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Labor shortage and early robotization in Japan

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ABSTRACT

In this paper, we study how labor shortage contributed to the rise of robots in the early stage of robotization in Japan from 1978 to 1991. Based on the newly digitalized industry-level data on labor shortage, we demonstrate that the shortage of unskilled factory workers is strongly positively associated with subsequent robot adoption. We also find the effect of the shortage of skilled factory workers on robot adoption to be negative, suggesting a potentially complementary role of skilled labor in the process of automation.

1. Introduction

Over the last four decades, Japan has played a dominant role in the global robot market. As the most important manufacturer of robots, the country is the birthplace of many leading industrial robot companies. As a pioneering adopter, Japan also has one of the largest markets for robots.[1] Given its prominence in the robot industry (Mansfield, 1988), Japan's experience of robotization provides a unique opportunity for economists to empirically examine the causes and consequences of automation, shedding light on the theory of skill-biased technical change (Acemoglu, 2002a,b). The labor market effects of robot adoption in Japan have been a topic of interest in recent research; however, considerably less attention has been paid to the factors behind Japan's emergence as a pioneer in robot adoption. This paper aims to fill this void.

In this paper, we examine how labor shortages are associated with robot adoption in the early period of robotization in Japan. Our analysis spans from 1978, only a few years after robots were first introduced into Japan, to 1991, before the country's bubble economy burst. Based on newly digitalized survey data on industry-level labor shortages, we document a strong and positive association between the shortage of unskilled factory workers and subsequent robot adoption. This finding is robust to a battery of robustness checks. We also find that a shortage of skilled factory workers has a *negative* effect on robot adoption, thus underscoring the occupation-task dimension in the association between labor shortage and automation (Acemoglu and Restrepo, 2018).[2]

This paper is related to a burgeoning strand of works that study the Japanese experience of robotization. Using the industry-level data, Dekle (2020) finds that robot adoption in Japan has a positive effect on aggregate employment outcomes. Adachi et al. (2022) develop a model-based identification framework to demonstrate that a decline in robot prices increases both robot installation and employment. They also provide a detailed account of the institutional underpinnings of their findings. Adachi (2023) goes beyond the domestic implications of the decline in robot prices to examine its effect on US wage polarization through the lens of a neatly specified structural model. Using firm-level data from 1995 to 2017, Ni and Obashi (2021) examine the effect of robots on employment composition and find positive effects on both job creation and destruction. In an influential earlier study, Morikawa (2017) examines Japanese firms' expectations of the impact of robots and artificial intelligence (AI) on business and employment. Our paper complements the existing work by focusing instead on the cause of early robotization in Japan.[3] It also provides fresh empirical evidence for

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[1] For more details, see *World Robotics 2018* by the International Federation of Robotics.

[2] Our findings also echo the differential effects of robot adoption on occupations (or skill groups) at the firm level as documented in Humlum (2021), Tang et al. (2021), and Deng et al. (2023).

[3] Adachi et al. (2022) provide, in their appendix, an informative discussion of labor market characteristics in relation to the early adoption of robots in Japan.

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the rich narrative and anecdotal account of the rise of Japan's robot industry (Fujiwara, 2018).

The rest of the paper is structured as follows. Section 2 briefly describes the historical background of our analysis. Section 3 introduces the data and empirical approach. Section 4 presents the main results and Section 5 offers concluding remarks.

2. Historical background

The history of industrial robots in Japan began in 1968 when Kawasaki Heavy Industries Ltd. (KHI henceforth) formed a technical alliance with Unimation Inc., a US company that produced the first industrial robot called *Unimate*. According to Akino (1994), Nissan Motor Co. Ltd. purchased its first Unimate for the spot-welding line of the body of the Bluebird, a small passenger car. In 1969, KHI began the domestic production of Unimates. Since then, industrial robots have been installed in establishments with 50 or more employees, amounting to approximately 3,000 installations in 1973, 16,000 in 1981, and 47,000 in 1987.

As for the drivers of the rapid growth of Japan's robot industry, Minami (1968) notes the labor shortage associated with economic growth since the 1950s, which is echoed in the recollection of KHI's history (Kawasaki Heavy Industries, Ltd., 2018). Yonemoto (1982) states that with the increase in higher education, more workers became white-collar workers, and firms introduced industrial robots due to the shortage of factory workers.[4] Although labor shortage has been part of the narratives of Japan's early robotization, the empirical support for such a claim in the literature is meager.

This paper focuses on the period between 1978 and 1991 when companies began to use industrial robots in earnest. KHI has provided robot education to a wide range of general users since 1969 to promote the practical use of industrial robots. According to Nakajima (1985), relevant personnel in engineering, sales, and management attended this user training for the first six years; after 1975, factory workers mainly attended the training. As production workers began to be trained in working with robots, the mid-1970s marked the transition from the early exploration of the industrial use of robots to mass adoption in Japan.

3. Data and empirical approach

We use two main data sources. The labor shortage data are from the *Survey on Labor Economy Trend* published by the Ministry of Health, Labor, and Welfare. Since September 1966, the Ministry has surveyed privately-owned establishments with 30 or more full-time workers about the excess or shortage of workers in seven occupational categories: factory workers, skilled (factory) workers, unskilled (factory) workers, professionals (including managerial and technical occupations), administrative workers, sales personnel, and service workers. We exclude the last three categories from our analysis because they do not directly participate in the production process. The survey reports, for each industry, the share of establishments reporting a "shortage" of labor for each occupation, which is used as our measure of labor shortage at the industry level by occupation. We convert the original quarterly data into annual frequency by taking the within-year average.

Our robot data are based on Japanese industrial robot data, which the Japan Robot Association (JARA) has collected and reported since 1974. The JARA dataset has been used extensively in the recent work on Japanese robots (Dekle, 2020; Ni and Obashi, 2021; Adachi et al., 2022). Our analysis is based on the annual shipments of robots by industry, which has been available since 1978.[5]

Table 1
Summary statistics.

Variable	Mean	Std. Dev.	Min	Max
Robot shipments	3,337	5,312	1	24,092
Robot price	1.68	0.36	0.99	2.62
Gross output	16.69	0.81	15.05	17.70
Imports	13.62	0.86	11.83	15.24
Exports	13.74	1.43	10.77	16.00
IT investment	10.92	1.74	7.15	14.10
Labor shortage by occupation group				
Factory workers	27.25	15.05	7.5	73.75
Unskilled	22.70	15.85	1.5	69.75
Skilled	26.62	11.48	5.25	65.75
Professionals	19.87	7.98	8	42

Notes: (i) This table reports the summary statistics for the main variables for our baseline regression sample (N = 107), an unbalanced panel covering 11 industries from 1978 to 1991. (ii) Robot shipments are reported as the number of robots. Robot price (deflated by JIP industry-level price index), real gross output, imports, exports, and IT investment are all in log scale. (iii) The labor storage measure (lagged by one year) is defined as the percentage share of firms reporting a shortage of labor for a given occupation group.

Our baseline regression sample is an unbalanced panel covering the period of 1978–1991 and 11 industries in total: grocery, metal, general machinery, electrical equipment, precision machinery, transport equipment, chemical products, paper and printing, leather, wood products, and textiles.[6] To further control for industry-level covariates, we use the *Japan Industrial Database* compiled by the Research Institute of Economy, Trade and Industry. Specifically, following Adachi et al. (2022), we include the real values of gross output, imports, exports, and IT investment by industry. Table 1 provides summary statistics of the key variables included in our regression analysis.

Our main regression is specified as follows

$$\log(\text{Robot}_{it}) = \alpha_i + \mu_t + \beta \text{Shortage}_{it-1} + X_{it}\gamma + \varepsilon_{it}, \quad (1)$$

where Robot_{it} is the number of domestic robot shipments in industry i and year t; Shortage_{it-1} is a labor shortage measure (share of firms reports labor shortage) for industry i in year $t-1$; α_i and μ_t are industry and year fixed effects;, and X_{it} is a vector of industry-level covariates including robot price, gross output, imports, exports, and IT investment. In our regression analysis, we focus on the labor shortage of three types of workers: unskilled (factory) workers, skilled (factory) workers, and professionals.

4. Results and discussions

Table 2 reports our main estimation results. The first three columns only include industry and year fixed effects without additional controls.[7] We find that the lack of unskilled workers is positively associated

[4] Yonemoto (1982) mentions labor unions seeking to improve the environment for workers and the need for companies to increase productivity in the face of inflation and rising wage rates due to the 1970s' oil shocks. Akino (1994) points to the economies of scope by the introduction of industrial robots equipped with microelectronics technology. Adachi et al. (2022) offer an in-depth discussion to underscore the role of the unique employment practice in Japan's large manufacturing firms.

[5] The original data are further classified by robot type and application; however, to match the industry-level labor shortage data, we aggregate the robot data by industry.

[6] We manually compile industry concordance between the two main datasets and consolidate the matched industries into 11 industries. For chemical products, our final sample only covers 1984–1991. For paper and printing, leather, and wood products, our sample only covers 1978–1984.

[7] The Ministry of International Trade and Industry has implemented government subsidy measures since 1980, primarily to encourage the adoption of robots in small and medium-sized enterprises (Takeda, 2013). As these measures are industry-neutral, their policy effects are captured by the year fixed effect.

Table 2
Robot adoption and labor scarcity.

Dependent variable	Number of Robot Shipments (in log)					
	(1)	(2)	(3)	(4)	(5)	(6)
Lack of unskilled workers	0.0367*	0.0592**	0.0601**	0.0558**	0.1002***	0.1039***
	(0.020)	(0.024)	(0.023)	(0.025)	(0.029)	(0.028)
Lack of skilled workers		−0.0417**	−0.0317		−0.0817***	−0.0681***
		(0.019)	(0.028)		(0.028)	(0.025)
Lack of professionals			−0.0293			−0.0470
			(0.045)			(0.040)
Additional controls	No	No	No	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
N	107	107	107	107	107	107

Notes: (i) This table reports the results of the OLS estimation of (1). (ii) The dependent variable is the log of robot shipments. (iii) Columns (1)–(3) show the results without additional control variables. Columns (4)–(6) control for real gross output, imports, exports, IT investment, and robot price. (iv) Both industry and calendar year fixed effects are included. (v) Standard errors clustered at the industry level are reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 3
Robot adoption and labor scarcity.

Dependent variable	Number of robot shipments (in log)					
	(1)	(2)	(3)	(4)	(5)	(6)
	Panel A: Exclud. Auto industry			Panel B: Timespan 1978–1987		
Lack of unskilled workers	0.0695***	0.1103***	0.1155***	0.0637**	0.1150***	0.1244***
	(0.026)	(0.029)	(0.026)	(0.032)	(0.031)	(0.025)
Lack of skilled workers		−0.0916***	−0.0766***		−0.1157***	−0.1024***
		(0.029)	(0.025)		(0.031)	(0.022)
Lack of professionals			−0.0527			−0.0554
			(0.038)			(0.037)
Additional controls	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
N	100	100	100	75	75	75
	Panel C: Falsification test			Panel D: Combin. skilled & unskilled		
Lack of unskilled workers	0.0142	0.0314	0.0305			
	(0.023)	(0.031)	(0.034)			
Lack of Skilled Workers		−0.0336	−0.0354			
		(0.038)	(0.034)			
Lack of professionals			0.0076		−0.0316	−0.0456
			(0.053)		(0.047)	(0.049)
Lack of factory workers				−0.0160	−0.0049	−0.0116
				(0.015)	(0.026)	(0.022)
Additional controls	Yes	Yes	Yes	No	No	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
N	101	101	101	107	107	107

Notes: (i) This table reports the robustness checks of our baseline results. (ii) The dependent variable is the log of robot shipments. (iii) Panel A excludes the automobile industry. Panel B restricts the sample period to 1978–1987. Panel C conducts the falsification test by regressing the robot shipments on the next-period (period $t+1$) labor shortage measures. Panel D uses the labor shortage measure for factory workers that does not distinguish skill levels. (iv) Additional controls include real gross output, imports, exports, IT investment, and robot price. (v) Both industry and calendar year fixed effects are included. (vi) Standard errors clustered at the industry level are reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

with robot adoption in the subsequent year. This effect is statistically significant and economically sizable. According to Column (1), an increase in the share of firms reporting a shortage of unskilled workers by one percentage point would be associated with an increase in robot shipments in the following year by 3.67%. When we introduce the labor shortage of skilled workers in Column (2), the estimated effect of the shortage of unskilled workers becomes even stronger with increased statistical significance. Interestingly, the shortage of skilled workers is estimated to be negatively associated with subsequent robot adoption, which is in line with the prediction of a task-based model of automation as in Acemoglu and Restrepo (2018): the lack of workers performing more complementary tasks to robots has an ambiguous – sometimes negative – effect on the incentives of automation. In Column (3), we introduce the shortage of professionals such as workers in technical and managerial occupations. The estimate for the shortage of unskilled workers remains significantly positive, whereas both coefficients for the lack of skilled workers and professionals are insignificant with negative signs.

In the next three columns, we include a full set of additional controls, including industry-level robot price, exports, imports, aggregate output, and IT investment. The results are largely similar. The magnitude of the point estimates for the shortages of unskilled and skilled workers becomes even higher with increased statistical significance. These results suggest that the shortage of unskilled workers is strongly and positively associated with future robot adoption, whereas the shortage of skilled workers tends to lower the incentives for robot adoption.[8]

We next subject our findings to a battery of robustness checks. First, to address the concern that our results could be driven by the automobile industry which is a heavy user of robots, we rerun our baseline specification by excluding the automobile industry and report our results in Panel A of Table 3. The results remain qualitatively unchanged. Second, due to a change in industry-level robot classification between 1987 and 1988, and to address the concerns that the last years of the bubble economy may bias our results, we restrict our analysis to the timespan of 1978–1987. The point estimates in Panel B deliver the same message: a strong positive association between the shortage of unskilled workers and robot adoption, and a negative association between the shortage of skilled workers and robot adoption.[9] Third, to alleviate the concern that labor shortage and robot adoption are driven by underlying common factors such as unobserved demand shocks, we also regress robot shipments on the *next-period* labor shortage measures and report the findings in Panel C of Table 3. We no longer observe a statistically significant association between robot adoption and any labor shortage measures. Fourth, we include instead the labor shortage of factory workers that does not distinguish by skill intensity. According to Panel D, the general shortage measure of factory workers is estimated to be insignificant. This suggests that the documented tight connection between labor shortage and robot adoption hinges on the underlying skill intensity.

5. Conclusion

In this paper, we document the role of labor shortage at the early stage of Japan's robotization. We find that the effect of labor shortage on robot adoption hinges on occupation characteristics: lack of unskilled workers is strongly positively associated with subsequent robot adoption, whereas the effect of lack of skilled workers is suggestively negative. Our results are correlational in nature; therefore, an important next step is to establish their causality. Japan has played a pioneering and pivotal role in the global robot industry; thus, we envision more work to be conducted in this area.

[8] The effect of the shortage of professionals is imprecisely estimated, but its negative sign is also in line with the complementary input argument in a task-based model.

[9] We also rerun our main specification using the labor shortage measures lagged by two years, and the results are qualitatively similar.

Data availability

The authors do not have permission to share data.

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