5. Past trends of NC share in installation, metal cutting and metal forming in the USA and in Japan.

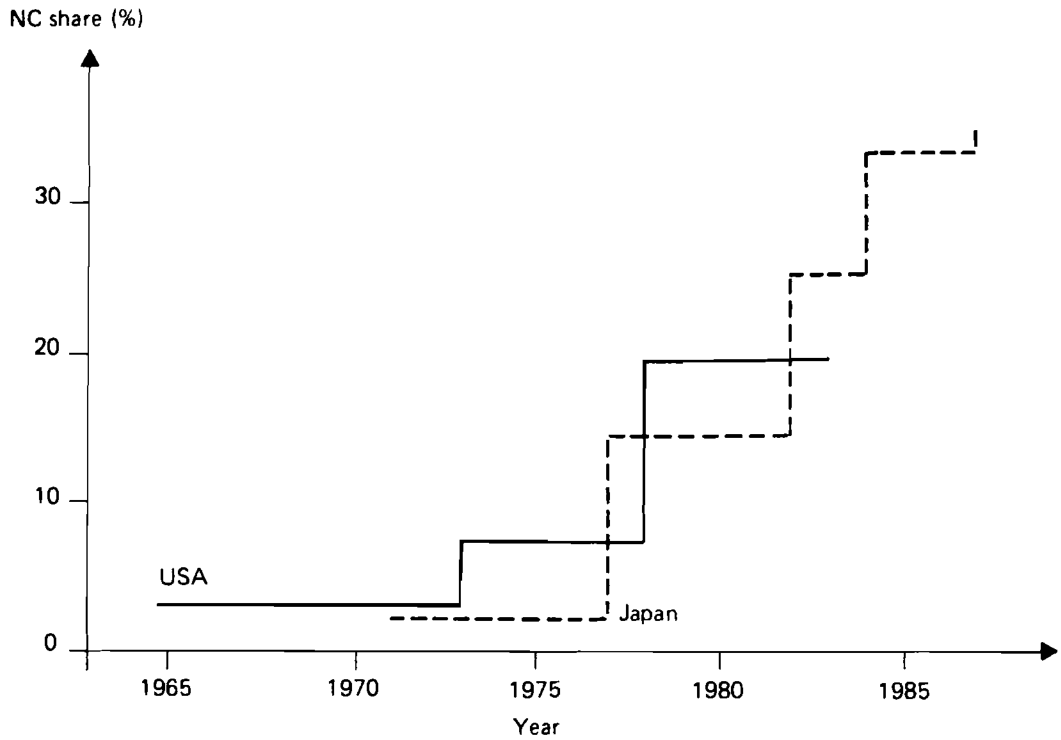

Figure 6. NC shares by installation year in the USA and in Japan (metal cutting).

Therefore, the forecasting of diffusion, and especially the estimation of the saturation level, will be more reliable if the trends of diffusion in consumption-base are taken into account.

(3) The strong impacts of NC machine-tools in the next decade

There were 601 000 metal machine-tools (metal cutting machines) in establishments of more than 50 employees relating to the Japanese machine industry at the end of September 1987. As described in the previous chapter, the NC share in recent installations is 33.2%, while that in 1987 was 11.2%. According to the relationship between the two kinds of NC shares, the NC share in installations will reach about 40% in 2000. This means that about 240 000 NC machine-tools will be used in the above Japanese establishments in the year 2000, while the corresponding number was 66 000 in 1987.

In other words, we are going to face a substantial diffusion of NC machine-tools from now up to 2000. A similar tendency can also be pointed out for the USA.

Such a large diffusion will cause various and significant impacts for our economy and society during the next decade.

(4) Diffusion of FMS

A high diffusion of NC machine-tools affects the diffusion of FMS, because NC machine-tools are regarded as basic components of FMS.

One way of estimating the diffusion of FMS can be expressed in the following equation.

$$\text{Number of FMS} = (N \times h)/d \qquad (22)$$

where

$$N = \text{number of NC machine-tools} \qquad (23)$$

$$h = \frac{\text{number of NC machine-tools used in FMS}}{N} \qquad (24)$$

$$d = \text{average number of NC machine-tools per FMS} \qquad (25)$$

According to the literature [ECE, 1986; Darrow, 1987], the coefficient d is estimated to be 7.5 machines/FMS in the case of Japan. The number of NC machine-tools (N) was 66 166 units in 1987 [MITI, 1988] and the saturation level is estimated at about 240 000, as described before.

On the other hand, the number of FMS for metal cutting in Japan was 186[6] at the end of September 1987 [MITI, 1988].

As a result, the number of NC machine-tools used in FMS is estimated to be 1395 at present in Japan. This indicates that the coefficient h is now 2.11%. If we investigate the FMS by installation year, the coefficient h is estimated as below.

Installation year	Number of FMS	h
before 1984	90	1.62%
1985-1987	96	2.95%

As shown above, the share of NC machines used in FMS (h) has been increasing.

It is very difficult to estimate the saturation level of h because the diffusion of FMS is now at a very early stage. However, it can be said that at least 5% of the NC machine-tools will be used in FMS at the saturation stage of FMS diffusion.

According to the assumptions described above, the number of FMS for metal cutting is forecast to be at least 1600 systems at saturation stage. If we add other types of FMS (metal forming, etc.) to the above figure, the total number of FMS will exceed at least 2000 systems only in Japan at the saturation stage of FMS diffusion.

In the above forecasts the future population of machine-tools is assumed to remain unchanged at the present level.

However, the number of machine-tools might decrease in the future for the following reasons:

a) Different functions are now going to be integrated into one machine.

b) The utilization of machine-tools is now going to be improved as a result of the benefits of FMS.

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[6]Other types (metal forming) of FMS ... 68 systems.

It is important to take this factor into account in further investigations on the future diffusion of NC machine-tools and FMS.

APPENDIX A. NOTATION OF VARIABLES

$u(t)$	Population of NC machine-tools at the end of year t
$U(t)$	Population of machine-tools at the end of year t
$g(t) \equiv u(t)/U(t)$:	NC share in population of machine-tools at the end of year t
$x(t)$	consumption of NC machine-tools in year t
$X(t)$	consumption of machine-tools in year t
$f(t) \equiv x(t)/X(t)$:	NC share in consumption of machine-tools in year t
m	replacement time (years)
f_∞	saturation level of NC share in consumption.

Appendix-B. NC shares by sector in USA and Japan.

NC machine-tools in Japan

	Year	Industrial sector SIC 34	SIC 35	SIC 36	SIC 37	SIC38
NC share in population						
NC share	1973	0.46%	1.25%	0.93%	0.55%	0.50%
Metal machine	1981	2.24%	4.57%	3.64%	2.56%	3.21%
tools	1987	7.40%	12.17%	13.46%	9.80%	9.15%
NC share	1973	0.08%	0.07%	0.13%	0.06%	0.02%
Secondary	1981	0.59%	1.04%	1.19%	0.42%	0.22%
metal machine	1987	2.08%	3.28%	2.60%	1.51%	1.30%
NC share in consumption	Installation year					
	-77	1.29%	3.08%	2.60%	1.66%	2.02%
Metal machine	78-82	10.60%	19.09%	17.20%	9.26%	14.53%
tools	83-84	15.57%	28.80%	27.92%	20.01%	21.84%
	85-87	23.31%	36.32%	34.86%	31.21%	24.80%
	-77	0.31%	0.85%	0.82%	0.36%	0.33%
Secondary	78-82	2.98%	4.58%	4.02%	1.35%	1.18%
metal machine	83-84	3.82%	7.96%	4.27%	2.84%	2.33%
	85-87	7.06%	10.59%	4.39%	4.08%	4.98%

NC machine-tools in USA

	Year	Industrial sector SIC 34	SIC 35	SIC 36	SIC 37	SIC38
NC share in population						
Metal cutting	1983	3.33%	7.09%	5.29%	5.79%	4.86%
Metal forming	1983	1.88%	2.04%	2.00%	1.63%	2.40%
NC share in consumption	Installation year					
	-63	0.78%	0.65%	1.08%	1.79%	0.29%
Metal cutting	64-73	1.81%	3.66%	2.52%	4.16%	2.46%
	74-78	4.17%	10.04%	6.45%	7.08%	6.03%
	79-83	13.98%	23.48%	18.13%	19.26%	15.39%
	-63	0.61%	0.44%	0.54%	0.32%	0.00%
Metal forming	64-73	1.58%	1.32%	1.06%	1.16%	1.12%
	74-78	2.90%	3.35%	2.05%	3.00%	4.87%
	79-83	7.75%	6.96%	8.73%	5.77%	7.83%

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