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Robotics, Demography and Industrial Automation. Case study of Japan and Germany

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Keywords: robotics market, industrial robots, demographic aging, Japan, Germany, automation, labour shortage, export forecast, econometric modelling, population aging.

Abstract: The study examines the relationship between demographic aging and the development of the robotics market in Japan and Germany from 2003 to 2023, with a forecast for 2024. As two of the world's most rapidly aging societies, both countries face significant labour shortages, which they have sought to mitigate through the large-scale adoption of industrial robots. Using a combination of descriptive statistics, comparative analysis, and econometric modelling, the study analyses trends in robot density, export-import dynamics, and macroeconomic drivers of robotics demand. The results confirm that Japan and Germany are global leaders in robotics integration and export, together accounting for approximately 40% of worldwide industrial robot exports in 2023. However, regression-based forecasts indicate a potential decline in exports for 2024, 10.76% for Japan and 21.84% for Germany, due to factors such as tightened export controls, international competition, and cyclical economic pressures. The findings support the hypothesis that robotics serves as a strategic response to demographic decline but also highlight the need for complementary policies in education, innovation, and social adaptation. The study concludes that robotization is an inevitable adaptation strategy for aging economies and offers lessons for other countries facing similar demographic transitions.

1 INTRODUCTION

The ongoing process of production automation represents a fundamental shift in global manufacturing and economic paradigms (Vonderembse et al.,1997; Zizic et al, 2022). The industrial automation has been developing for more than six decades. Since the appearance of the first industrial manipulator in the 1960s, robots have become one of the key drivers of modern production systems and industrial evolution (Dey & Sen, 2020).

For businesses robotics integration offers a compelling value proposition such as significant cost reduction, enhanced economic efficiency through accelerated production cycles, increased productivity, and improved product quality (Mahr et al., 2025). Furthermore, automation presents a strategic response to labor market challenges, potentially mitigating dependencies on human labor in the face of demographic shifts (Aghion et al., 2023). While this raises concerns about job displacement and unemployment, it simultaneously fosters the creation of new, high-skilled professions in engineering, programming, and robotics maintenance, thereby reshaping the labor market structure (Reshef & Toubal, 2024; Zubair, 2024).

Today, the global robotics market is rapidly expanding, and international competition in this field is growing, the leading countries in terms of industrial robot installations are China, Japan, the United States, South Korea, and Germany (Makedon et al., 2021; Keisner et al., 2016). At the same time, many developed economies are facing demographic challenges, primarily population ageing, which leads to shortages of labour resources and rising fiscal burdens (İnce Yenilmez, 2015; Christensen et al., 2009; Khan, 2019). This dual trend -technological progress and demographic decline - makes the study of robotics especially relevant.

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Japan (Wright, 2023; Adachi et al., 2024) and Germany (Deng et al., 2024) occupy unique positions in this context (Klump et al., 2021). Both countries are global leaders in robotics adoption, consistently ranking among the top five in robot density. At the same time, they are also among the fastest-ageing societies. In Japan, almost one-third of the population is over 65 years of age (Obi et al., 2013), while in Germany the share is above 23% (Bahnsen & Wimmesberger, 2023). This demographic phenomenon, characterized by a growing proportion of citizens aged 65 and older, is common among developed economies (Pham & Vo, 2021) and poses significant challenges, including a shrinking workforce, increased fiscal pressure on pension and healthcare systems, and potential constraints on economic growth.

Consequently, the integration of robotic systems is increasingly viewed as a critical strategy to counteract labor shortages and maintain high levels of industrial output (Llopis-Albert, et al., 2021; Westcott,2023). The experiences of Japan and Germany, representing distinct Asian and European contexts with different socio-political approaches to migration and industrial policy, offer valuable insights. Japan, with its historically restrictive immigration policies (Davison & Peng, 2021), and Germany, with a more open approach (Helbling et al., 2025), both heavily invest in robotics as a solution to a common demographic problem. This makes a comparative analysis particularly relevant for understanding different adaptive strategies.

This article examines the relationship between demographic change and the development of robotics markets in Japan and Germany during 2003–2023, with a forecast for 2024. The purpose of the study is to analyse how robotics can compensate for the shortage of labour resources caused by ageing and what risks and opportunities this creates for national economies.

To achieve this goal, the following tasks were addressed:

- Analysis of the main trends in the robotics industry.
- Examination of the demographic situation and labor market in Japan and Germany.
- Analysis of the global robotics market, including export-import operations.
- Development of econometric models to forecast the volume of industrial robot exports.

The research hypothesis is that there is a direct relationship between the process of population aging, the decline in the working-age population, and the intensity of robotics adoption as a tool for compensating for the labor shortage.

2 METHODS

The methodological framework integrates descriptive statistics, comparative analysis, and econometric modelling. The research proceeds in several stages:

1. Data collection. Quantitative data were obtained from the International Federation of Robotics (IFR) on the number of installed robots, robot density, and global market trends; from the International Trade Centre (ITC) on export and import flows of industrial robots; from the World Bank on demographic indicators (population size, fertility, age structure, labour force, unemployment); and from national sources on GDP, inflation, R&D expenditure, and exchange rates.
2. Comparative analysis. Trends in Japan and Germany were compared with global averages and with leading economies such as China, South Korea, and the USA. Special attention was paid to the interaction between demographic indicators and robotics adoption.
3. Econometric modelling. Multiple regression models were constructed for Japan and Germany to identify the factors influencing the export of industrial robots.

Table 1 lists the definitions of the variables used in the empirical procedure for Japan; Table 2 lists the definitions of the variables used in the empirical procedure for Germany.

Table 1: Description of variables for Japan.

Variable	Description
$\hat{Y}1$	Value of exports (billion USD)
$G1_i$	GDP (billion USD in constant 2015 prices)
$UN1_i$	Unemployment (% to total labor force)
$RD1_i$	R&D expenditure (% to GDP)
$I1_i$	Inflation, GDP deflator (annual %)
$RC1_i$	RC (100 yen to USD)

Source: compiled by the authors

Table 2: Description of variables for Germany.

Variable	Description
$\hat{Y}2$	Value of exports (billion USD)
$G2_i$	GDP (billion USD in constant 2015 prices)
$RD1_i$	R&D expenditure (% to GDP)
$UN2_i$	Unemployment (% to total labor force)
$RC2_i$	RC (1 euro to USD)

Source: compiled by the authors

Table 3 and Table 4 present the Pearson correlation coefficients for variables.

Table 3: Correlation matrix, Japan.

	$\hat{Y}1$	$UN1_i$	$RD1_i$	$I1_i$	$RC1_i$
$\hat{Y}1$	1				
$UN1_i$	-0,83	1			
$RD1_i$	0,83	-0,81	1		
$I1_i$	0,50	-0,55	0,35	1	
$RC1_i$	0,53	-0,68	0,61	0,74	1

Source: compiled by the authors

Table 4: Correlation matrix, Germany.

	$\hat{Y}2$	$UN2_i$	$RD2_i$	$I2_i$	$RC2_i$
$\hat{Y}2$	1				
$UN2_i$	-0,93	1			
$RD2_i$	0,70	-0,84	1		
$I2_i$	0,87	-0,97	0,88	1	
$RC2_i$	0,49	-0,55	0,62	0,56	1

Source: compiled by the authors

4. Forecasting. Based on the regression equations, forecast values of exports for 2024 were calculated using expected macroeconomic parameters.

The final estimated equation describing the dependence of industrial robot exports in Japan on the selected economic factors is

$$\hat{Y}1 = -11178328{,}34 + 23781{,}76 * RC1_i + 1719{,}8 * G1_i - 175569{,}63 * I1_i + 1258188{,}86 * RD1_i$$

The final estimated equation describing the dependence of industrial robot exports in Germany on the selected economic factors is $\widehat{Y2} = -186375{,}28 - 4470{,}87 * RC2_i + 402{,}14 * G2_i - 54674{,}04 * UN2_i$

5. Limitations. The research relies on secondary data sources, which may have reporting discrepancies. The forecast is short-term and does not account for possible shocks, such as geopolitical crises or technological breakthroughs, which could significantly alter the trajectory.

3 RESULTS

3.1 Demographic Situation and Labor Market

The analysis confirmed the acute nature of the population aging challenge in both Japan and Germany. This demographic shift, characterized by a steadily increasing share of elderly citizens, poses significant long-term economic and social challenges.

In Japan, the proportion of the population aged 65 and over rose markedly from 18.0% in 2003 to 28.47% in 2023, representing an increase of over 10 % in two decades (Fig. 1). The country reached its peak population of 128.07 million in 2010, followed by a decline to 124.52 million by 2023. This depopulation is compounded by a persistently low fertility rate, which remained at a critical low of 1.2 births per woman in 2023 (Okui, 2024), far below the replacement level.

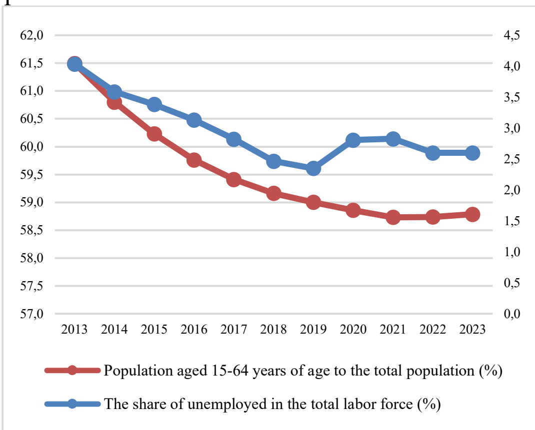

Figure 1: Proportion of population aged 65 + to the total population in Germany and Japan in the period 2003-2023, %

Source: compiled by the authors based on The World Bank Group

Germany exhibits a similar, though slightly less rapid, aging pattern. The share of the population over 65 increased from 17.44% to 22.51% during the same period (Fig. 1). Unlike Japan, Germany's total population saw a slight increase over the 20-year period, largely attributable to positive net migration, which has acted as a mitigating factor against more severe population decline (Gereke et al., 2022).

Data analysis reveals a consistent decline in the population aged 15-64 in both nations over the studied period (see Fig. 2 and Fig. 3). In Japan, this cohort shrunk by 12.31 million people between 2003 and 2023. A similar, though less steep, downward trend is observed in Germany.

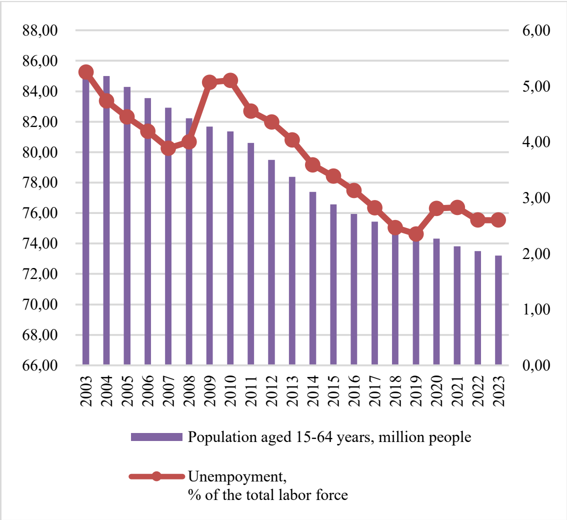

Figure 2: Population aged 15-64 in 2003-2023 (millions of people) and unemployment rate as a percentage of the total labour force in Japan in 2003-2023 (%).

Source: compiled by the authors based on The World Bank Group

Figure 3: Population aged 15-64 in 2003-2023 (millions of people) and unemployment rate as a percentage of the total labour force in German in 2003-2023 (%).

Source: compiled by the authors based on The World Bank Group

Both Japan and Germany are experiencing record-low unemployment rates, which stood at 2.6% and 3.07% respectively in 2023 (Fig. 2 and Fig.3). These figures are significantly below the commonly accepted natural rate of unemployment (4-5%), indicating a tight labor market where demand for workers substantially exceeds supply. This critical shortage of labor underscores one of the primary economic imperatives for automation and robotics adoption as a strategic response to demographic pressures.

3.2 Global Robotics Market and the Positions of Japan and Germany

The global robotics market demonstrates robust and sustained growth, driven by the increasing adoption of automation across various industries. In 2023, the market volume was estimated at $82.42 billion USD. A key indicator of this expansion is the number of industrial robot installations worldwide, which nearly tripled between 2013 and 2023, with an average annual growth rate of 12.62% (Fig. 4). This underscores the strategic importance assigned to robotics for enhancing productivity and maintaining competitive advantage.

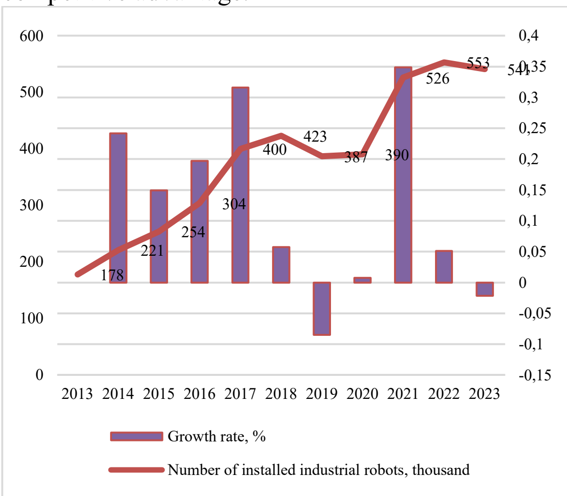

Figure 4: Dynamics of industrial robots' installation in production facilities worldwide in 2013-2023, thousands of units and growth rate, %.

Source: compiled by the authors based on IFR, International Federation of Robotics

Japan and Germany have established themselves as pivotal players in this global landscape. Their roles, however, exhibit distinct characteristics reflective of their industrial structures and historical development. An analysis of the global export structure for industrial robots in 2023 reveals Japan's dominant position as the world's leading exporter, accounting for 29.38% of the total export volume (Fig.5). Germany follows as the second-largest exporter, with a significant 10.84% share. Collectively, these two nations were responsible for approximately 40% of all industrial robots exported globally in 2023, highlighting their immense production capacity and technological leadership.

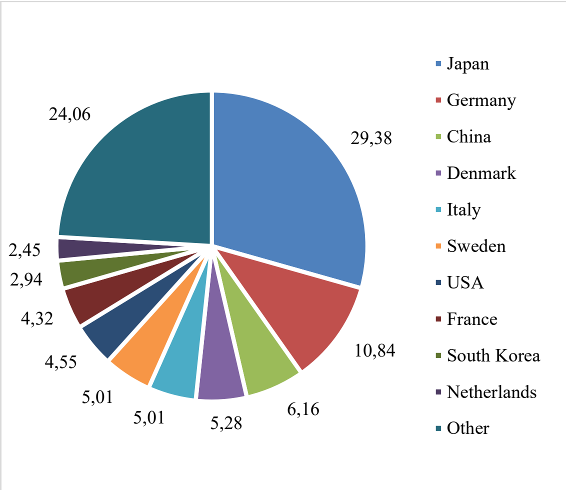

Figure 5: Share of countries in total industrial robot exports in 2023, %

Source: compiled by the authors based on International Trade Centre

A stark contrast emerges when examining import patterns. Japan's robotics industry is primarily oriented towards external markets, with minimal reliance on imports; the country ranked only 23rd globally as an importer in 2023, fulfilling domestic demand almost entirely through its own sophisticated manufacturing base. Conversely, Germany is also a major importer of industrial robots, holding the 3rd position globally with an 8.49% share of world imports (Fig. 6). This indicates a more integrated and potentially diverse market within Germany, where domestic production is supplemented by foreign technology to meet robust internal demand.

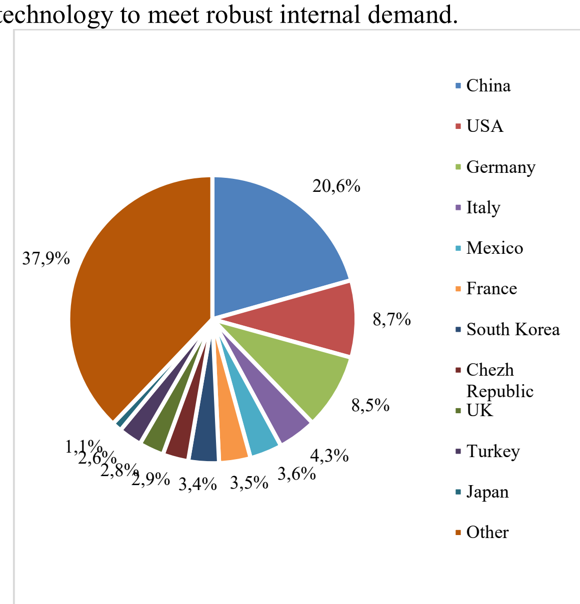

Figure 6: Share of countries in total industrial robot imports in 2023, %

Source: compiled by the authors based on International Trade Centre

The export dynamics for both countries over the 2003-2023 period show a clear positive trajectory, despite cyclical fluctuations (Fig. 7 and Fig. 8). Japan's exports grew at an average annual rate of 12.59%, while Germany's exports increased by 10.28% per year on average. Both economies experienced their most significant export contraction in 2009, a clear consequence of the global financial crisis that dampened investment worldwide. The recovery and subsequent growth in the following years underscore the resilience and long-term strategic importance of their robotics sectors.

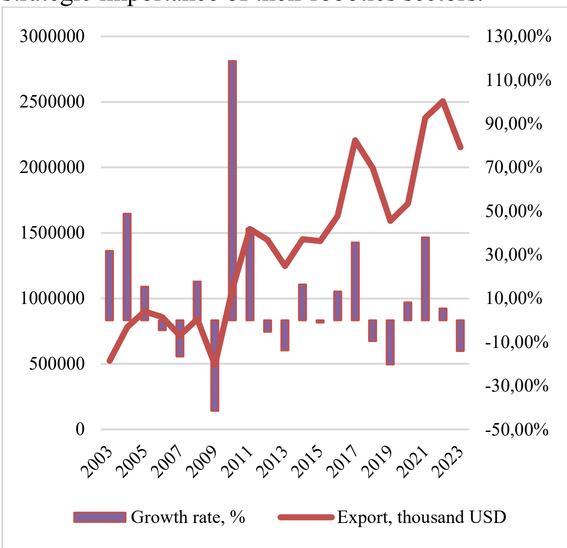

Figure 7: Industrial robot exports in Japan in the period 2003-2023, thousand dollars

Source: compiled by the authors based on International Trade Centre

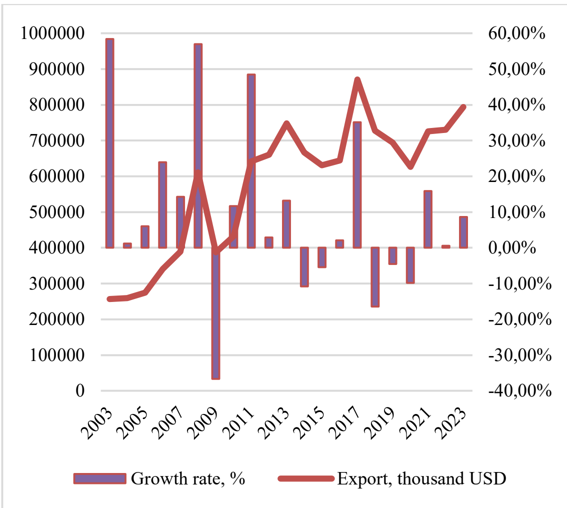

Figure 8: Industrial robot exports in Germany in the period 2003-2023, thousand dollars

Source: compiled by the authors based on International Trade Centre

3.3 Results of Econometric Modelling and Forecast

To quantitatively assess the future trajectory of industrial robot exports from Japan and Germany, econometric modeling was employed. The goal was to identify key macroeconomic drivers and build predictive models for export volumes in 2024. For Japan, a statistically significant multiple regression model was constructed. The model selection process began with a correlation analysis (Table 3), which revealed strong relationships between export value and several factors: the exchange rate of the Japanese Yen (JPY), real GDP, inflation (GDP deflator), and expenditure on Research & Development (R&D). The initial model included all these factors along with the unemployment rate, which showed a high negative correlation (-0.83). However, the unemployment rate was found to be statistically insignificant in the multivariate model and was subsequently excluded to enhance model accuracy.

This model is statistically significant at all conventional levels (F-statistic = 22.88; $p < 0.01$) and demonstrates high explanatory power, with an adjusted R^2 of 81.4%. This indicates that the selected independent variables explain over 81% of the variation in Japan's industrial robot exports over the 2003-2023 period. All included factors were statistically significant at least at the 10% level.

For Germany, a similarly robust model was developed. The correlation analysis (see Table 4) indicated that the most significant factors influencing German exports were the unemployment rate (showing a very high negative correlation of -0.93), real GDP, the exchange rate of the Euro (EUR), and R&D expenditure. Inflation was excluded from the initial model due to a weaker correlation (<0.50). The most robust and statistically significant model included real GDP, the EUR exchange rate, and the unemployment rate.

This model is also highly significant (F-statistic = 54.57; $p < 0.01$) and has an even higher explanatory power than the Japanese model, with an adjusted R^2 of 84.92%.

Using projected values for the independent variables in 2024 from sources like the World Bank, Statista, and Trading Economics, the models predict a decline in exports for both countries. Japan's export of industrial robots is forecasted to be 1,920,723.2 thousand USD, a decrease of 10.76% compared to 2023. Germany's exports are projected to fall to 648,769.08 thousand USD, a more substantial decline of 21.84% (Fig. 9)

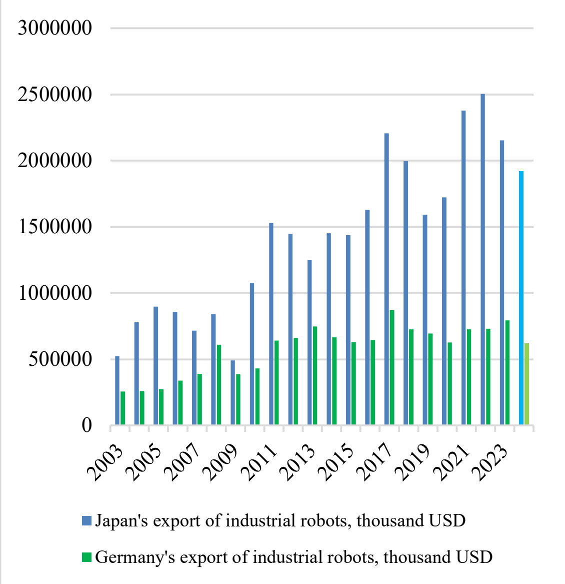

Figure 9: Industrial robot exports in Japan and Germany in the period 2003-2023, as well as their forecast value in 2024, in thousands of USD

Source: compiled by the authors based on NHK, Trading Economics, ,Statista

4 DISCUSSIONS

The results of this study confirm the central hypothesis that Japan and Germany, both facing significant population aging and a shrinking working-age population, are actively utilizing robotics as a key tool to compensate for labour shortages. This strategic response is clearly reflected in their leading global positions in both robot density (number of robots per 10,000 employees) and export volumes of industrial robots. The parallel trends of demographic contraction and robotics expansion in these two technologically advanced countries underscore automation as a critical adaptive strategy for mature economies.

The differing demographic policies between the two countries, Germany's more open migration model compared to Japan's historically restrictive approach, highlight that there is no single solution to demographic challenges. However, these differences do not negate the common strategic emphasis on robotization. This suggests that while migration can alleviate labor market pressures, automation is perceived as a fundamental, long-term component of industrial policy. It is crucial to recognize, however, that robotization is not a panacea. Its successful integration requires a comprehensive approach that includes substantial investments in education, workforce reskilling, and social support systems to manage the transition and ensure inclusive growth.

The constructed econometric models demonstrated high explanatory power, validating the selection of key macroeconomic factors as significant influencers of industrial robot exports. The identified strong inverse correlation between the unemployment rate and export volume provides indirect but compelling evidence for the core thesis: in conditions of labour scarcity, companies are incentivized to invest more heavily in automation to maintain production capacity and competitiveness.

The forecasted decline in exports for 2024, however, points to emerging challenges. This anticipated contraction can be attributed to a confluence of factors specific to each country and broader global trend. For Japan, the projected decrease is likely influenced by government plans to tighten controls on the export of critical technologies, including advanced robotics (Hayakawa et al., 2023). This policy shift, aimed at preventing the leakage of strategically important technology, could temporarily restrain export growth by adding regulatory complexity.

For Germany, the more pronounced forecasted decline stems from a distinct set of challenges. The German robotics industry faces intensifying competition from Asian manufacturers, particularly China, which is rapidly advancing its technological capabilities and competing on cost. Furthermore, the strong interdependence of the German robotics sector with the cyclical automotive industry makes it vulnerable to slowdowns in automotive production and shifts towards new mobility solutions. This necessitates a significant technological reorientation and diversification for German robotics firms (Lechowski & Krzywdzinski, 2022).

Broader macroeconomic factors also play a significant role. A general slowdown in global economic growth, persistent inflationary pressures increasing production costs, and ongoing geopolitical instability collectively contribute to an environment of reduced investment and caution, potentially delaying capital-intensive decisions such as the purchase and implementation of robotic systems.

A key limitation of this study is its primary focus on industrial robots. While crucial for manufacturing, the service robotics segment plays an increasingly vital role in addressing social tasks associated with an aging population, such as healthcare, logistics, and personal assistance. Future research should be directed towards a detailed analysis of this rapidly growing segment, as it may represent an even more direct response to the demographic challenges examined in this paper and could follow different market dynamics.

5 CONCLUSIONS

This study provides a comprehensive analysis that demonstrates a strong and compelling interrelationship between profound demographic challenges and the development of the robotics market in Japan and Germany. Confronted with the parallel trends of rapid population aging and a sustained contraction of their labour forces, both nations have strategically leveraged their long-standing history and expertise in automation. Robotics is not merely an industrial tool but a fundamental strategic response to secure economic resilience and maintain productive capacity in the face of demographic decline. This strategic prioritization is unequivocally confirmed by their dominant global positions in both the production and export of industrial robots.

The econometric analysis, while affirming the robustness of their export-oriented models, projects a potential short-term contraction in export volumes for 2024. This forecasted decline underscores the dynamic nature of the global market, influenced by a combination of internal policy shifts, such as stricter export controls in Japan, and external pressures, including intensifying international competition, particularly from Asian manufacturers, and sector-specific vulnerabilities in Germany. To navigate these challenges and preserve their competitive edge, it is imperative for both countries to sustain and amplify investments in research and development (R&D), foster proactive state-level support for the robotics industry, and facilitate the adaptation of business models to the rapidly evolving and increasingly competitive global landscape.

The experiences of Japan and Germany offer a critical and highly instructive case study for other developed economies that are projected to encounter analogous demographic pressures in the near future. Their journeys illustrate that the large-scale integration of robotic technologies is not a matter of choice but an inevitable and necessary component of economic adaptation to new demographic realities. The proactive embrace of robotization, coupled with supportive policies for workforce transition, emerges as a crucial strategy for sustaining economic growth and social stability in an aging world.

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REFERENCES

Adachi, D., Kawaguchi, D., Saito, Y. U., 2024. Robots and employment: Evidence from Japan, 1978–2017. *Journal of Labor Economics, 42(2),* 591-634.

Aghion, P., Antonin, C., Bunel, S., Jaravel, X., 2023. The effects of automation on labor demand. *Robots and AI*, 15-39.

Bahnsen, L., Wimmesberger, F. M., 2023. Curbing the demographic "drifting dune" in long-term care insurance financing: The case of Germany. *International Social Security Review*, *76*(1), 35-56.

Christensen, K., Doblhammer, G., Rau, R., Vaupel, J. W., 2009. Ageing populations: the challenges ahead. *The lancet*, *374*(9696), 1196-1208.

Deng, L., Plümpe, V., Stegmaier, J., 2024. Robot adoption at German plants. *Jahrbücher für Nationalökonomie und Statistik*, *244*(3), 201-235.

Dey, C., Sen, S. K., 2020. *Industrial automation technologies*. CRC Press.

Gereke, J., Hellyer, J., Behnert, J., Exner, S., Herbel, A., Jäger, F., Anh, V. N., 2022. Demographic change and group boundaries in Germany: The effect of projected demographic decline on perceptions of who has a migration background. Sociological Science, 9, 206-220.

Hayakawa, K., Ito, K., Fukao, K., Deseatnicov, I., 2023. The impact of the strengthening of export controls on Japanese exports of dual-use goods. *International Economics*, *174*, 160-179.

Helbling, M., Jäger, F., Maxwell, R., Traunmüller, R. (2025). Broad and detailed agreement: Public preferences for German immigration policy. *International Migration Review*, *59*(3), 1219-1232.

İnce Yenilmez, M., 2015. Economic and social consequences of population aging the dilemmas and opportunities in the twenty-first century. *Applied Research in Quality of Life*, *10*(4), 735-752.

Keisner, A., Raffo, J., Wunsch-Vincent, S., 2016. Robotics: Breakthrough technologies, innovation, intellectual property. *Форсайт*, *10*(2 (eng)), 7-27.

Khan, H. T., 2019. Population ageing in a globalized world: Risks and dilemmas? *Journal of evaluation in clinical practice*, *25*(5), 754-760.

Klump, R., Jurkat, A., Schneider, F., 2021. Tracking the rise of robots: A survey of the IFR database and its applications.

Lechowski, G., Krzywdzinski, M., 2022. Emerging positions of German firms in the industrial internet of things: A global technological ecosystem perspective. *Global Networks*, *22*(4), 666-683.

Llopis-Albert, C., Rubio, F., Valero, F., 2021. Modelling an industrial robot and its impact on productivity. *Mathematics*, *9*(7), 769.

Mahr, D., Odekerken-Schröder, G., Steins, M., 2025. Service robots and innovation: An ecosystem approach. *Journal of Product Innovation Management*, *42*(5), 874-896.

Makedon, V., Mykhailenko, O., Vazov, R., 2021. Dominants and Features of Growth of the World Market of Robotics. *European Journal of Management Issues*, *29*(3), 133-141.

Obi, T., Ishmatova, D., Iwasaki, N., 2013. Promoting ICT innovations for the ageing population in Japan. *International journal of medical informatics*, *82*(4), e47-e62.

Okui, T., 2024. The effect of educational attainment on birthrate in Japan: an analysis using the census and the vital statistics from 2000 to 2020. *BMC Pregnancy and Childbirth*, *24*(1), 198.

Pham, T. N., Vo, D. H., 2021. Aging population and economic growth in developing countries: a quantile regression approach. *Emerging Markets Finance and Trade*, *57*(1), 108-122.

Reshef, A., Toubal, F., 2024. Automation, techies, and labor market restructuring. In *Handbook on Labour Markets in Transition* (pp. 15-35). Edward Elgar Publishing.

Vonderembse, M. A., Raghunathan, T. S., Subba Rao, S., 1997. A post-industrial paradigm: to integrate and automate manufacturing. *International Journal of Production Research*, *35*(9), 2579-2600.

Westcott, J. R., 2023. Industrial automation and robotics.

Davison, J., Peng, I., 2021. Views on immigration in Japan: identities, interests, and pragmatic divergence. *Journal of Ethnic and Migration Studies*, *47*(11), 2578-2595.

Wright, J., 2023. *Robots won't save Japan: An ethnography of eldercare automation*. Cornell University Press.

Zizic, M. C., Mladineo, M., Gjeldum, N., Celent, L., 2022. From industry 4.0 towards industry 5.0: A review and analysis of paradigm shift for the people, organization and technology. *Energies*, *15*(14), 5221.

Zubair, S., 2024. AI-Driven Automation: Transforming Workplaces and Labor Markets. *Frontiers in Artificial Intelligence Research*, *1*(3), 373-411.