WORKING PAPER

INTERNATIONAL COMPARISONS OF INDUSTRIAL ROBOT PENETRATION

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OF THE AUTHOR

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Summary

This paper shows the international comparisons of industrial robot penetration. The results of comparisons are summarized as follows:

(a) There is a big gap of robot density between the leading country, Japan and other major developed market economy countries.

(b) However, the penetration trend curves show a very similar pattern among those countries.

(c) Therefore, the differences of I.R. penetration can be expressed by introducing a time-lag for each country. The time-lag of other countries are estimated by regression analysis for multi-national time-series data, resulting in a figure of 4.4 to 7.8 years behind Japan.

(d) With regard to the application and industrial distribution of I.R., remarkable differences are found between Japan and other countries, namely, with regard to assembly robots in the Japanese electric/electronics industry as opposed to welding robots in the automotive industry of other countries.

Foreword

One of the important tasks of the CIM project is to investigate the diffusion of advanced manufacturing technologies, such as CIM and its components, for various countries in the world. The viewpoint of international comparisons is of great importance for international institutes such as IIASA.

The present paper analyzes the penetration of industrial robots, important components of CIM, from this viewpoint. The data for the international comparisons are based on the existing statistics. This paper is the second one of the studies entitled "International Comparisons." Milan Maly published the "Economic Benefits of FMS (East-West Comparison)" as the first paper of this kind and in the near future the CIM project will continue to publish new papers under the same headline.

The international comparisons in this paper give us interesting results and new questions to be investigated in further work. The previous studies of the author, "Future Penetration of Advanced Industrial Robots in the Japanese Manufacturing Industry" and "Enterprise Size and Its Impact on Penetration of Industrial Robots", indicated that it is the augmentation of labor which has so far been the main driving force behind robotization, and the price of labour explains quite well the diffusion of robotics. This report shows that these conclusions have some generality. These phenomena can also explain the diffusion patterns of different industries and application patterns. However, we can expect the diffusion to become more complicated with the increasing share of systems applications, such as assembly and FMS applications as well as with the increasing technological sophistication of robots.

It is hoped that this study will be continued and revised in the near future by updating the database as the author mentioned in the last chapter of this paper. Such an effort will provide the basis for investigations of the impact of CIM on the international socio-economic environment.

Prof. Jukka Ranta
Project Leader
Computer Integrated Manufacturing

Contents

1. Introduction

It is of great importance to investigate the diffusion of high-technologies such as CIM (Computer Integrated Manufacturing) from the viewpoint of international comparisons. Some countries introduced these new technologies earlier than other countries. As a result, we can see the different penetration levels not only between the developed countries and the developing countries, but also among the developed countries.

As a part of the international comparisons of the diffusion of CIM technologies, we focus in this paper on the penetration of industrial robots for major developed countries.

Several papers have so far reported on international comparisons of industrial robots.[1] However, the comparisons in these papers have been faced with the following difficulties:

(1) Definition and classification of industrial robots are different among the countries to be compared;

(2) Statistics of the industrial robots are usually compiled from the viewpoints of I.R. suppliers. The data from the viewpoints of I.R. users are often not available.

(3) There are only a few time-series data of I.R. population which are internationally comparable.

In this paper we made an effort to collect and review the data of industrial robot population reported recently in various countries, and to make international

[1] see [Edquist & Jacobsson 86].

comparisons of the penetration levels and patterns of industrial robots. In other words, this paper tries to answer the following questions:

(a) How big are the differences of the present I.R. penetration among the developed countries?

(b) Do the penetration trend curves show the different patterns among the above countries?

(c) How many years of time-lag in diffusion of I.R. has each country?

(d) Does the applications of I.R. show the different distributions among the countries?

(e) Are there differences in industrial distribution of I.R. among the countries?

(f) If there are differences in application and industrial distribution, does the relationship exist between both of them?

2. Industrial robot penetration in selected countries

2.1 Definitions

Definition of Industrial Robots

As mentioned in the previous chapter, different definitions of industrial robots are employed among countries. This makes it difficult to compare *Industrial Robots* data internationally. Especially the Japanese Industrial Robot Association (JIRA) employs a much wider definition than other major countries. Japanese robot data include "manual manipulators" and "fixed sequence robots", which are not classified as robots but rather as automatic machines in other countries [Edquist & Jacobson 86].

In this paper we use the following definition of I.R., which has been proposed by the International Organization for Standardization (ISO):

> *The industrial robot is an automatic position-controlled reprogrammable multi-functional manipulator having several degrees of freedom capable of handling materials, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks. [ECE 85]*

According to the definition by ISO we have, in order to compare the data of industrial robots internationally, adjusted the Japanese data in this paper by excluding "manual manipulator" data and "fixed sequence robot" data. (Edquist and Jacobsson also made an effort to adjust in their paper; however, the adjustment is insufficient.)

In addition, some statistics of I.R. in Italy also include "fixed sequence manipulators". Therefore, the same adjustments are made for the Italian data.

Definition of the Penetration Level

Some alternatives are considered as an indicator showing the penetration level of I.R. in a country. It is important to select the indicator from the viewpoint of international comparability. In this paper we use the following I.R. population density as an indicator of I.R. penetration level:

$$I.R.\ population\ density = (U/L) \tag{1}$$

where U and L denote I.R. population (in units) and paid employment in manufacturing (in thousand persons), respectively. The reasons why the above indicator is selected are as follows:

I.R. stock in value is an alternative which can take into account the quality of I.R. in terms of prices for various types of robots. However, if we use this indicator, it is very difficult to compare the time series data internationally, because recent exchange rates are not stable and robot prices have been decreasing for the same type of robot. Therefore, we use the robot population in this paper instead of robot stock in value.

For a comparison of the degrees of robotization among different countries, robot population is not adequate as a comparable indicator because of the different size of national socio-economic activities.

Therefore, we use I.R. population density in this paper. The reasons why paid employment in manufacturing is selected as a denominator are partly due to availability of reliable and comparable time-series data for many countries, and they are partly due to the fact that almost all I.R. are used in the manufacturing sector.

Edquist and Jacobsson [Edquist & Jacobsson 86] have chosen to use employment in the engineering industry in the denominator since most robots are actually used in this industrial sector. As they mentioned, however, the picture is very much the same if employment in the whole manufacturing sector is used.

2.2 Comparisons

In Table 1 the industrial robot populations for 1974 to 1985 are shown for eight developed market economy countries, namely: Japan, the U.S.A., the U.K., the FRG, Italy, France, Belgium and Sweden. This table was compiled by reviewing the statistics and papers reported in those countries.

According to Yonemoto [Yonemoto 87], more than 90 percent of I.R. in the OECD countries are installed in the above eight countries.

Table 1. Industrial robot population in selected countries

Year	*Japan*	*USA*	*UK*	*FRG*	*France*	*Italy*	*Belgium*	*Sweden*
1974	1000	1200	50	130	30	90		85
1975	1400							
1976	3600	2000						
1977	4900		80	541			12	
1978	6500	2500	125			300	21	415
1979	9100						30	
1980	14250	3400	371	1255	580	454	58	795
1981	21000	4700	713	2300	790	691	242	950
1982	31857	6250	1152	3500	1385	1143	361	1400
1983	46757	9387	1753	4800	1920	1850	514	1600
1984	67300	14550	2623	6600	2750	2585	860	1900
1985	93000	20000	3017	8800				

The above data are mainly based upon the following references:

[JIRA 75-76] [SIRI 85]
[Yonemoto 87] [Revista Robotica 85]
[JIRA 86] [Edquist & Jacobson 86]
[BRA 86] [AFRI 85]
[BIRI 85]

We calculate the I.R. densities according to equation (1), using Table 1 and paid employment in manufacturing as shown in Table 2. Table 3 shows the past trends of I.R. density for the eight countries.

According to Table 3, Japan has been the leading country since 1981, while Sweden was the leading country until 1980. If we look at robot density in 1984, we find Japan with 5.553 robots/thousand employment, Sweden with 3.565, Belgium with 1.126, and other countries with less than 1.0.

In smaller countries with one million workers in manufacturing, such as Belgium and Sweden, special situations as, for example, some big company's installation of I.R., might greatly contribute to the high level of robot density for whole country.

From the above statistical viewpoints we will compare the robot density among the six major countries with more than 4 million employments in manufacturing.

Figure 1 shows the international comparisons of robot penetration trends among six countries. We can see a big gap of I.R. density between Japan and the other five countries during the whole period from 1974 to 1985. Japan has been six to eleven times higher than other countries as shown in Figure 1.

In order to compare the patterns of penetration trends, the robot density of the vertical axis in Figure 1 will be changed into a logarithmic scale as shown in Figure 2.

According to Figure 2 we can see the similar gradients of the penetration curves, which denote the annual increase rates of robot density among the six countries, excluding the U.S.A. curve until 1980. In the U.S.A. the annual increase rate of robot density during the latter half of the 1970's was lower than the usual case, which may be called a "slowdown of robotization." The U.S.A. has, however, recovered its robotization speed since 1980, which has thus become similar to the usual case.

**Table 2. Paid employment in manufacturing [ILO 86]
(in thousand workers)**

Year	*Japan*	*USA*	*UK*	*FRG*	*France*	*Italy*	*Belgium*	*Sweden*
1974	12010	20277	7873	9000	5660	5189	1100	667
1975	11380	17081	7526	8555	5501	5201	1033	669
1976	11330	18997	7281	8375	5458	5215	991	664
1977	11260	19682	7327	8340	5443	4771	952	634
1978	11090	20505	7293	8340	5365	4698	913	608
1979	11070	21040	7260	8389	5285	4715	888	608
1980	11350	20285	6939	8433	5230	4745	870	608
1981	11520	20170	6216	8193	5065	4639	823	602
1982	11510	18781	5889	7913	4995	4535	792	579
1983	11750	18430	5592	7601	4882	4404	773	548
1984	12120	19378	5506	7516	4742	4205	764	533
1985	12350	19314	5508	7596				

**Table 3. Industrial robot population density
(units of I.R. per thousand workers)**

Year	*Japan*	*USA*	*UK*	*FRG*	*France*	*Italy*	*Belgium*	*Sweden*
1974	0.083	0.059	0.006	0.014	0.005	0.017		0.127
1975	0.123							
1976	0.318	0.105						
1977	0.435		0.011	0.065			0.013	
1978	0.586	0.122	0.017			0.064	0.023	0.683
1979	0.822						0.034	
1980	1.256	0.168	0.053	0.149	0.111	0.096	0.067	1.308
1981	1.823	0.233	0.115	0.281	0.156	0.149	0.294	1.578
1982	2.768	0.333	0.196	0.442	0.277	0.252	0.456	2.418
1983	3.979	0.509	0.313	0.631	0.393	0.420	0.665	2.920
1984	5.553	0.751	0.476	0.878	0.580	0.615	1.126	3.565
1985	7.530	1.036	0.548	1.159				

Fig. 1: I.R. POPULATION DENSITY TREND

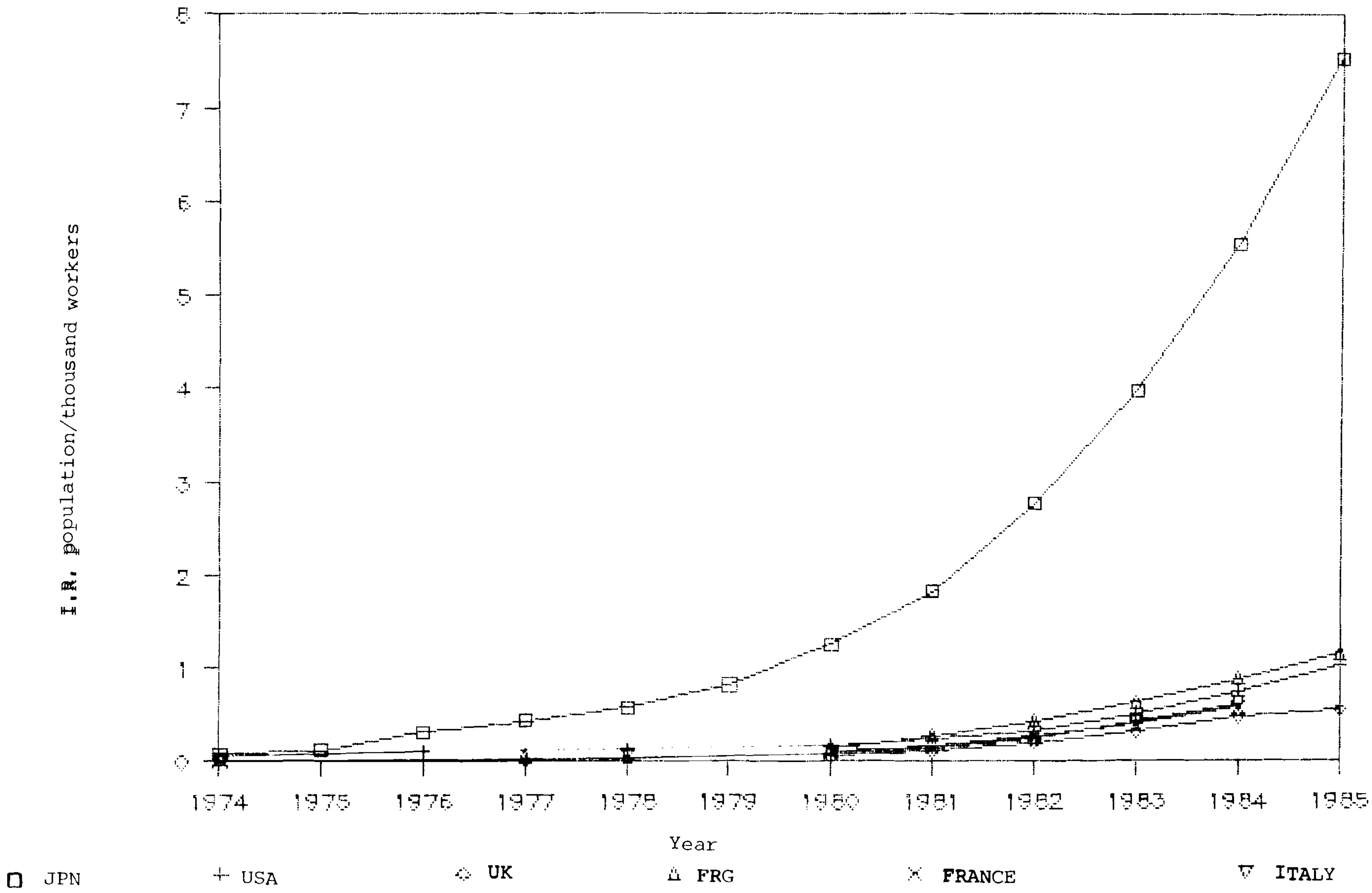
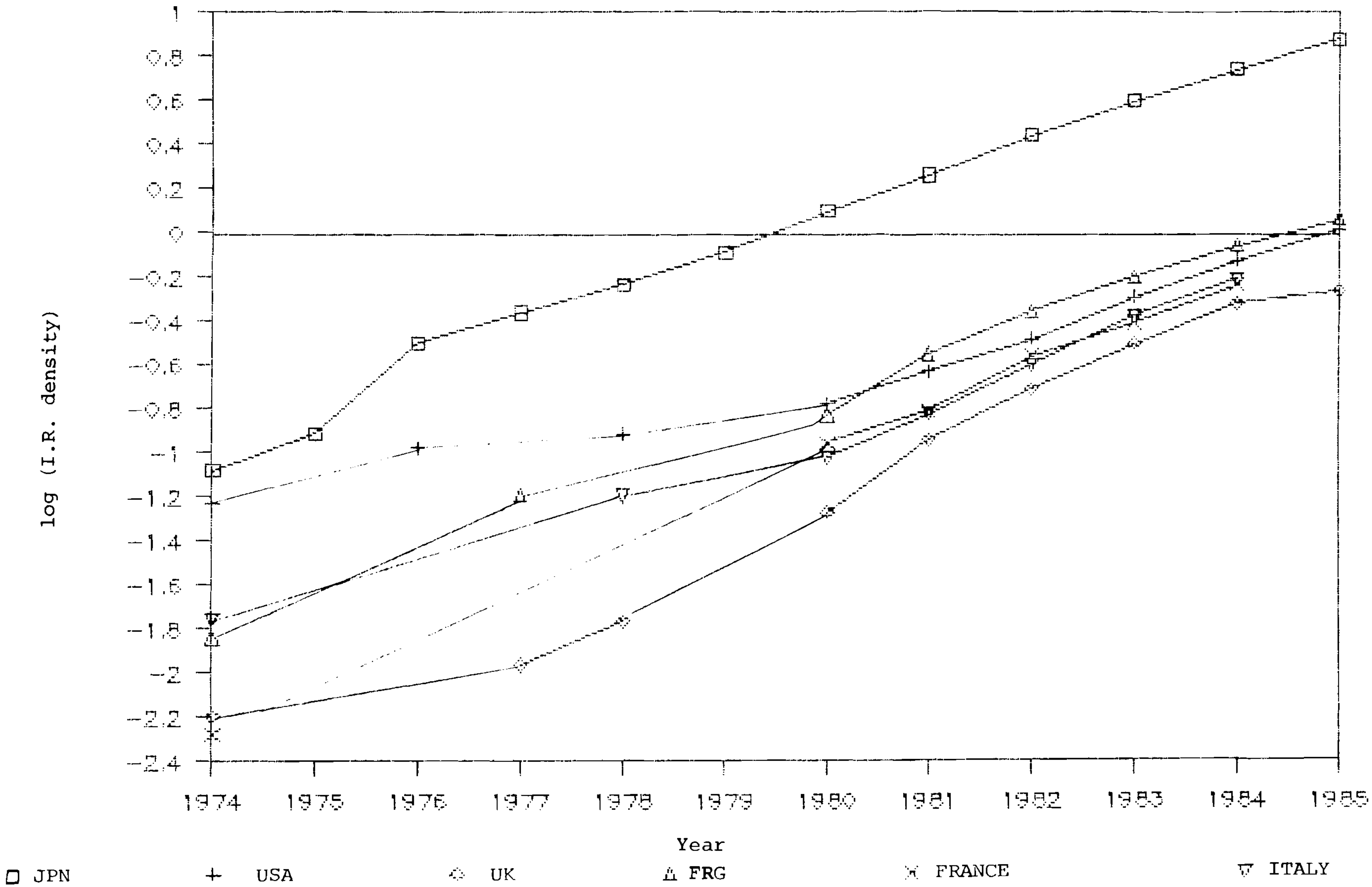


Fig. 2: I.R. POPULATION DENSITY TREND

log (density)



3. Penetration trend analysis

3.1 Method of multi-national time trend analysis

As shown in Figure 1, there is a big gap of I.R. penetration in terms of absolute figures between Japan and other countries. But the annual increase rates are almost similar among these countries as shown in Figure 2. This implies that a common trend pattern exists for penetration of I.R. In other words, the differences of I.R. densities can be expressed by introducing *time-lag* parameters for each country.

In order to compare the trend patterns among several countries, simple time trend analysis is usually used for each country. After that, comparisons of the estimated parameters of the trend curves are made among several countries. However, such a simple method can not give us the time-lag parameters explicitly. Therefore, we introduce in this paper a method of multi-national trend analysis as described below, in order to clarify the above structure.

In this method we firstly introduce a *country dummy* variable X_i for the i-th country as defined below.

$$X_i\ (j) = \begin{matrix} 1 --- & if\ j=i \\ 0 --- & if\ j \neq i \end{matrix} \tag{2}$$

By adding these dummy variables to time variable t as explanatory variables, the robot density of the i-th country at the time t, namely $(U/L)_{it}$, can be expressed in the following form:

$$\log\ (U/L)_{it} = A + \sum_{j=2}^{m} b_j \cdot X_i(j) + a \cdot t \tag{3}$$

where m denotes the number of countries. A, b_j and a are parameters to be determined later in the regression analysis.

The reason why j ranges from 2 to m in the second term of the right-hand side of equation (3) is that the number of independent dummy variables is m-1, because of the following relationship among them:

$$\sum_{i=1}^{m} X_i \ (j) \ = \ 1 \tag{4}$$

In this paper we set forth that Japan is the first country (i=1).

In order to clarify the meaning of parameters A, b_j (j=2~m) and a, we can write down equation (3) explicitly for each country as shown below.

Japan $(i=1)$ (4)

$$\log \ (U/L)_{it} \ = \ A \ + \ a \cdot t$$

Other country $(2 \leq i \leq m)$

$$\log \ (U/L)_{it} \ = \ A \ + \ b_i \ + \ a \cdot t \tag{5}$$

Equation (5) can also be expressed in the following form by introducing the time-lag parameter C_i instead of b_i:

$$\log \ (U/L)_{it} \ = \ A \ + \ a \cdot (t + C_i) \tag{6}$$

$$\textit{where} \ \ C_i \ = \ b_i / a \tag{7}$$

By comparing equation (6) to equation (4), the parameter C_i can be interpreted as a time-lag of the i-th country behind Japan.

The parameter a denotes the common annual increase rate of robot density.

As explained above, one regression analysis is applied for all of the multi-national time-series data through the introduction of country dummy variables.

As a result of this regression analysis, the common speed of robotization among the countries and the time-lag of I.R. penetration in each country will be estimated explicitly.

3.2 Results of the Analysis

Table 5 summarizes the results of this analysis, and the data used are shown in Table 4. As can be seen from Table 4, the regression analysis gives us the good results in statistical form.

If we shift the penetration trend curve by the time-lag for each country, almost the same trend curve can be drawn as shown in Figure 3.

According to this estimation the annual increase rate is 47%, at which the robotization has so far proceeded in major developed market economy countries.

As to the time-lag, Japan is the leading country, the USA is the second with a time-lag of 4.3 years behind Japan, the FRG comes next with 4.9 years behind, and 5.8 years, 6.3 years, and 7.5 years are the respective figures for the FRG, France and the UK.

The above results are considered useful for predicting future penetration of IR in various countries. If we investigate the penetration curve in the leading country, this result can also be applied to other countries, taking into account time-lag parameters.

Table 4. Data for trend analysis

Year	*Log(U/L)*	*Year*	*USA*	*UK*	*FRG*	*France*	*Italy*	*Nation*
1974	-1.0795	-6	0	0	0	0	0	JAPAN
1975	-0.9100	-5	0	0	0	0	0	JAPAN
1976	-0.4979	-4	0	0	0	0	0	JAPAN
1977	-0.3613	-3	0	0	0	0	0	JAPAN
1978	-0.2320	-2	0	0	0	0	0	JAPAN
1979	-0.0851	-1	0	0	0	0	0	JAPAN
1980	0.09881	0	0	0	0	0	0	JAPAN
1981	0.26076	1	0	0	0	0	0	JAPAN
1982	0.44212	2	0	0	0	0	0	JAPAN
1983	0.59980	3	0	0	0	0	0	JAPAN
1984	0.74451	4	0	0	0	0	0	JAPAN
1985	0.87681	5	0	0	0	0	0	JAPAN
1974	-1.2278	-6	1	0	0	0	0	USA
1976	-0.9776	-4	1	0	0	0	0	USA
1978	-0.9139	-2	1	0	0	0	0	USA
1980	-0.7756	0	1	0	0	0	0	USA
1981	-0.6326	1	1	0	0	0	0	USA
1982	-0.4778	2	1	0	0	0	0	USA
1983	-0.2929	3	1	0	0	0	0	USA
1984	-0.1244	4	1	0	0	0	0	USA
1985	0.01515	5	1	0	0	0	0	USA
1974	-2.1971	-6	0	1	0	0	0	UK
1977	-1.9618	-3	0	1	0	0	0	UK
1978	-1.7659	-2	0	1	0	0	0	UK
1980	-1.2719	0	0	1	0	0	0	UK
1981	-0.9494	1	0	1	0	0	0	UK
1982	-0.7085	2	0	1	0	0	0	UK
1983	-0.5037	3	0	1	0	0	0	UK
1984	-0.3220	4	0	1	0	0	0	UK
1985	-0.2614	5	0	1	0	0	0	UK
1974	-1.8402	-6	0	0	1	0	0	FRG
1977	-1.1879	-3	0	0	1	0	0	FRG
1980	-9.8273	0	0	0	1	0	0	FRG
1981	-0.5517	1	0	0	1	0	0	FRG
1982	-0.3542	2	0	0	1	0	0	FRG
1983	-0.1996	3	0	0	1	0	0	FRG
1984	-0.0564	4	0	0	1	0	0	FRG
1985	0.06389	5	0	0	1	0	0	FRG
1974	-2.2756	-6	0	0	0	1	0	FRANCE
1980	-0.9550	0	0	0	0	1	0	FRANCE
1981	-0.8069	1	0	0	0	1	0	FRANCE
1982	-0.5570	2	0	0	0	1	0	FRANCE
1983	-0.4052	3	0	0	0	1	0	FRANCE
1984	-0.2366	4	0	0	0	1	0	FRANCE
1974	-1.7608	-6	0	0	0	0	1	ITALY
1978	-1.1947	-2	0	0	0	0	1	ITALY
1980	-1.0191	0	0	0	0	0	1	ITALY
1981	-0.8269	1	0	0	0	0	1	ITALY
1982	-0.5985	2	0	0	0	0	1	ITALY
1983	-0.3766	3	0	0	0	0	1	ITALY
1984	-0.2113	4	0	0	0	0	1	ITALY

Table 5. Results of regression analysis for multi-national trends

Constant	0.07183
Std Err of Y Est	0.14496
R Squared	0.96243
No. of Observations	51
Degree of Freedom	44

	Year	*USA*	*UK*	*FRG*	*France*	*Italy*
Regression coef.	0.1675	-0.7285	-1.2500	-0.8167	-1.0563	-0.9752
Std Err of Coef.	0.0060	0.0641	0.0642	0.0666	0.0728	0.0691

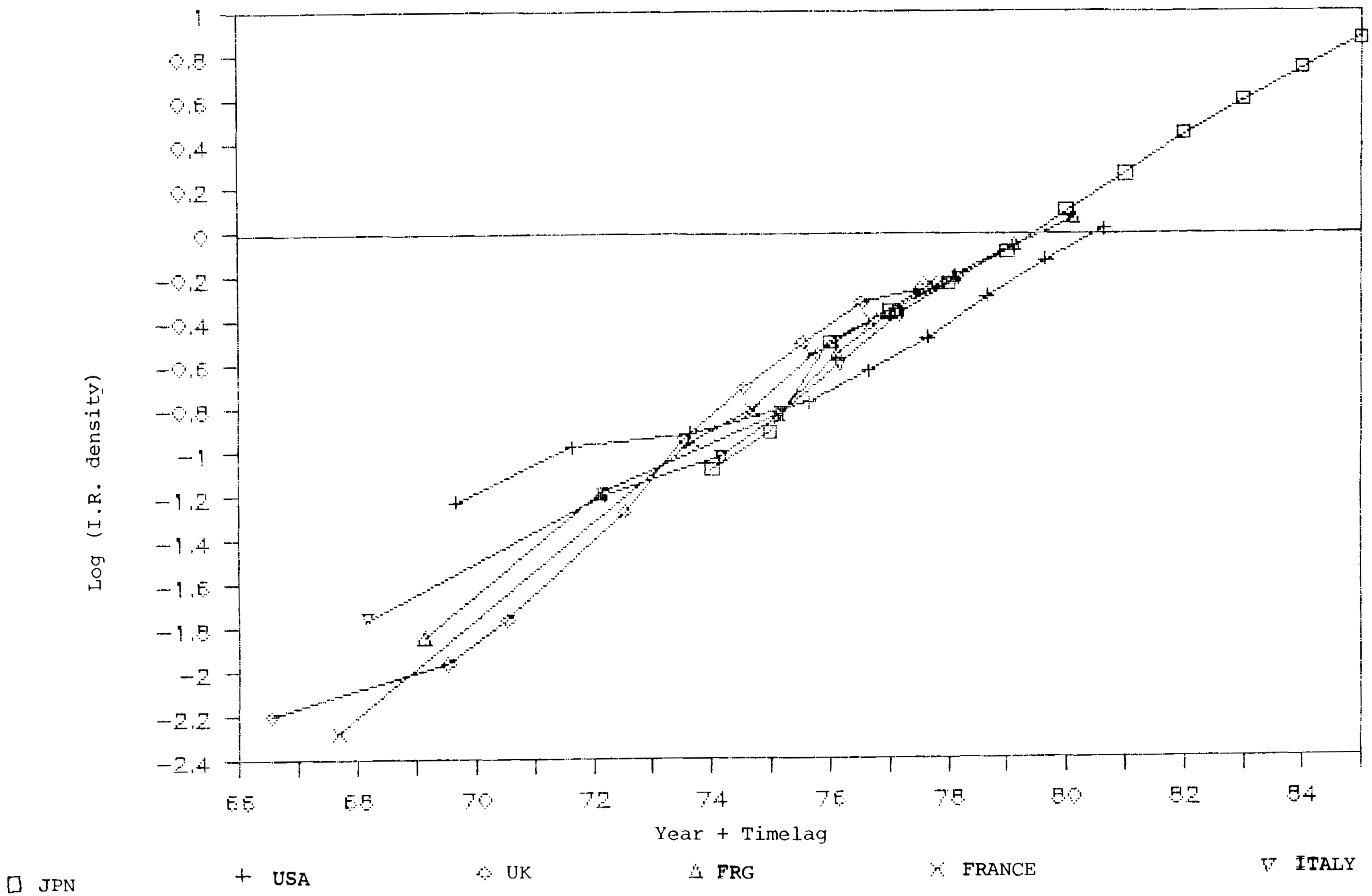
Regression Equation

log(U/L) = 0.07183

+0.1675*	YEAR	(=19XX-1980)	TIMELAG
+0 *	JAPAN	(1 or 0)	0
-0.7285*	USA	(1 or 0)	-4.3491
-1.2500*	UK	(1 or 0)	-7.4619
-0.8167*	FRG	(1 or 0)	-4.8753
-1.0563*	FRANCE	(1 or 0)	-6.3057
-0.9752*	ITALY	(1 or 0)	-5.8214

log(U/L)= 0.1675 * (YEAR+TIMELAG) + 0.07183

Fig. 3: I.R. PENETRATION TREND WITH TIMELAG SHIFTS



4. Cross-sectional analysis

In this chapter we will investigate the reasons why I.R. penetration levels in 1984 are different among countries.

Although there are many factors inducing such differences, we focus on the wage rate factor in this paper. The reason is as follows:

According to Mori [Mori 87] and Tani [Tani 87], the ratio of wage rate to robot price is one of the most important factors affecting the degree of robotization. In the case of international comparisons, the price difference among countries is considered small for the same type of robot, because I.R. are exported/imported internationally.

Based upon the exchange rates in 1984 [OECD 86], the relationship between wage rate [ILO] in the U.S. dollars and robot density in 1984 are tested as shown in Figure 4. The result of the regression analysis is shown in Table 6. According to Table 6, the correlation coefficient squared between these variables is 0.808 in case of excluding the U.S.A., while it is 0.191 for all of the eight countries. If we exclude the data of the USA, we can see the general tendency that a country with higher wage rates has introduced more I.R. This tendency is also observed in nationally-based analyses.

Exchange rates have greatly changed since 1984, especially as the US dollar is getting lower at present compared to the values of 1984.

If the point of the USA were shifted to the left on the line of the regression equation in Figure 4, the exchange rate could be 124 yen/US dollar, which is very near to the latest rate in 1987.

Table 6. Cross-sectional regression analysis
I.R. density vs wage rate (US$/hr) in 1984

Data for regresssion analysis					
	U/L	*W.rate*		*log(U/L)*	*log(W)*
USA	0.751	9.19	USA	-0.1244	0.9633
UK	0.476	4.89	UK	-0.3224	0.6893
FRG	0.878	5.44	FRG	-0.0565	0.7356
FRANCE	0.580	4.08	FRANCE	-0.2366	0.6107
ITALY	0.615	4.86	ITALY	-0.2111	0.6866
BELGIUM	1.126	4.88	BELGIUM	0.0515	0.6884
SWEDEN	3.565	6.51	SWEDEN	0.5521	0.8136
JAPAN	5.553	6.82	JAPAN	0.7445	0.8338

Regression output: case with USA data

Constant	-1.0966
Std Err of Y Est	0.37902
R Squared	0.19079
No. of observations	8
Degrees of freedom	6

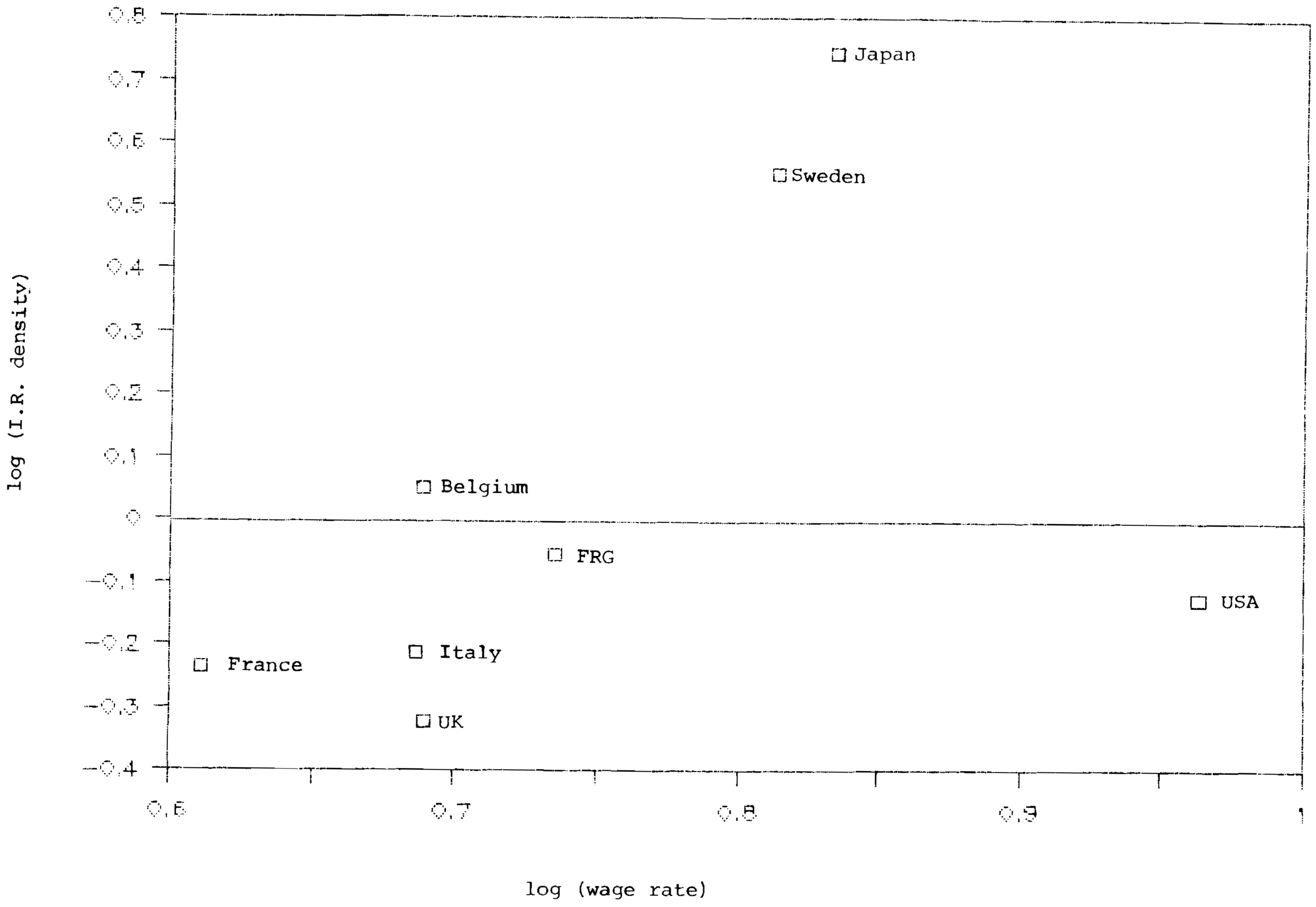
X Coefficient(s) 1.52292
Std Err of Coef. 1.28042

Regression output: case without USA data

Constant	-3.3580
Std Err of Y Est	0.19882
R Squared	0.80821
No. of observations	7
Degrees of Freedom	5

X Coefficient(s) 4.75044
Std Err of Coef. 1.03489

Fig. 4: I.R. DENSITY VS WAGE RATE



As we have seen from the above, it is very difficult to compare the monetary value indicator among the various countries during a period of unstable exchange rates. However, the wage rate can be pointed out as one of the most important factors in the case of international comparisons of I.R. penetration.

5. Applications

Table 7 shows the international comparison of industrial robots by applications.[2] I.R. are used mainly in the fields of welding (spot welding and arc welding), loading/unloading, assembly and painting. Plastic injection moulding is also one of major applications both in the UK and Japan. Among the major applications welding and assembly are most important at the present stage of robotization in the world.

(a) Welding

Welding robots accounted for 67.2% in Belgium, 63.5% in Spain, 49.2% in the FRG, 38.8% in Italy, 30.5% in the UK and 23.1% in Japan. In the European countries it can be said that welding is the most important application of I.R. Although Japan apparently has the lowest share, it must be noted that the absolute level of I.R. penetration in welding is more than two times higher than in the European countries. As explained later, a high share of welders in I.R. is related to a high share of automotive industry.

Within welding applications, spot welding was dominant in the European countries, while arc welding was dominant in Japan.

(b) Assembly

Japan has a much higher share of assembly robots compared to that of other countries. In Japan this share was about 40% during the period from 1982 to 1985, while it was only about 10% in other countries.

The gap of introducing assembly robots leads to the gap of I.R. penetration as a whole.

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[2] Only few statistical data are available about robotization in the USA. The comparisons between Japan and the USA are shown in Appendix A. The detailed data of Table 7 is shown in Appendix B.

As explained later, most assembly robots are used in the electric machine industry (including the electronics industry) in Japan. With regard to the absolute level, Japan has a more than twenty times higher penetration of assembly robots than other countries.

Table 7. Application distribution of I.R.

Application	*(1)* Japan (82-85) [%]	*(2)* UK (1985E)* [%]	*(2)* FRG (1985E) [%]	*(3)* Italy (1984E) [%]	*(4)* Belgium (1984E) [%]	*(5)* Spain (1985E) [%]
Welding (Spot)	9.2	16.9	29	28	60	50.2
(Arc)	13.9	13.6	20.2	10.8	7.3	13.3
Assembly	39.9	9.7	8.6	11.8	0.5	6.4
Loading/Unloading	6.3	9.5	9.2	26.5	8.4	15.4
Painting	2.2	6.4	8.8	8.9		6.8
Injection moulding	13.9	18.3				
Inspection/Test	1.2	1.9		1.2		2.1
Others	13.9	23.7	24.2	12.8	23.8	5.8
(Educational, etc.)		(5.5)	(2.4)		(11.4)	

* "1985E" means "at the end of 1985."

(1) [JIRA 75-86]
(2) [BRA 86]
(3) [SIRI 85]
(4) [BIRA 85]
(5) [Revista de Robotica 85]

6. Industrial distribution

Table 8 summarizes the international comparison on the industrial distribution of I.R.[3]

The automotive industry and the electric/electronics industry are considered to be the most important industries with regard to I.R. penetration.

(a) Automotive Industry

The automotive industry is the largest user of industrial robots in European countries. The share of automotive industry is about 70% in Spain and Belgium, about 50% in Italy. The recent US Industrial Outlook published in 1987 reported that nearly half of the installed units were in automotive and automotive-related industries.

On the other hand, the Japanese automotive industry has about a quarter of all robots in Japan. With regard to the absolute level, however, it must be noted that the Japanese automotive industry has a more than two times higher robot density than other countries.

(b) Electric/Electronics Industry

This industry is the largest user of I.R. in Japan, whose share is about 34%. In contrast, the share of this industry is much lower in other countries than in Japan. For example, it is about 10% in the UK and Italy, and less than 2% in Spain and Belgium.

This gap is related to the gap of assembly robot penetration.

[3]The detailed data of Table 8 is shown in Appendix C.

Table 8. Industrial distribution of I.R.

Sector	*(1)* Japan (1985E) [%]	*(2)* UK (1985E) [%]	*(3)* Spain (1985E) [%]	*(4)* Belgium (1984E) [%]	*(5)* Italy (1984) [%]
Automotive	24.4	34.3	72.3	66.9	48.9
Electric/Electronics	33.9	11.5	1.9	1.7	9.4
Mechanical Engineering	18.2	16.3	11.4	11.9	24.1
Plastics	16.7	17.3		2.1	1.9
Others	6.8	20.6	14.4	17.4	15.7

(1) [JIRA 75-86]
(2) [BRA 86]
(3) [Revista de Robotica 85]
(4) [BIRA 85]
(5) [SIRI 85]

7. Relationship between application and industrial distribution

The conclusions of the previous two chapters are summarized as follows:

In Japan, the largest user is the electric/electronics industry and the largest application is assembly, while the automotive industry and welding robots have the largest share in other countries.

In order to investigate the differences mentioned above, we will look at the applications of I.R. in the Japanese automotive and electric machinery industries. Table 9 shows the application share of these two industries.

As shown in Table 9, the share of welding robots is 65% in the Japanese automotive industry, which is similar to other countries. In contrast, 82.5% of I.R. in the Japanese electric machinery industry are occupied by assembly robots. Roughly speaking, the following relationship can be observed.

Industry vs application

Automotive <--------> Welding

Electric/Electronics <-------> Assembly

Taking into account the time-lag and the differences in industrial distribution of I.R. between the leading country, Japan, and other countries, the following hypothesis may be considered.

Robotization has started mainly in the automotive industry for welding at the first stage of diffusion. The second stage of robotization started mainly in the electric/electronic industry for assembly about five years after the first stage.

However, the actual Japanese diffusion pattern of I.R. by industry is not so simple. According to Table 10, the share of the electric/electronics industry was over 30 percent even before 1980, while the share of the automotive industry has decreased from 37.2% in 1978 to 24.4% in 1985. The electric machinery industry has, since 1978, taken an important role as leading the robotization as well as the automotive process in Japan.

Table 9. Application distribution of I.R. in Japanese automotive and electric/electronics industries

Automotive Industry		*Electric/Electronics Industry*	
Application	(82-85) [%]	Application	(82-85) [%]
Welding (Spot)	35.0	Assembly	82.5
(Arc)	33.0	Machine loading	4.9
Assembly	14.4	Others	12.5
Machine loading	9.1		
Others	8.5		

The above data are estimated by excluding Manual Manipulator and Fixed Sequence Robots.

Source [JIRA 75-86]

Table 10. Japanese industrial robots by sector (VSR-ITR)

(accumulated units since 1978)

Sector	*1978*	*1979*	*1980*	*1981*	*1982*	*1983*	*1984*	*1985*
Metal and its products	14.6%	10.7%	8.8%	7.5%	6.2	6.2%	6.1%	5.8%
Electric machinery	36.7%	29.2%	33.3%	32.3%	31.2%	31.2%	33.5%	33.9%
Automotives	37.2%	32.7%	32.6%	30.8%	28.0%	27.1%	25.5%	24.4%
Other machinery	5.6%	15.7%	9.5%	9.1%	9.8%	10.4%	11.9%	14.2%
Plastics	5.3%	9.7%	12.8%	17.9%	21.6%	21.3%	18.3%	16.7%
Others	0.6%	2.0%	3.0%	2.4%	3.1%	3.8%	4.7%	5.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

8. Conclusions

As described in Chapter 1, this paper tries to answer the six questions about the differences of I.R. penetration in various countries. The conclusions of this paper are summarized below:

(a) Differences amounting to a factor of more than five in I.R. penetration are not only observed at present, but they also existed ten years ago between the leading country, Japan, and other major countries.

(b) The penetration trend curves show a very similar pattern among the above countries, including Japan.

(c) The differences of I.R. penetration can be expressed by introducing a time-lag for each country. The time-lags behind Japan range from 4.4 to 7.8 years fro the USA and the major European countries.

(d) The application distribution of I.R. is different between Japan and other countries, i.e., assembly robots prevail in Japan, while welding robots prevail in other countries.

(e) The industrial distribution of I.R., as well as their application, is also different between these countries, i.e., they are mainly applied in the electric/electronics industry in Japan, and in the automotive industry in the other countries.

(f) Industrial robots have so far been used mainly as welders in the automotive industry and as assemblers in the electric/electronics industry. The above two distributions are strongly correlated.

Finally, the latest data on industrial robots in various countries are still being collected. For example, we received the news that the robotization in some countries showed the slowdown in 1986. Therefore, we plan to revise this working paper by updating the data next year as soon as possible.

Nevertheless, it might be said that the data and the results of the analysis described in this paper can be regarded as a useful tool for further investigations on international comparisons of high technology diffusion such as CIM.

Appendix A

Comparisons of industrial robots between Japan and U.S.A.

	JAPAN	U.S.A.
I.R. Population at the end of 1985	65,513 (1) (93,000)	20,000 (2)
User Industries at the end of 1985	(3)	(4) Nearly half of these installed units are in the automotive or automotive-related industries.
Automobiles	29%	
Electric Machines	41%	
Others	30%	
(I.R. distribution)		

Recent Application in 1984 and 1985	Domestic Shipments (3)	Shipments (5) (Servo-)	Imports (6) (Japan exports)
Welding	27%	34%	27%
Assembly	51%	16%	55%
Others	22%	50%	18%

Robot Price (US$thousands)	Domestic (7)	Exports (7)	Shipments (8)	Imports (8)
1984	48.2	35.4	77.0 [34.51]	[27.0]
1985	32.8	34.1	90.7 [54.8]	[29.2]

(1) JIRA domestic shipment data: amount of 1978 to 1985 for advanced type robots, namely, playback robots, numerical controlled robots and intelligent robots. (93,000) is an estimated population of industrial robots including variable sequence control robots by Yonemoto.

(2) British Robot Association, ROBOT FACTS 1985.

(3) JIRA data for advanced type robots.

(4) U.S. Industrial Outlook 1987 - Metalworking Equipment, 21-6

(5) BUREAU OF THE CENSUS, U.S. Department of Commerce, Current Industrial Reports: Robots (Shipments), MA35x(85)-1 August 1986. The data in Table are for servo-controlled robots, excluding nonservo-controlled robots (less than 20% compared to servo-type) and other robots (such as educational, hobby, experimental robots). Shipment data include exports.

(6) Industrial Outlook 1987 - Metalworking Equipment, 21-6. U.S. imports of complete robots are estimated to have increased again in both units and value in 1986 and to have captured 80 percent of the U.S. market. Currently, Japan's share of U.S. robotics imports amount to 80 percent of all U.S. robotics imports. Therefore, JIRA exports data for advanced type robots are used in Table. The share of conventional type robots in exports is only 8.8 percent of total exports.

(7) JIRA data for advanced type robots. Exchange rates: 237.52 Yen/US$ in 1984 and 238.54 Yen/US$ in 1985.

(8) BUREAU OF THE CENSUS, U.S. Department of Commerce, Current Industrial Reports: Robots (Shipments), MA35x(85)-1 August 1986. The data in Table are for servo-controlled robots. [ ] means averaged price for all of industrial robots based upon the CIR recently revised.

Appendix B

Applications of I.R. in selected countries

(1) J A P A N [JIRA 75-86]

Industrial robot shipment by application and type :82-85

Application	*Units*	*Percent*
Casting	126	0.1%
Diecasting	1737	1.96%
Plastic moulding	12979	13.9%
Heat treatment	49	0.1%
Forging	40	0.0%
Press loading	524	0.6%
Arc welding	12973	13.9%
Spot welding	8559	9.2%
Gas welding	16	0.0%
Painting	2029	2.2%
Plating	168	0.2%
Machine loading	5830	6.3%
Assembly	37161	39.9%
Palletizing/Packaging	1912	2.1%
Inspection/Test	1160	1.2%
Others	7733	8.3%
(Special purpose)	148	0.2%
Total	93144	100.0%

(2) UK and FRG [BRA 86]

Industrial robots by application at the end of 1985

Application	*UK*	*(Percent)*	*FRG*	*(Percent)*
Surface coating	193	6.4%	775	8.8%
Spot welding	511	16.9%	2548	29.0
Arc welding	411	13.6%	1781	20.2%
Grinding/deburring	52	1.7	25	0.3%
Assembly	294	9.7%	753	8.6%
Investment casting	15	0.5%		0.0%
Glueing/sealing	43	1.4%		0.0%
Laser cutting	5	0.2%		0.0%
Water jet cutting	6	0.2%		0.0%
Other tool manupilation		0.0%	293	3.3%
Diecasting	40	1.3%	174	2.0%
Injection moulding	551	18.3%		0.0%
Machine loading	287	9.5%	806	9.2%
Press loading	74	2.5%	173	2.0%
Inspection/test	56	1.9%		0.0%
Handling/palletizing	130	4.3%		0.0%
Forging	10	0.3%	84	1.0%
Other workpiece manupilation		0.0%1179	13.4%	
Other applications	174	5.8%	0.0%	
Education/research	165	5.5%210	2.4%	
Total	3017	100.0%	8800	100.0%

(3) ITALY [SIRI 85]

Application	*Units*	*1984E Percent*
Loading/unloading	686	26.5%
Spot welding	723	28.0%
Arc welding	280	10.8%
Painting	230	8.9%
Assembly	304	11.8%
Inspection	30	1.2%
Others	332	12.8%
Totals	2585	100.0%

(4) S P A I N [Revista de Robotica 85]

Application	*Units*	*Percent*
Sealing	20	3.0%
Inspection/test	14	2.1%
Work loading	104	15.4%
Grinding/deburring	3	0.4%
Medicion	5	0.7%
Assembly	43	6.4%
Painting	46	6.8%
Arc welding	90	13.3%
Spot welding	339	50.2%
Others	11	1.6%
Totals	675	100.0%

(5) BELGIUM [BIRI 85]

Application	*1984E Units*	*Percent*
Machine loading	72	8.4%
Spot welding	516	60.0%
Arc welding	63	7.3%
Handling	21	2.4%
Assembly	4	0.5%
Education Others	98	11.4%
Others	86	10.0%
Totals	860	100.0%

(6) USA [U.S. Doc 86]

Total shipments of complete robots USA (1984 + 1985)

Application	*Units*	*Percent*
Welding, soldering, brazing, and/or cutting	1992	16.2%
Foundry, forging, and/or heat treating	32	0.3%
Inspection, measuring, guaging, and/or sorting		0.0%
Spraying, painting, gluing, and/or sealing	1075	8.7%
Machine tool loading and/or unloading	120	1.0%
Assembly	958	7.8%
Material handling and others	1508	12.2%
Others (nonservo- & servo-[continuous path type])	1329	10.8%
Other robots (educational, hobby, experimental, etc.)	5316	43.1%
Total	12330	100.0%

The above data include exports, without imports (Imports=8220[1984+1985]. Imports are estimated to have increased again in both units and value in 1986 and to have captured 80 percent of all U.S. market. Currently Japanese imports amount to 80% of all U.S. robotics imports.

Appendix C

Industrial distribution of I.R. in selected countries

(1) JAPAN [JIRA 75-86]

Industrial robot shipments by sector and type: 1978-1985

Sector	*Total*	*Percent*
Food processing	610	0.7%
Textiles	86	0.1%
Lumber products	154	0.2%
Pulp and paper	150	0.2%
Chemicals	652	0.7%
Oil and coal products	184	0.2%
Rubber products	131	0.1%
Ceramic and stone products	404	0.5%
Steel	352	0.4%
Non-ferrous metals	1186	1.3%
Metal products	3649	4.1%
Boilers and motors	210	0.2%
Construction machinery	928	1.0%
Metal processing machinery	2805	3.1%
Other general-use machinery	3428	3.8%
Electric machines	30284	33.9%
Automobiles	21739	24.4%
Bicycles	608	0.7%
Shipbuilding	146	0.2%
Precision machinery	4518	5.1%
Synthetic	14930	16.7%
Other manufacturing	1028	1.2%
Other industries	1064	1.2%
DOMESTIC	89246	100.0%
EXPORTS	19707	
TOTAL	108953	

(2) UK [BRA 86]

Industrial robots by sector at the end of 1985

	Units	*(Percent)*
Energy/water supply	46	1.5%
Metal manufacture	17	0.6%
Metal goods	273	9.0%
Mechanical engineering	221	7.3%
Electrical/electronics	348	11.5%
Automotive	1036	34.3%
Aerospace/Shipbuilding	105	3.5%
Food/drink/pharmaceutical	26	0.9%
Timber/paper/furniture	17	0.6%
Rubber/plastics	522	17.3%
Other industries	406	13.5%
Total	3017	100.0%

(3) ITALY [SIRI 85]

Industrial Sector	*Units*	*1984* *Percent*
Mechanical engineering	150	13.8%
Transport machinery		
Automotive	533	48.9%
Others	112	10.3%
Electrical/electronics	102	9.4%
Textiles	8	0.7%
Plastics	21	1.9
Others	164	15.0%
Total (including FSM)	1090	100.0%

(4) SPAIN [Revista de Robotica 85]

	1985E *Units*	*Percent*
Automotive	488	72.3%
Metal processing	63	9.3%
Electric/electronics	13	1.9%
Bicycles	10	1.5%
Others	101	15.0%
Total	675	100.0%

(5) BELGIUM [BIRI 85]

Industrial sector	*1984E* *BELGIUM*	*Percent*
Automotive	575	66.9%
Machinery	87	10.1%
Plastics	18	2.1%
Electronics	15	1.7%
Education	98	11.4%
Others	67	7.8%
Total	860	100.0%

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