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Enterprise Size and its Impact on Penetration of Industrial Robots: Application of Econometric Analysis

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IIASA Working Paper

WP-87-108

October 1987

WORKING PAPER

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- Application of Econometric Analysis -

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FOREWORD

In the diffusion process of "Computer Integrated Manufacturing" (CIM), enterprise size seems to be one of the most important factors influencing the penetration level of CIM.

In order to forecast the diffusion of CIM, as well as to promote the diffusion more widely, the difference in penetration levels between large and small enterprises should be analyzed.

The author has analyzed past penetration data of industrial robots in Japan and has quantitatively estimated the penetration gap by size of enterprises. This paper does not only show the existence of a gap, but also the reasons why such a gap is generated. It is hoped that the results will be used for establishing an industrial policy which would promote the wider and deeper diffusion of CIM in the world.

Subsequent work in this direction will also provide a viable model to make forecasting of the penetration of CIM more reliable.

Prof. Jukka Ranta
Project Leader
Computer Integrated Manufacturing

SUMMARY

This paper shows the results of econometric analyses on the penetration of industrial robots from the viewpoint of the enterprise size. Penetration rates are greatly different between large and small enterprises. This paper makes the gap quantitatively clear. In addition to those fact analyses, the reason why smaller enterprises introduce less industrial robots was also qualitatively analyzed. The difference of wages according to the size of the enterprises has a great influence on the penetration rate. Another factor is related to economy of scale in the cost of I.R. usage, although this factor is not so important in the case of I.R. as in the case of computers.

CONTENTS

1. Introduction

There is a lot of research on the relationship between company size and innovation capability of high technology.

In order to investigate the diffusion processes of high technology such as CIM (Computer Integrated Manufacturing), "company size (or enterprise size)" is one of the most important factors which should be taken into account. According to the review done by Maly [Maly 87], there is a wide diversity of opinion on the issue among researchers as follows:

> *Some researchers think that small, young companies are more innovative than larger, older ones.*
>
> *On the other hand, many authors cite examples where large companies seem more innovative. The above hypothesis is supported by several analyses.*
>
> *As to the diffusion of mature technologies, Ray (1984) came to the conclusion that size has less to do with the diffusion of new technologies in mature phase than was believed some 10 or 20 years ago.*

The results of the case study carried out on BOF technology in the steel industry by Maly [Maly 87] show us distinctly that the group of large companies is almost twice as innovative as the groups of small and medium companies.

With regard to CIM, Baark and Anxian (1985) have demonstrated by comparing the different diffusion patterns of CIM (NC, IR and CAD/CAM) that smaller companies lack both the financial and technical base for adopting such a technology in its early stage.

2. Aims of this Paper

The first aim of this paper is to validate the following hypothesis:

Computer Integrated Manufacturing (CIM) penetrates mainly in large enterprises at the early stage, and diffuses in smaller enterprises as its price as well as that of other high technological products decreases.

The second aim is to analyze the relationship between enterprise size and penetration level of CIM, quantitatively, by using an econometric approach.

The author developed an econometric model predicting the future population of industrial robots as a part of models forecasting the penetration of CIM [Tani 87]. That model integrates two sub-models. One of them is the production function model, explaining the relationship between the penetration level and the relative prices of industrial robots to wage. The other model is related to the learning curve for robot prices.

Using the above model, we can forecast the future population of I.R. in the manufacturing industry as an aggregated volume.

However, detailed information about the meaning of diffusion patterns can not be obtained by that model, because it does not explicitly deal with the factors of industrial structure.

In order to clarify the diffusion process of high technologies such as CIM, it is necessary to develop an econometric model taking into account the effects of enterprise size as explicit variables.

Though the significance of the penetration gap caused by the size of enterprises has been widely emphasized, there is little research validating the gap and its causes as a statistical basis. Most of the research work carried out so far deals mainly with large companies or selected companies which are not chosen by a random sampling method. The lack of information on the penetration gap is thus mainly due to the non-availability of correct statistical data including the lack of information on which high-technological product was implemented in each company or not. It is not appropriate either to use the survey data of almost all of the questionnaires on robot user companies, because both the statistical population and the respondents generally have a tendency to deviate to larger and more innovative companies with high possibilities to introduce such a high technology.

Therefore we mainly use statistical data in this paper, such as census of manufacturers.

The third aim of this study is to analyze quantitatively those factors which determine the penetration gap among various sizes of enterprises.

The development of an econometric model which can estimate the population of I.R. by size of enterprises is included in this task.

In this paper we focus on the penetration of industrial robots in the Japanese manufacturing industry as an example of CIM penetration on the basis of the availability of reliable and detailed data.

3. Facts Analysis of the Penetration Gap by Size of Enterprises

(a) FA equipment and CAD system

As a starting point, we review the reliable existing data on the penetration gap of factory automation (FA) equipment and CAD systems.

The survey done by MITI [MITI 86-a] shows the present situation on factory automation among establishments[1] located in the northeast districts of Japan as follows:

- Only a quarter of establishments having less than 50 workers introduced some kind of FA equipment. On the other hand, all establishments of more than 1000 workers have already implemented such equipment. There is a tendency that larger establishments introduce at a higher rate (see Table 1).
- As to the CAD system, the data in Table 1 show its tendency more distinctly. Only 3% of small establishments introduced CAD systems, while the corresponding number 55.6% for large establishments was 55.6%. We can find a wider gap of penetration

[1]Definition of "Establishments" in Japanese statistics. An establishment is defined as a physical location where either goods are produced or services are rendered on business. In principle, each business carried on in a compound by the same proprietor is regarded as an establishment. Accordingly, businesses run by the same proprietor at different places are counted as separate establishments according to each location, and similarly, businesses run by different proprietors in a compound are counted separately by each proprietor. Establishments are generally called shops, factories, offices, branches, banks and so forth.

Table 1

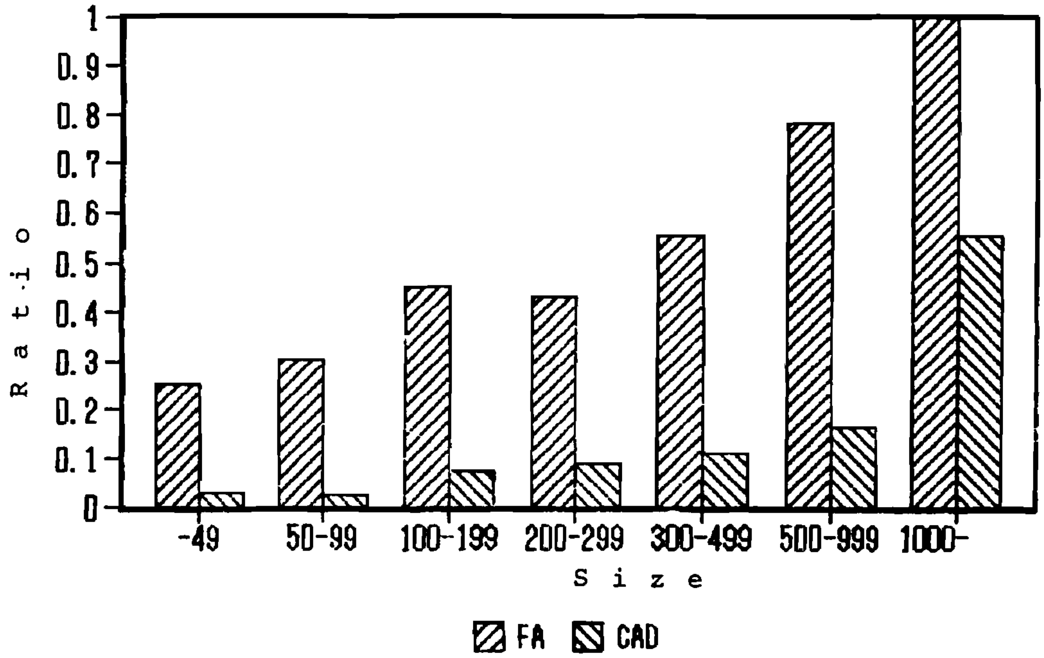
Penetration of FA Equipments and CAD System by Size of Establishments in Japan

SIZE	FA EQUIP TOTAL	YES	RATIO	CAD SYSTEM TOTAL	YES	RATIO
- 49	72	18	25.0%	69	2	2.9%
50- 99	132	40	30.3%	124	3	2.4%
100-199	136	61	44.9%	135	10	7.4%
200-299	44	19	43.2%	45	4	8.9%
300-499	27	15	55.6%	27	3	11.1%
500-999	28	22	78.6%	30	5	16.7%
1000-	9	9	100.0%	9	5	55.6%
TOTAL	443	184	41.5%	439	32	7.3%

SIZE: Persons Engaged in Establishment
TOTAL: Total Number of Responses
YES: Number of Responsing "Yes"

SOURCE: [MITI 86]

Figure 1



between large and small establishments in CAD systems than in FA equipment (see Figure 1).

The above fact implies that a bigger gap exists in the early stage (i.e. for CAD systems) compared to the mature stage (FA equipment).

The higher the penetration, the narrower will be the ratio of penetration levels (small/large), although the gap in absolute terms still remains big.

As mentioned above, these facts prove that company size (or establishment size) is one of the most important factors to determine the penetration level of new technological equipment.

(b) Industrial Robots

Recent data of JIRA include the information on the value of shipments to small and medium enterprises (robot users) as well as their total value [JIRA 75-86].

According to these data of the years 1984 and 1985, the averaged shares of shipment to small and medium (S&M) enterprises are shown by sectors in Table 2.

The share of S&M enterprises is 24.5% in the whole manufacturing industry. We can see a diversity of shares among sectors in Table 2.

In order to estimate the penetration gap among various sizes of enterprises, it is necessary to take into account the distribution data of enterprise sizes in addition to the above JIRA data.

In this paper we employ the size distribution data of "establishments"[1] -- for reasons of data availability

Table 2

Industrial Robot Shipments by Size of Customers (1984 + 1985) in Japan

Sector	Total	S&M	Ratio	Name of Sector
1	5858	960	16.4%	Food and Textiles
2	2545	1232	48.4%	Lumber, Wood, Pulp and Paper Products
3	7226	1031	14.3%	Chemical, Petroleum and Coal Products
4	4276	482	11.3%	Rubber, Ceramic, Stone & Clay Products
5	3150	290	9.2%	Iron and Steel
6	5637	2727	48.4%	Non-ferrous Metals and Products
7	16568	5115	30.9%	Fabricated Metal Products
8	34500	9849	28.5%	Machinery, excluding Electric
9	204156	45809	22.4%	Electric Machinery, Equipment & Supplies
10	93202	17711	19.0%	Transport Equipment
11	17539	3907	17.7%	Precision Instruments
12	36303	17306	47.7%	Other Manufacturing*
MFG	430960	105609	24.5%	All Manufacturing

S&M: Small and Medium Enterprises (Definition: Capital fund <100 million yen or workers < 300)
UNIT: in million yen
SOURCE: [JIRA 85] & [JIRA 86]

*including "Plastic molding products" which is a major sector introducing cheap robots.

-- in terms of number of workers as a substitute for size of "enterprises".

Another reason why the use of "establishment" data is more adequate for our study than "enterprise" data, is that "establishment" means approximately factory.

Persons (workers) engaged in manufacturing by size of persons engaged in establishments and sectors are shown in Table 3.

We calculate the share of S&M enterprises in the population of I.R. at the end of 1984, based upon the above data and the following assumptions:

- o Replacement period of I.R. is assumed to be seven years according to the JIRA report [JIRA 85].
- o Robot price does not vary by size of establishment. It, of course, varies by sector and year of shipments.
- o Establishments of less than 300 workers are assumed to correspond to S&M enterprises. This assumption is generally employed in the study of S&M enterprises in Japan.
- o As there are no data prior to 1983 on the share of shipments to S&M enterprises in terms of value available, we set two cases based upon the following assumptions:

  Case 1. We assume that the share of S&M enterprises in 1977 was zero and increased linearly up to the averaged figure of 1984 and 1985.

  Case 2. A constant share is assumed in this case to be the averaged figure of 1984 and 1985.

Table 3
Persons Engaged in Manufacturing by Size of Establishments in 1984

SECTOR	4-9	10-19	20-29	30-99	-299	-999	1000-	TOTAL	R[300-]
1	17.7%	12.6%	11.5%	24.2%	20.9%	13.2%	*	1755	13.2%
2	22.8%	18.8%	12.9%	22.2%	12.9%	7.9%	2.5%	558	10.4%
3	3.0%	4.1%	4.6%	16.4%	23.5%	48.6%	*	434	48.6%
4	12.7%	13.6%	13.3%	23.9%	15.3%	13.4%	7.8%	632	21.2%
5	4.3%	6.1%	5.6%	13.4%	13.1%	13.6%	44.2%	396	57.8%
6	7.2%	6.6%	6.1%	13.8%	19.3%	29.3%	17.7%	181	47.0%
7	24.4%	17.1%	13.0%	22.4%	13.5%	8.3%	1.3%	755	9.7%
8	12.9%	10.8%	8.7%	19.8%	16.7%	14.4%	16.8%	1087	31.2%
9	4.3%	5.5%	6.7%	18.4%	19.8%	19.8%	25.6%	1795	45.3%
10	4.8%	4.5%	4.5%	11.6%	12.3%	17.4%	44.7%	924	62.1%
11	9.3%	8.1%	8.1%	20.5%	18.9%	22.4%	13.1%	259	35.5%
12	21.9%	16.1%	13.2%	24.1%	15.1%	6.4%	3.0%	1957	9.4%
MFG	13.6%	11.1%	9.7%	20.5%	17.0%	13.9%	14.3%	10733	28.2%
NO. EST	56.7%	20.2%	10.0%	9.7%	2.6%	0.7%	0.2%	429042	0.9%

TOTAL: IN 1000 PERSONS
NO. EST: NUMBER OF ESTABLISHMENTS

*Included in the size of 300-999

According to the facts described in the penetration gap of FA and CAD systems, Case 1 seems more realistic than Case 2.

Then we define the penetration level of I.R. as the robot population per thousand workers.

The results of robot population by size (Large and S&M) and sector are shown in Table 4.

According to our analyses, the following points are summarized:

Case 2. The share of S&M enterprises in robot population is estimated to be 30.9% in the whole manufacturing industry, higher than 24.5% in terms of value.

The above difference is due to the robot price differences among sectors.

Case 1. (more realistic case)

The share of S&M enterprises in robot population is estimated to be 20.0% in the whole manufacturing industry at the end of 1984.

Next, we calculated the penetration gap between large and S&M enterprises by sector. The results are shown in Table 5.

As to the whole manufacturing industry, the penetration level of I.R. in S&M enterprises is only at 10.2% of that in large enterprises.

Most sectors have penetration gaps more than six times higher.

Table 4

Estimated Ratio of I.R. Population in 1984
[S&M/Total]

Sector	Total	Case 1		Case 2	
		S&M	Ratio	Ratio	S&M
1	1120	115	10.3%	16.4%	184
2	277	110	39.8%	48.4%	134
3	1215	126	10.4%	14.3%	173
4	878	77	8.8%	11.3%	99
5	1070	67	6.3%	9.2%	98
6	3303	938	28.4%	48.4%	1598
7	5869	1230	21.0%	30.9%	1812
8	11887	2198	18.5%	28.5%	3393
9	35462	5472	15.4%	22.4%	7957
10	27874	3619	13.0%	19.0%	5297
11	6051	752	12.4%	17.7%	1068
12	45338	14180	31.3%	47.7%	21613
MFG	140344	28884	20.6%	30.9%	43427

Case 1: S&M Ratio of Shipments (0% in 1977 and JIRA DATA in 1984)

Case 2: Constant between 1978 and 1984: JIRA DATA

Table 5

Penetration Gap of I.R. Between Large and Small & Medium Enterprises

SECTOR	POPULATION TOTAL	POPULATION (S&M)	WORKERS TOTAL	WORKERS (S&M)	U/L (L)	[CASE 1] U/L (S&M)	GAP (S&M/L)
1	1120	10.3%	1755	86.8%	4.35	0.08	0.017
2	277	39.8%	558	89.6%	2.88	0.22	0.077
3	1215	10.4%	434	51.4%	5.16	0.57	0.110
4	878	8.8%	632	78.8%	5.98	0.15	0.026
5	1070	6.3%	396	42.2%	4.38	0.40	0.092
6	3303	28.4%	181	53.0%	27.82	9.77	0.351
7	5869	21.0%	755	90.3%	63.55	1.80	0.028
8	11887	18.5%	1087	68.8%	28.58	2.94	0.103
9	35462	15.4%	1795	54.7%	36.84	5.58	0.151
10	27874	13.0%	924	37.9%	42.26	10.34	0.245
11	6051	12.4%	259	64.5%	57.60	4.50	0.078
12	45338	31.3%	1957	90.6%	170.26	7.99	0.047
MFG	140344	20.6%	10733	71.8%	36.86	3.75	0.102

WORKERS: IN 1000
U: POPULATION OF I.R.
U/L: UNITS/1000 WORKERS

GAP: [U/L (S&M)]/[U/L(L)]
(S&M): SMALL AND MEDIUM ENTERPRISES
(L): LARGE ENTERPRISES

Our facts analyses validate the existence of a big penetration gap between large and S&M enterprises in robot population.

4. The Reasons for the Existence of the Penetration Gap

In this chapter, we analyze quantitatively the reasons why larger enterprises introduce I.R. at a higher rate. At the beginning of the analysis, we extract the factors affecting the penetration level of I.R.

Mori [Mori 87] and the author [Tani 87] developed an econometric model to explain the penetration level (Robot population/Workers) as a function of P/W. Variable P/W denotes the relative price of robot to labor wage. Robot price P and annual wage W are considered to be the most important factors in the penetration analysis.

Therefore, we focus in this paper on the effects of these factors on the penetration level.

(a) Wage gap effects

Averaged annual wages of persons engaged by the size of establishments are shown for each sector in Table 6. According to these data, the wage in establishments with 4-9 workers is less than 50% of that of large establishments. We can find a "wage gap" between large and small enterprises.

Larger companies have a tendency to pay higher wages for each sector.

According to the previous studies [Mori 87] [Tani 87], the penetration rate (U/L) can be expressed as follows:

$$(U/L) = A \,.\, (P/W)^{-\alpha} \qquad (1)$$

Table 6

Wage in Manufacturing by Size of Establishments in 1984

SECTOR	4-9	10-19	20-29	30-99	-299	-999	1000-	TOTAL
1	1.502	2.041	2.129	2.405	2.681	3.026	*	2.308
2	1.913	2.343	2.542	2.847	3.486	4.205	4.571	2.735
3	2.846	3.111	3.350	3.845	4.245	4.844	*	4.346
4	1.875	2.547	2.679	2.934	3.309	4.012	4.265	3.016
5	2.647	3.125	3.318	3.698	4.173	4.537	5.166	4.432
6	2.538	2.750	2.909	3.440	3.714	4.283	4.156	3.724
7	2.402	2.822	2.908	3.065	3.382	4.032	4.400	2.981
8	2.750	3.154	3.200	3.353	3.652	4.218	4.858	3.668
9	2.026	2.010	1.967	2.064	2.400	3.256	4.074	2.869
10	2.091	2.571	2.690	2.935	3.351	4.006	4.692	3.889
11	2.250	2.619	2.476	2.434	2.796	3.534	4.294	3.000
12	1.956	2.327	2.360	2.498	2.980	4.280	6.431	2.631
MFG	2.019	2.446	2.494	2.694	3.072	3.808	4.607	3.047

*included in the size of 300-999.

where U, L, P and W denote the population of I.R., number of workers, price of I.R. and annual wage, respectively.

Equation (1) is estimated on the basis of the time-series data in our previous studies.

By applying cross-sectional wage data to the equation, we can also estimate the penetration rates by size of establishments.

In order to investigate the effects of the wage gap, the following procedures is employed

$$U_{ij} = C_i . L_{ij} . W^{\alpha} \qquad (2)$$

U_{ij}: robot population in sector i and size j

L_{ij}: number of workers in sector i and size j

W_{ij}: annual wage in sector i and size j

C_i: constant of sector i

Constant C_i can be calculated in equation (4) from the given data of total population in sector i (U_i) through equation (3).

$$U_i = \sum_{j=1}^{M} U_{ij} \qquad (3)$$

$$C_i = U_i / \left[\sum_{j=1}^{M} L_{ij} . W_{ij}^{\alpha} \right] \qquad (4)$$

where M denotes the number of sizes.

Penetration rate of sector i and size j and penetration rate gap i (G_i) between large and S&M enterprises (D_{ij}) can be calculated from the following definition:

$$D_{ij} = U_{ij}/L_{ij} \qquad (5)$$

$$G_i = \left[\sum_{j=1}^{m} U_{ij} / \sum_{j=1}^{m} L_{ij}\right] / \left[\sum_{j=m+1}^{M} U_{ij} / \sum_{j=m+1}^{M} L_{ij}\right] \qquad (6)$$

The data used in this estimation are shown as L_{ij} in Table 3, U_{ij} in Table 5 and W_{ij} in Table 6.

In order to carry out the above estimation, parameter α should be given. α denotes the elasticity of substitution between robots and workers and is defined in the following labor argumentation subproduction function [Mori 87]:

$$F(U,L) = (L^a + A.U^a)^{1/a} \qquad (7)$$

$$\alpha = 1/(1-a) \qquad (8)$$

In our previous study [Tani 87] parameter a is estimated by using the time-series data to be 0.7171. The results of estimation by sector through the above procedure are shown in Table 7.

According to the comparisons to the penetration[2] rate gap shown in Table 5, considerable parts of the gap can be explained by the existence of a wage gap between large and S&M enterprises as shown in Fig. 2.

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[2]As to sectors 1 and 3, the data of large establishments (more than 1000 workers) are not disclosed (these are included in the figures of size [300-999]). Therefore, we should exclude those sectors in our comparisons.

Table 7

Estimation of I.R. Population by Size of Establishments in 1984
(Effects of Wage Differences by Size)

SECTOR	4-9	10-19	20-29	30-99	-299	-999	1000-	TOTAL	S&M.R S(i)
1	37	77	81	265	336	324	*	1120	(71.1%)
2	13	22	20	53	63	74	32	277	61.8%
3	8	14	21	120	245	807	*	1215	(33.6%)
4	17	53	61	152	150	259	186	878	49.3%
5	7	17	19	67	101	140	720	1070	19.6%
6	55	68	76	312	574	1437	780	3303	32.9%
7	592	733	620	1287	1100	1264	273	5869	73.8%
8	476	646	552	1475	1678	2407	4652	11887	40.6%
9	317	393	449	1452	2664	7832	22355	35462	14.9%
10	123	244	286	990	1685	4475	20072	27874	11.9%
11	164	246	201	478	722	1957	2283	6051	29.9%
12	1978	2685	2313	5168	6045	9182	17968	45338	40.1%

Estimation of U/L by Size of Establishments and its Gap

SECTOR	4-9	10-19	20-29	30-99	-299	-999	1000-	TOTAL	GAP (S&M/L)
1	0.12	0.35	0.41	0.62	0.92	1.40	*	0.64	(0.372)
2	0.10	0.21	0.28	0.42	0.87	1.68	2.26	0.50	0.188
3	0.58	0.80	1.04	1.69	2.40	3.83	*	2.80	(0.476)
4	0.21	0.61	0.73	1.01	1.55	3.05	3.79	1.39	0.262
5	0.39	0.70	0.86	1.26	1.93	2.60	4.11	2.70	0.332
6	4.27	5.66	6.91	12.50	16.39	27.12	24.39	18.25	0.433
7	3.22	5.68	6.32	7.61	10.78	20.06	27.33	7.77	0.302
8	3.40	5.52	5.81	6.86	9.27	15.43	25.42	10.94	0.310
9	4.12	4.01	3.71	4.40	7.50	22.06	48.70	19.76	0.145
10	2.79	5.80	6.80	9.25	14.78	27.79	48.60	30.17	0.223
11	6.84	11.69	9.59	9.03	14.73	33.74	67.14	23.36	0.234
12	4.61	8.52	8.96	10.95	20.42	73.45	309.79	23.17	0.069

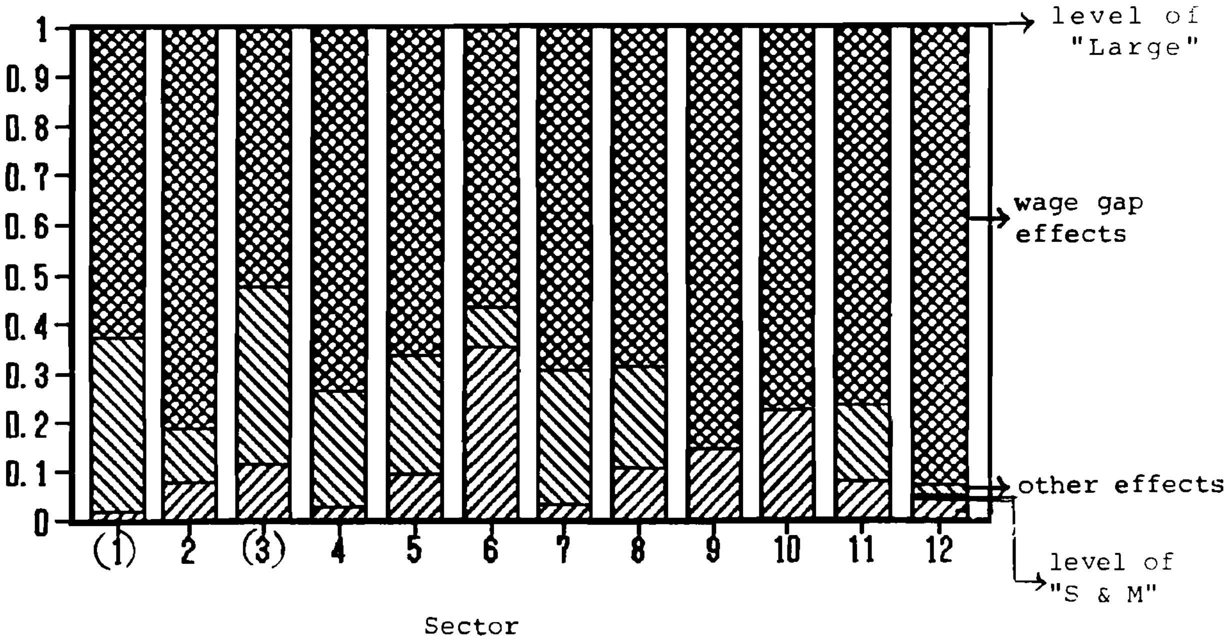


Figure 2 Penetration Gap[Di(S&M)/Di(Large)] of I.R. by Sector

(b) "Economy of scale" effects on costs of robot use

Another factor affecting the penetration rate gap between large and small enterprises is related to robot price (P) in equation (1).

There is a tendency that larger companies will use production equipment at cheaper unit costs, because for them the "law of economy of scale" applies. With regard to the EDP expenses and the number of computer personnel, the evidence of the "economy of scale" is reported as shown in Figure 3 and Figure 4 by the Japan Information Processing Development Center [JIPDEC 86 & 87].

In the case of I.R., unfortunately, we cannot obtain the data of robot costs by size of establishment. However, we can find the existence of economy of scale in the ratio of workers related to I.R. as shown in Table 8.

Then, we analyze the effects of economy of scale by the following procedures:

We assume robot price P as a function of the number of workers in establishment (x), based upon the law of economy of scale. The form of the function assumed is shown below.

$$P(x) = Po.x^{-c} \qquad (9)$$

On the other hand, wage W can be expressed in the following form:

$$W(x) = Wo.x^{-d} \qquad (10)$$

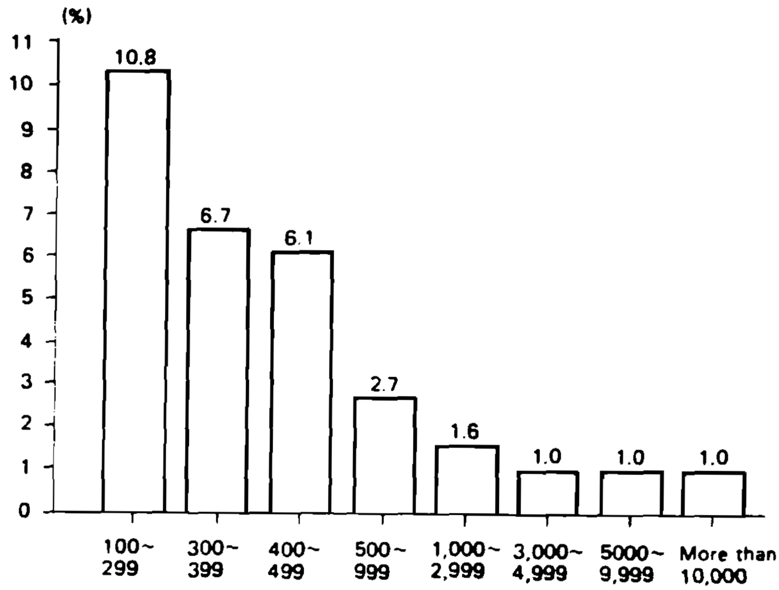
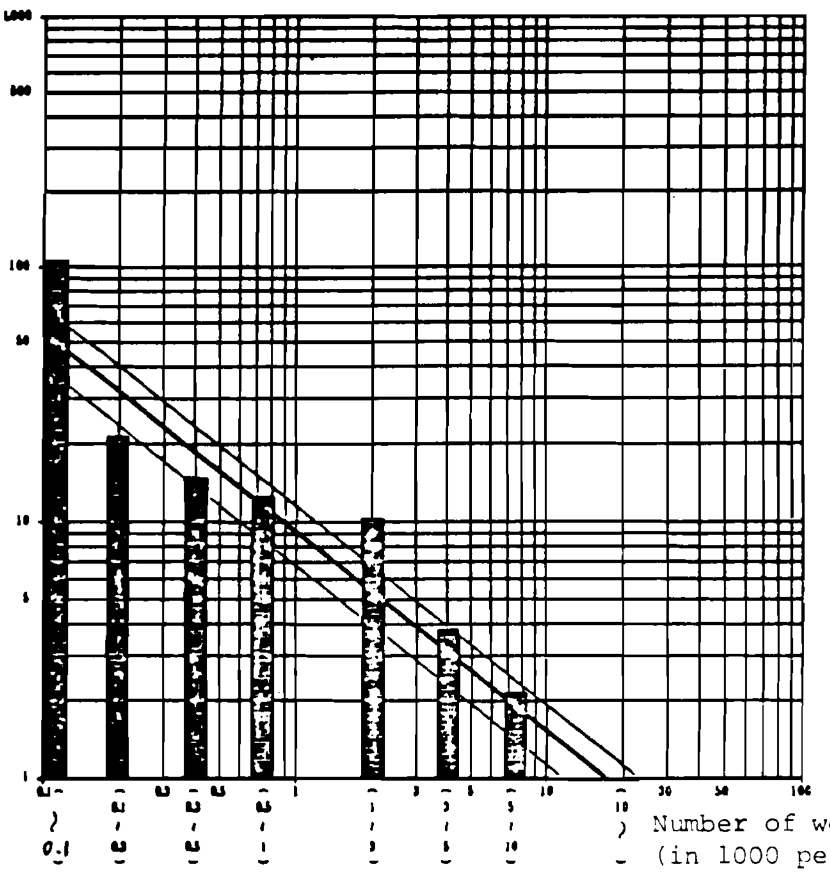


Fig. 3 Percentage of Total No. of Employees Accounted for by Computer Personnel

Source: (JIP Dec 86)

Average Monthly
EDP Expenses
per Worker
(in 1000 yen
per month)



Number of workers
(in 1000 persons)

R=0.98
Samples: 236

$$\frac{c}{x} = 8.66 . x^{-0.7785}$$

c: EDP expenses in million yen/month
x: Number of workers in thousands
Batch Processing System

Fig. 4 Economy of Scale in EDP Expenses
(Company Size and EDP Expenses)

Source: (JIPDEC 87)

Table 8

Share of Workers Related to I.R. by Size of Establishments

A	B	C	D
1-29	19	17	21.6%
30-99	61	57	7.37%
100-299	108	182	5.20%
300-499	70	390	3.93%
500-999	73	692	3.60%
1000-	132	4842	2.05%

A. Size of Establishments (workers)

B. Number of Establishments

C. Averaged Number of Workers

D. Share of Workers related to I.R. (%)

Source: [JIRA 85]

The results of the regression analysis applying to equation (10) is shown in Table 9. The parameter d is estimated to be 0.1337.

By substituting equation (10) by (9), robot price P can be expressed as a function of wage W as shown below.

$$P = \left[\frac{P_o}{W_o^{c/d}}\right] . W^{-c/d} \qquad (11)$$

From equations (1) and (11) we can derive the penetration rate (U/L) as a function of W:

$$(U/L) = C. \left[\frac{P_o}{W_o^{-c/d}}\right]^{-\alpha} . W^{\alpha(1+\beta)} \qquad (12)$$

where parameter β is defined in the following equation:

$$\beta = c/d \qquad (13)$$

Equation (12) gives the effects of the wage gap when β=0. In the case of non-zero β, the equation implies the total effects of wage gap and economy of scale. We introduce the assumption that the total effects consist of the above two factors. Based upon the above assumptions, we can calculate the value of parameter β when equation (12) gives us the penetration rate gap equal to the value (0.102) shown in Table 5.

The results of estimation for the whole manufacturing industry are shown in Table 10. Parameter β is estimated to be 0.375. This means that the contribution ratio of the factors causing the

Table 9

Estimation of Wage Gap Function

Size	Wage	Worker	LN(W)	LN(X)	EST.W
4- 9	2.019	6.0	0.7023	1.7908	2.0643
10- 19	2.446	13.7	0.8945	2.6203	2.3064
20-29	2.494	24.4	0.9137	3.1958	2.4909
30-99	2.694	52.8	0.9909	3.9665	2.7613
-299	3.072	160.4	1.1222	5.0778	3.2036
-999	3.808	498.8	1.3372	6.2122	3.7283
1000-	4.607	2288.5	1.5276	7.7356	4.5706

Result of Regression Analysis: LN(W)=LN(A)+d*LN(X)

LN(A)=	0.4853		
STD of Estimation	0		
R^2=	0. 986	*R^2=	0. 983
Number of Samples	7		
Degree of Freedom	5	W=	1.6247 * X^(0.1337)

Table 10

Estimation of I.R. Population by Size of Establishments in 1984
(Whole Manufacturing)

	4-9	10-19	20-29	30-99	-299	-999	1000-	TOTAL
WORKERS	1458	1188	1045	2195	1822	1493	1531	10733
WAGE	2.019	2.446	2.494	2.694	3.072	3.808	4.607	3.047

ESTIMATION BY WAGE GAP EFFECT

	4-9	10-19	20-29	30-99	-299	-999	1000-	TOTAL
POP(U)	3273	5260	4953	13666	18045	31607	63541	140344
(%)	2.3%	3.7%	3.5%	9.7%	12.9%	22.5%	45.3%	100.0%
U/L	2.245	4.427	4.740	6.226	9.904	21.170	41.503	13.076

FINAL ESTIMATION OF I.R. POPULATION BY SIZE (WAGE GAP & OTHER)
OTHER FACTOR CONTRIBUTES 37.5% OF WAGE GAP FACTOR

	4-9	10-19	20-29	30-99	-299	-999	1000-	TOTAL
POP(U)	1387	2875	2778	8490	13342	31071	80401	140344
(%)	1.0%	2.0%	2.0%	6.0%	9.5%	22.1%	57.3%	100.0%
U/L	0.951	2.420	2.658	3.868	7.322	20.811	52.516	13.076

	RATIO OF S&M ESTABLISHMENTS (U)	PENETRATION GAP [S&M/LARGE]
OBSERVED	20.6%	0.102
WAGE GAP EFFECT:	32.2%	0.186
TOTAL EFFECTS:	20.6%	0.102

penetration gap is 1:0.375 (wage gap : economy of scale).

The parameter c, therefore, is estimated to be 0.05 from equation (13).

In the case of I.R., economy of scale for robot costs is considered to work as follows:

The robot unit cost in large establishments of 1000 workers becomes by 10.9% cheaper than that in establishments of 100 workers.

Since we assume that other effects, except for wage rate, are caused exclusively by economy of scale for robot costs, this value (10.9%) constitutes the upper limit.

Compared to the case of EDP expenses shown in Figure 4, economy of scale for robot costs is considerably small.

(c) Estimation of penetration rate of I.R. by size of establishments

The final result on the penetration rate gap of I.R. by size of establishments is illustrated in Figure 5. Very large factories of more than 1000 workers introduce industrial robots at a rate 50 times higher than that of very small factories of 4-9 workers. Because of this big gap, 57.4% of I.R. population is used in very large factories as shown in Figure 6; however, only 14.3% of the workers and 0.2% of the number of factories fall into the group of these very large factories.

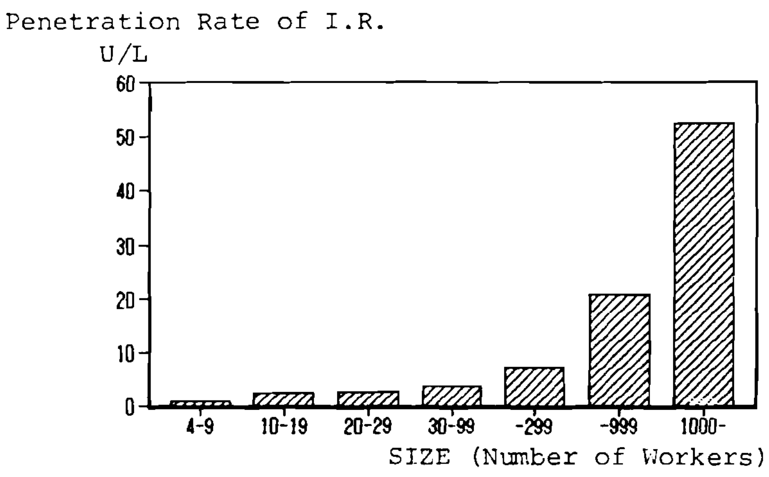


Fig. 5 Penetration Rate of I.R. by Size of Establishments in whole Manufacturing Industry (Final Estimation)

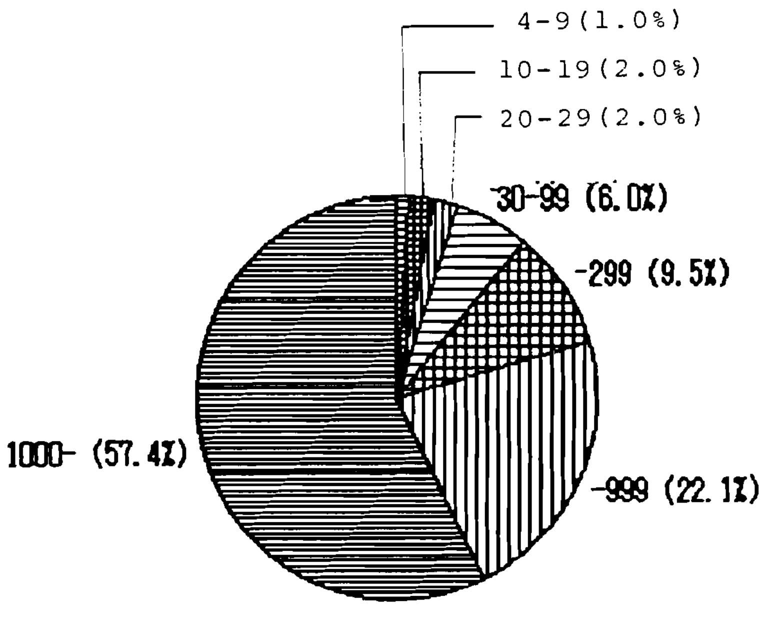


Fig. 6 I.R. Population by Size of Establishments

Finally, we compare our estimation with the response data of the JIRA survey to robot users. The data of the JIRA survey are shown in Table 11, and the results of comparison in Table 12.

As mentioned in the JIRA report, the response data of the JIRA survey are directed towards larger establishments. According to the comparison, we can point out that response rate of the JIRA survey has a tendency to be lower for smaller factories. This kind of tendency is usually observed in such a survey.

5. Conclusions

The results of our study are summarized as follows:

The penetration rate gap of industrial robots between large and small enterprises is very big.

Therefore, most industrial robots are introduced in large enterprises at the present stage.

The gap of I.R. penetration mentioned above is caused mainly by the wage gap between large and small enterprises.

Another factor causing the gap is economy of scale for cost of robot use, although this effect is not as big as in the case of EDP expenses.

The econometric model developed in our previous studies [Mori 87], [Tani 87] can also be applied through the modifications described in this paper to forecast the robot population by size of enterprises.

As described above, our model can successfully explain the present gap of I.R. penetration rate. However, in order to apply this model to forecasting at the mature stage, some

Table 11

Response Data of Robot Population in 1984 Surveyed by JIRA
Size of Establishments [Persons Engaged]

SECTOR	1-29	30-99	-299	-499	-999	1000-	TOTAL	R[-299]
1	0	0	0	12	7	23	42	0.0%
2	0	8	0	0	32	3	43	18.6%
3	0	0	7	10	5	105	127	5.5%
4	0	17	13	22	1	16	69	43.5%
5	0	19	52	0	0	657	728	9.8%
6	1	33	80	4	22	57	197	57.9%
7	7	45	92	236	217	474	1071	13.4%
8	2	9	87	58	110	440	706	13.9%
9	20	9	18	72	567	4942	5628	0.8%
10	1	169	430	252	584	10357	11793	5.1%
11	0	1	5	133	363	201	703	0.9%
12	34	31	190	105	11	305	676	37.7%
MFG	65	341	974	904	1919	17580	21783	
RATIO	0.4%	1.6%	4.5%	4.2%	8.8%	80.7%	100.0%	6.3%

Source: [JIRA 85]

Table 12

Comparison of I.R. Population by Size of Establishments Between our Estimation and JIRA Survey (Whole Manufacturing Industry)

Size	Our Estimation	Robot User Survey by (JIRA) [see Table 11]
- 29	5.0%	0.3%
30- 39	6.0%	1.6%
100-299	9.5%	4.5%
300-999	22.1%	13.0%
1000-	57.3%	80.7%
Total	100.0%	100.0%

modifications are necessary. As indicated in Figure 1, the gap is considered to be narrower at a higher diffusion. This tendency should be built in for further research. For one of the modifications it is considered to introduce the cut-off levels in equation (1). These levels consist of parameters $(P/W)_c$ and $(P/W)_m$, as shown in Figure 7. When (P/W) is greater than $(P/W)_c$, the penetration rate is zero. On the other hand, the penetration rate is saturated when (P/W) is less than $(P/W)_m$. If we could estimate these parameters, we might solve the above problem.

Though the results described in this paper are derived from the study on the Japanese manufacturing industry, it may be concluded that the methods proposed here and their significance from the viewpoint of company size can be regarded as a useful step towards further international investigations on the diffusion of CIM technologies.

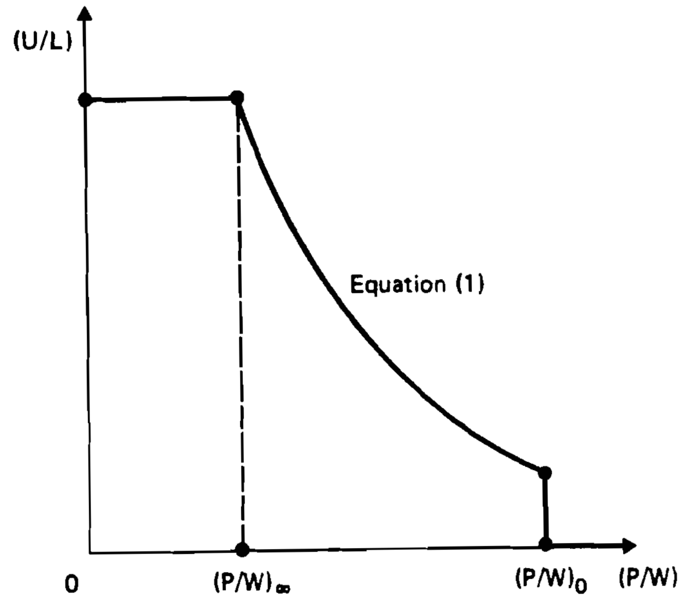


Fig. 7 Idea of Modification to Equation (1)

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