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The effects of robotization on public pension expenditures

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Masters in Economics and Public Policies

Supervisor:
PhD Ricardo Barradas,
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CIÊNCIAS SOCIAIS
E HUMANAS

Department of Political Economy

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Resumo

Este estudo avalia os efeitos da robotização na despesa pública com pensões na União Europeia. Utiliza um painel balanceado UE-27 (n=243 observações) e estimações por efeitos fixos mínimos quadrados em dois estágios com quatro desfasamentos internos como instrumentos. Comparámos um modelo de base composto pelo índice de dependência de idosos, taxa de desemprego, produtividade laboral, e índice de generosidade de pensões com um modelo que inclui interações entre a robotização e cada determinante. A robustez é verificada numa subamostra de 12 países com regimes públicos predominantemente de benefício definido. Os resultados mostram efeitos positivos e significativos da taxa de desemprego e índice de generosidade de pensões na despesa e um efeito negativo e significativo de produtividade laboral. O índice de dependência de idosos apresenta coeficiente negativo e significativo na amostra completa. A robotização não tem efeito direto, mas atua como moderador: produtividade laboral é positivo e o índice de generosidade é também positivo, sobretudo nos países com regimes públicos predominantemente de benefício definido. A robotização aumenta a pressão sobre a despesa com pensões, ao reduzir a capacidade da produtividade para a conter e ao amplificar o impacto de sistemas mais generosos, especialmente em regimes de benefício definido. A originalidade do estudo reside em tratar a robotização como moderador dos determinantes, usando dados recentes da UE-27 e distinguindo explicitamente os regimes públicos predominantemente de benefício definido.

Palavras-chave: Robotização; Despesa pública com pensões; União Europeia; Dados em painel.

Classificação JEL: H55, J11.

Abstract

This study assesses the effects of robotization on public pension expenditure across the EU. It uses a balanced panel EU-27 (n=243 observations) and two-stage least squares instrumenting with four internal lags as a fixed-effects instrument. We compare an interaction model adding robotization interactions of each of its determinants with a baseline model including the old-age dependency ratio, unemployment rate, labour productivity, and the benefit ratio. Robustness is checked in a subsample of 12 countries with predominantly defined benefit public schemes. Our results show positive and statistically significant effects of unemployment rate and benefit ratio on spending, and negative and statistically significant labour productivity. Old-age dependency ratio has negative coefficient significant across full sample. Robotization does not exhibit stable direct but moderating effect, the labour productivity is positive, and benefit Ratio is also positive, specifically for defined benefit countries. Robotization increases pressure on pension expenditure by reducing productivity's ability to contain it and by amplifying the impact of more generous systems, especially in defined benefit schemes. The study's originality lies in treating robotization as a moderator of determinants, using recent EU-27 data and specifically separate defined benefit systems.

Keywords: Robotization; Public Pension Expenditure; European Union, Panel data.

JEL Classification: H55, J11.

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Glossary

2SLS - Two-Stage Least Squares

BR – Benefit ratio

DB – Defined benefit

EU – European Union

GDP – Gross domestic product

ICT - Information and Communication Technologies

IFR – International Federation of Robotics

LP – Labour productivity

OAD – Old-age dependency ratio

OECD - Organization for Economic Co-operation and Development

PE – Pension expenditure

RB – Robotization

UR – Unemployment rate

VECM - Vector Error Correction Model

1. Introduction

The sustainability of public pension systems in the European Union has been increasingly challenged by demographic and economic transformations. Population ageing, labour-market productivity fluctuations, and labour-market shocks place pension expenditure on an increasing trajectory and demand policy actions. At the same time, robotization push is redesigning the work organisation structure but transmission channels of such technological forces impacting public pension expenditure remain poorly understood. This gap motivates examining the effects of robotization through the traditional determinants of pension expenditure.

Our objective is to assess the effects of robotization on the usual drivers UR, LP, OAD and BR affect public pension spending. We contribute by modelling robotization through interactions ($RB \times UR$, $RB \times LP$, $RB \times OAD$, $RB \times BR$) using a recent balanced EU-27 panel (2016–2024) and comparing a subsample of defined benefit countries to capture institutional differences.

We focus on six research questions: (i) what is the impact of robotization on public pension expenditure? (ii) how does robotization interacts with the unemployment rate on public pension expenditure?; (iii) how does robotization interacts with the labour productivity on public pension expenditure; (iv) how does robotization interacts with the old-age dependency ratio on public pension expenditure; (v) how does robotization interacts with the benefit ratio on public pension expenditure?; and (vi) do these effects differ in countries with predominantly public defined benefit schemes?

Methodologically, we assemble a balanced panel covering all EU-27 countries from 2016 to 2024 ($n=243$ observations). We estimate fixed-effects two-stage least squares (FE-2SLS) models to address unobserved heterogeneity and potential endogeneity, using four internal lags as instruments. We compare a baseline model, including the old-age dependency ratio, unemployment rate, labour productivity and the benefit ratio, with an interaction model that augments the baseline by introducing robotization as a moderator through $RB \times OAD$, $RB \times UR$, $RB \times LP$, and $RB \times BR$. To probe institutional heterogeneity and strengthen internal validity, we conduct a robustness exercise on a subsample of 12 countries with predominantly defined benefit public pension schemes.

The main results show that UR and BR have positive and significant effects on expenditure, while LP has a negative and significant effect. OAD exhibits a negative and significant coefficient in the full sample. Robotization effect on pensions is indirect, it weakens productivity and strengthens generosity, especially in DB systems.

The following section presents the theoretical framework and literature review. Section 3 describes the data used for our estimations. Section 4 outlines the econometric methodology used. Section 5 presents the results and discussion of our estimations. Finally, the section 6 outlines our conclusions, policy implications, limitations and approaches for future research.

2. Literature Review

In European countries, demographic and economic transformations have been occurring, putting the sustainability of pension systems at risk and generating significant impacts on public finances and poverty levels (Lagoa & Barradas, 2019). Pension systems in Europe face structural challenges that compromise their long-term viability, especially the ones supported by pay-as-you-go schemes. One of the main factors is population ageing, a phenomenon characteristic of developed societies (Lagoa & Barradas, 2022). This scenario results, on the one hand, from the increase in life expectancy, driven by medical advances and improved living conditions. On the other hand, the decline in birth rates reflects social and cultural changes that contribute to this challenge.

Recent studies show that demographic pressures can lead to an increase in public pension expenditures. (Martín & Ramos, 2023).

One of the more comprehensively analysed determinants of pension spending is population ageing, which impacts the ratio between the contributors and the beneficiaries.

As pointed out by Carone *et al.* (2005), population ageing in the European Union exerts significant pressure on social security systems, particularly in the domain of pensions. The increase in the old-age dependency ratio, combined with a stagnating workforce, creates an imbalance between contributions and benefits, jeopardising the viability of pension systems. Ciobanu *et al.* (2014) supports this perspective, stating that, in the coming decades, demographic ageing will continue to be a source of pressure on public expenditures, including those related to pensions.

This dynamic reduces contributions while increasing expenditures, placing additional pressure on public budgets. These concerns have prompted the emergence of several empirical studies aiming to analyse the impact of ageing on pension expenditure.

Salomaki (2006) highlights that population ageing is the main factor putting pressure on pension expenditure, driven by increasing life expectancy and declining birth rates. Projections indicate that, without structural reforms, pension spending will rise significantly by 2050. Factors such as the employment rate, the benefit ratio (the relationship between average pensions and average wages), and productivity growth can either mitigate or intensify this impact.

Verbič and Spruk (2014) analyse the impact of population ageing on the sustainability of public pension expenditures by applying an Instrumental Variable-Two-Stage Least Squares model to a panel of 33 countries, mostly European. The results indicate that population ageing puts pressure on public spending, but that human capital accumulation can mitigate part of this

impact by promoting higher productivity levels and an adjusted demographic balance. However, the study also highlights that, without structural reforms, the sustainability of pension systems may be compromised due to the reduction in the active workforce and the increasing financial burden on taxpayers.

Even with potential mitigating factors, the literature generally agrees that population ageing is a serious challenge to the long-term financial sustainability of pension systems. On its own, it's enough to create significant upward pressure on pension expenditures.

In addition to demographic trends, labour market factors such as unemployment and productivity also play a crucial role in the sustainability of pension systems.

Lagoa & Barradas (2022) identify unemployment as a key element in the future of pension systems, an idea reinforced by Garcia & Da Silva (2023), who highlight the direct impact of unemployment on pension-related expenditure. The latter study explores the relationship between demographic and economic variables, namely population ageing, labour productivity, and unemployment, and their impact on the financial sustainability of the Portuguese pension system. For this analysis, the authors use time-series data covering the period from 1975 to 2014, applying econometric methods to identify the effects of these variables on pension expenditure. The results reveal that population ageing has a limited impact on pension expenditure in the long run, whereas unemployment and labour productivity are the main determining factors. This counter-intuitive result may reflect the maturity of the Portuguese pension system and the adoption of structural adjustments in the last few years that mitigate demographic pressures. In contrast, unemployment and productivity fluctuations have a more immediate effect on contributions and pension claims, making them more influential in shaping expenditure dynamics. Thus, the authors argue that public policies focused exclusively on ageing may not be effective in ensuring the sustainability of the pension system, suggesting that strategies aimed at increasing productivity and reducing unemployment would have a more significant effect in curbing the growth of public pension expenditure.

The literature tends to agree on the challenges faced by the European Union regarding the public pension system and acknowledges that the identified determinants, such as unemployment, labour productivity, and ageing, are very important and have a significant impact on public expenditure on the pension systems.

Another critical variable influencing pension expenditure is the benefit ratio, which reflects the generosity of the pension system relative to average earnings.

The benefit ratio is defined as the average pension relative to the average wage. It reflects the generosity of the pension system and is influenced by pension indexation rules, retirement age, and reforms affecting pension calculation (European Commission, 2009).

Bongaarts (2004) shows that countries with higher benefit ratios often also have a greater number of retirees per worker, partly because generous pension systems encourage early retirement. His projections suggest that without policy reforms, ageing population will lead to unsustainable increases in pension costs. The study concludes that a mix of policy responses, including adjustments to retirement age, benefit levels, and demographic measures will be necessary to ensure long-term sustainability.

Martin & Ramos (2023) define the benefit ratio as the average benefit, calculated as pension expenditure divided by the number of pensioners. The study shows a positive correlation between the benefit ratio and the level of public pension expenditure (as a percentage of GDP). Countries with higher benefit ratios, such as France, Italy, or Portugal, tend to have higher levels of pension spending, whereas those with lower values such as Ireland, Lithuania, or Latvia, bear a lower financial burden. The study uses this metric to demonstrate that a significant part of the variation in pension expenditure across countries can be explained by the average generosity of pensions relative to wages, that is, by the level of the benefit ratio.

Along with the challenges already mentioned, Lagoa & Barradas (2019) identify technological development as a factor that threatens the financial sustainability of the European pension systems. Acemoglu & Restrepo (2019) explain that technological development can replace routine jobs. Replacing jobs can reduce the number of active contributors to pension systems consequently threatens the financial sustainability of the European pension system.

In this regard, as highlighted in the literature, robotization has become increasingly relevant in developed economies, with the potential to reshape labour markets and productivity dynamics (Graetz & Michaels, 2018; Acemoglu & Restrepo, 2019). In general, periods of increased automation are often associated with notable shifts in labour dynamics due to greater use of industrial robots and automated technologies (Graetz & Michaels, 2018). The advancement of robotics technology accelerated throughout the 1990s and 2000s, resulting in a fourfold increase in the number of industrial robots in the United States and Western Europe between 1993 and 2007 (Acemoglu & Restrepo, 2020).

Automation refers to the adoption and implementation of innovative technologies that enable the replacement of human labour with capital in various activities. This process generates a displacement effect, negatively altering the nature of tasks as capital takes over functions previously performed by workers (Acemoglu & Restrepo, 2019).

According to the International Federation of Robotics (IFR), based on ISO 8373:2021, that revokes ISO 8373:2012, a robot is defined as a programmed actuated mechanism with a degree of autonomy to perform locomotion, manipulation or positioning. A robot can include the control system, and examples of mechanical structure of robots are manipulator, mobile platform and wearable robot. Accordingly, an industrial robot is defined as a automatically controlled, reprogrammable multipurpose manipulator, programmable in three or more axes, which can be either fixed in place or fixed to a mobile platform for use in automation applications in an industrial environment.

Thus, robotization refers to the process of introducing robots into activities, processes, or functions previously performed by workers and is therefore considered a subcategory of automation.

According to the “World Robotics 2023” (IFR, 2023), it was reported a record of 553,052 industrial robot installations in factories around the world, a growth rate of 5% in 2022, year-on-year. In 2023 the industrial robot market it was expected to grow by 7% to more than 590,000 units worldwide.

Among the most discussed effects of robotization is its potential impact on unemployment, one of the main determinants of public pension expenditure.

Klenert *et al.* (2023) analyse the impact of robot adoption on employment in Europe between 1995 and 2017. Using sectoral data and robust econometric techniques, the authors conclude that robotization is associated with an increase in total employment and does not reduce the share of low-skilled workers. Autor (2015) argues that robotization can also create new employment opportunities in more specialised and innovative fields.

Clements *et al.* (2015) warn that, in economies with lower productivity levels, the gains achieved through automation may be insufficient to alleviate the financial pressures of an ageing population. Dauth *et al.* (2021), when examining Germany between 1994 and 2014, found that, in the cases analysed, the introduction of each new robot led to the elimination of two jobs. In other study, Acemoglu & Restrepo (2020) observed a decline in wages and employment rates in the areas most affected by robotization.

The literature remains divided on the employment effects of robotization. Some studies have found that robotization can lead to overall job growth, particularly in roles that require more advanced skills (Klenert *et al.*, 2023; Autor, 2015), but others highlight significant displacement and wage depression, particularly in sectors reliant on routine labour (Dauth *et al.*, 2021; Acemoglu & Restrepo, 2020).

Labour productivity is frequently cited as a key factor in the sustainability of pension systems, with recent discussions highlighting how robotization may influence productivity dynamics across different sectors.

One of the key factors driving companies to adopt robots is their efficiency in enhancing productivity and, consequently, increasing output. Robots are generally capable of operating continuously, performing tasks all day long. (De Backer *et al.*, 2018). Emerging technologies have the potential to enhance competitiveness, as they generally lead to greater productivity. By reducing costs and prices, firms may experience increased demand for their products, which in turn can drive a higher need for labour, partially offsetting the job-reducing impact of technological advancements. (Arntz *et al.*, 2016)

Recent studies, such as Koch *et al.* (2019) analyse robot adoption in Spanish manufacturing firms (1990–2016) and find that larger, more productive firms are more likely to adopt robots, while those with a higher share of skilled labour tend to avoid them. Adoption increases productivity by up to 25%, reduces labour costs, and leads to net employment growth. However, non-adopting firms lose jobs and market share, underlining the need for policies that support technological transition and workforce upskilling.

However, Graetz & Michaels (2018) show that, despite technological advances, the impact of robotization on productivity does not always translate into significant improvements in public finances, especially in countries with structural limitations. In the context of robotization, the authors suggest that, despite technological advantages, productivity gains do not always result in direct improvements in public finances, particularly in economies facing structural challenges. Similarly, Acemoglu & Restrepo (2017) demonstrate that automation tends to replace jobs in sectors reliant on routine labour.

Although the literature often treats robotization and population ageing as separate issues, Lagoa & Barradas (2022) note that rising life expectancy in developed countries is driven by advances in medicine and improved living conditions, both closely linked to technological progress. Similarly, Bayar *et al.* (2024) demonstrate that information and communication technologies (ICT) usage significantly influences life expectancy in emerging economies, and that this relationship can be both bidirectional and asymmetric. This highlights the need to consider robotization and population ageing together, rather than separate challenges.

The growing of robotization may influence several determinants of pension expenditure as suggested by the existing literature. These changes could have implications for the evolution of the benefit ratio.

While the existing literature emphasises the central role of the benefit ratio in determining pension expenditure, the potential effects of robotization on this indicator remain underexplored. Aisa *et al.* (2023) highlight that automation may significantly reshape labour force composition, particularly among older workers, by encouraging early retirement among low-skilled individuals and extending the working lives of high-skilled ones. These shifts in employment structure, driven by automation, may directly affect the evolution of both wages and pensions, thereby influencing the benefit ratio itself.

The reviewed literature reveals that public pension systems in the European Union face significant pressures, mainly stemming from population ageing, unemployment, labour productivity trends, and the generosity of benefits (benefit ratio). These factors interact in complex ways, influencing both contribution revenues and expenditure levels. While there is broad consensus on the structural challenges to sustainability, there is less agreement regarding the magnitude and nature of each determinant's impact, particularly concerning the potential indirect role caused by robotization.

Robotization has been identified, on the one hand, as a catalyst for productivity gains and job creation in innovative sectors, and on the other, as a driver of labour substitution and unemployment. These tensions generate some effects on pension systems, whose financial sustainability depends on employment and the size of the contributory base. Notably, the literature still lacks studies that link robotization to key determinants of public pension expenditures.

The present study aims to address this gap by examining the effects of robotization on public pension expenditure in the EU, through its interaction with four critical determinants: unemployment, labour productivity, the old-age dependency ratio, and the benefit ratio. This approach will contribute to a better understanding of the mechanisms through which technological change may affect the long-term financial sustainability of pension systems.

3. Data

Our dataset comprises annual data for all the 27 EU countries over the 2016–2024 period, resulting in a balanced panel of 243 country–year observations with no missing values. All series are released on a yearly basis, and data were collected in June 2025. This corresponds to the period and the periodicity for which all data were available.

We now describe the units and sources for all the variables. The robotization is given by the total number of industrial and service robots in EU divided by the nominal Gross domestic product (GDP) per country, which was collected from the Statista database and Eurostat database, respectively.

Pension expenditure is measured as the total public spending on pensions, expressed as a percentage of GDP. This variable was collected directly from the Eurostat database.

Real labour productivity per hour worked is defined as real GDP at constant prices divided by total hours worked by employees and the self-employed. This variable was collected directly from the Eurostat database.

Unemployment rate is defined as the percentage of the labour force (aged 15–74) that is without work, available for work, and actively seeking employment. This variable was collected directly from the Eurostat database.

Old-age dependency ratio is defined as the number of individuals aged 65 and over relative to those aged 15–64, expressed as a percentage. This variable was collected directly from the Eurostat database.

Benefit ratio is proxied by the aggregate replacement ratio, defined as the gross median pension income of individuals aged 65–74 relative to the gross median earnings of those aged 55–64. It reflects the average generosity of public pensions. This variable was collected directly from the Eurostat database.

Table 1 presents the period and observations for the all the EU countries, Figure 1 presents the plots for all the variables, Table 2 presents the units and sources for all the variables, Table 3 presents the descriptive statistics for each variable and Table 4 presents the correlations between all the variables.

Table 1 - The structure and composition

Country	Period	Observations
Austria	2016-2024	9
Belgium	2016-2024	9
Bulgaria	2016-2024	9
Croatia	2016-2024	9
Cyprus	2016-2024	9
Czechia	2016-2024	9
Denmark	2016-2024	9
Estonia	2016-2024	9
Finland	2016-2024	9
France	2016-2024	9
Germany	2016-2024	9
Greece	2016-2024	9
Hungary	2016-2024	9
Ireland	2016-2024	9
Italy	2016-2024	9
Latvia	2016-2024	9
Lithuania	2016-2024	9
Luxembourg	2016-2024	9
Malta	2016-2024	9
Netherlands	2016-2024	9
Poland	2016-2024	9
Portugal	2016-2024	9
Romania	2016-2024	9
Slovakia	2016-2024	9
Slovenia	2016-2024	9
Spain	2016-2024	9
Sweden	2016-2024	9

Table 2 - Variables and sources

Variable	Description	Source
RB	Volume of Industrial and Service Robots divided by nominal GDP	Statista/Eurostat
PE	Public Pension Expenditure (% of GDP)	Eurostat
BR	Benefit Ratio (Aggregate replacement ratio)	Eurostat
UR	Unemployment Rate (% of total labour force)	Eurostat
OAD	Old age dependency ratio	Eurostat
LP	Real Labour Productivity per hour worked	Eurostat

Table 3 - The descriptive statistics for each variable

Variable	Mean	Median	Maximum	Minimum	Standard Deviation	Skewness	Kurtosis
RB	0.884	0.227	13.927	0.006	2.197	4.425	22.999
PE	0.105	0.102	0.176	0.037	0.031	0.177	2.232
BR	0.547	0.530	1.040	0.350	0.127	0.838	3.642
UR	0.068	0.062	0.239	0.020	0.034	2.067	8.831
OAD	0.303	0.308	0.384	0.202	0.043	-0.474	2.834
LP	0.012	0.009	0.183	-0.071	0.029	1.159	8.614

Table 4 - The correlations between all the variables

Variable	RB	PE	BR	UR	OAD	LP
RB	1.000					
PE	0.343***	1.000				
BR	0.257***	0.501***	1.000			
UR	0.154**	0.478***	0.346***	1.000		
OAD	0.239***	0.468***	-0.056	0.128**	1.000	
LP	-0.079	0.243***	-0.160**	-0.098	-0.115*	1.000

Note: *** indicates statistically significance at 1% level, ** indicates statistically significance at 5% level and * indicates statistically significance at 10% level

Figure A1 in the Appendix displays the plots for all variables. Table 3 presents the descriptive statistics for the variables included in the analysis. From Table 4, we see that most pairwise correlations are statistically significant. The descriptive analysis and correlation matrix offers preliminary evidence in support of the theoretical relationships proposed. The results provide justification for proceeding with the panel data estimation. Since all correlations lie below 0.8, there is no indication of severe multicollinearity among our variables in our model.

4. Methodology

The existing literature shows that most of the research on pension expenditure relies on panel data analysis (Bongaarts, 2004; Salomäki, 2006; Ciobanu, 2014; Verbič & Spruk, 2014; Martín & Ramos, 2023). Garcia & Da Silva (2023) examine the determinants of public pension expenditure in Portugal, using a VECM to assess the long-run roles of unemployment, labour productivity, and population ageing.

Our econometric method involves the estimation of a fixed effects two stage least squares model to address unobserved country heterogeneity and potential endogeneity, following Greene (2017) and Wooldridge (2019). All specifications include country fixed effects. We treat all the regressors and, when included the interaction terms, as potentially endogenous and instrument them with their own lags. We fix the lag length at four annual lags. We confirmed the validity of the instrumental variables using the Sargan test, which checks the over-identifying restrictions within a given statistical model (Sargan, 1958; 1975).

The baseline specification relates pension expenditure to the old-age dependency ratio, labour productivity, unemployment and the benefit ratio allowing us to compare our results with the main empirical findings in the literature. The interaction specification augments the baseline model by including $RB \times OAD$, $RB \times LP$, $RB \times UR$ and $RB \times BR$, to test whether robotization moderates each determinant. Robustness is assessed by re-estimating the baseline comprising only countries with predominantly defined benefit public pension schemes, according to the OECD (2023). Limiting the analysis to DB countries such as Austria, Belgium, Czechia, Finland, France, Greece, Hungary, Italy, Luxembourg, Portugal, Slovenia and Spain, reduces institutional heterogeneity, strengthens internal validity, and clarifies the interpretation of RB interaction effects.

The results for our work were obtained by using the STATA 18 software with the command `xtivreg2`.

5. Results

Our estimates are presented and discussed throughout this Section. This dissertation examined the effects of robotization on public pension expenditure in European Union countries.

Table 5 - Estimates of the four models

Variable	Model 1 (Baseline)	Model 2 (+ interactions)	Model 3 (subsample)	Model 4 (subsample + interactions)
OAD	-0.403*** (0.068) [-5.97]	-0.381*** (0.063) [-6.01]	-0.399*** (0.085) [-4.70]	-0.402*** (0.071) [-5.69]
RB x OAD	-	-0.352 (0.025) [-1.44]	-	-0.043** (0.022) [-1.91]
LP	-0.478*** (0.017) [-2.75]	-0.080*** (0.020) [-4.07]	0.047 (0.042) [1.12]	-0.025 (0.031) [-0.81]
RB x LP	-	0.027*** (0.008) [3.44]	-	0.032*** (0.008) [3.86]
UR	0.365*** (0.060) [6.03]	0.353*** (0.058) [6.09]	0.367*** (0.516) [7.12]	0.386*** (0.046) [8.42]
RB x UR	-	0.013 (0.023) [0.57]	-	0.021 (0.20) [1.06]
BR	0.358** (0.015) [2.43]	0.023* (0.013) [1.78]	0.001 (0.012) [0.07]	0.005 (0.009) [0.58]
RB x BR	-	0.020* (0.012) [1.68]	-	0.028** (0.012) [2.40]
Observations	135	135	60	60
Years	9	9	9	9
Countries	27	27	12	12
Sargan Test (<i>p</i> - <i>value</i>)	0.4828	0.2145	0.2281	0.1813
<i>R</i> -Squared	0.5593	0.5905	0.7576	0.8240
Adjusted <i>R</i> - Squared	.428	.447	0.670	0.734

Note: Standard errors are in parentheses, and *z* statistics in square brackets. ***Statistical significance at the 1% level. **Statistical significance at the 5% level. *Statistical significance at the 10% level.

This dissertation estimated a series of econometric models to assess the effects of robotization on public pension expenditures (PE) in all the European Union, focusing both on the traditional determinants, the unemployment rate (UR), labour productivity (LP), the old-age dependency ratio (OAD), and the benefit ratio (BR) and on whether robotization alters the influence of these variables. Using a balanced panel of 27 EU countries from 2016 to 2024, we applied fixed-effects two-stage least squares models (FE-2SLS), with internal instruments (four lags) and interaction terms.

In the first model, the baseline one, we examined the impact of the four key determinants on PE without introducing robotization. Unemployment exerts a positive and statistically significant effect on public pension expenditure, consistent with labour-market pressures raising spending (Garcia & Da Silva, 2023). Likewise, the benefit ratio also shows a positive and statistically significant effect, indicating that more generous systems are associated with higher pension spending (Salomäki, 2006; Martín & Ramos, 2023). Labour productivity exhibits a negative and significant effect, consistent with the idea that more productive economies generate higher output with lower contribution pressure (Verbič & Spruk, 2014) while Garcia & Da Silva (2023) suggest that labour productivity has a more immediate and significant effect on pension expenditure than demographic ageing itself. Notably, the old-age dependency ratio, however, shows a negative and significant coefficient, which is a relatively counterintuitive result. Although this contradicts much of the literature (Carone et al., 2005; Ciobanu et al., 2014), it aligns with findings from Garcia & Da Silva (2023) for Portugal and may reflect recent structural reforms such as increases in the retirement age or changes in eligibility rules that have reduced the sensitivity of pension systems to demographic pressures.

The second model extended the analysis by including interaction terms to test whether robotization moderates the effect of each determinant on public pensions spending. The baseline results remained robust, with UR and BR retaining their positive effects, and LP and OAD continuing to show negative and significant coefficients. Importantly, the interaction between robotization and labour productivity (RB x LP) is positive and statistically significant, suggesting that the cost-reducing effect of productivity weakens as economies become more automated. This finding supports the arguments of Graetz & Michaels (2018), who caution that productivity gains from automation do not necessarily translate into improved public finances. This result is also consistent with Acemoglu and Restrepo (2017; 2020), who show that automation reallocates tasks and substitutes routine labour, reshaping employment and wage dynamics. The positive and significant interaction between robotization and the benefit ratio indicates that generous pension systems face heightened fiscal pressure in more automated

economies. This aligns with Aisa et al. (2023), who note that automation alters labour force composition and may indirectly increase average pension benefits. Combined with findings by Martin & Ramos (2023) on the fiscal weight of benefit generosity, this suggests that robotization exacerbates the expenditure implications of generous public pension schemes. The remaining interaction terms (with UR and OAD) are not statistically significant in this specification.

To assess the robustness of the findings and explore institutional heterogeneity, we re-estimated the models on a subsample of 12 EU countries with public pension systems based on defined benefit (DB) schemes, as classified by the OECD (2023). This subsample is not only useful for robustness purposes but is also theoretically relevant, as DB systems involve a commitment by the state to pay a predetermined pension benefit, regardless of future economic conditions or demographic changes. Such systems are inherently more rigid and fiscally vulnerable, since public pension expenditures tend to be more structurally pressured in these contexts. As a result, the impact of the usual determinants, as well as the way robotization interacts with them, may differ in countries where pension obligations are more fixed and less adaptable to changes in the economic environment.

In Model 3, which replicates the baseline specification for the subsample of 12 EU countries with defined benefit (DB) pension systems, unemployment (UR) and the old-age dependency ratio (OAD) maintain their statistical significance and expected signs, reinforcing their structural importance in shaping public pension expenditure. However, labour productivity and the benefit ratio lose statistical significance in this subsample. This suggests that, in systems where public pensions are primarily funded through DB schemes, broader macroeconomic and demographic variables may play a more decisive role than system-level parameters such as productivity or generosity.

Although the OAD coefficient remains negative and significant, its magnitude is smaller than in the full sample baseline model (Model 1). This could indicate that, despite demographic ageing, these 12 countries have implemented more effective or aggressive pension reforms, such as raising the retirement age or tightening eligibility, thereby mitigating the direct fiscal impact of ageing. This interpretation aligns with findings from Garcia & Da Silva (2023), who highlight how structural reforms can attenuate the link between demographic ageing and pension expenditure, particularly by reducing system sensitivity to increases in the old-age dependency ratio.

Conversely, the coefficient on the unemployment rate is higher in the DB subsample, reinforcing the idea that rigid benefit commitments render these systems more vulnerable to

labour market shocks. Labour productivity and the benefit ratio, in turn, lose statistical significance, which is consistent with the institutional nature of DB systems, where pension formulas are fixed and less sensitive to economic conditions.

Finally, Model 4 applies the interaction specification to the same DB subsample. The results reinforce the previous patterns. The interaction between robotization and productivity remains positive and highly significant, again indicating that the fiscal benefits of productivity improvements are diminished in more automated contexts. In addition, the interaction between robotization and the benefit ratio is also positive and significant, implying that the fiscal burden of generous pensions is amplified under high automation. While the interaction between robotization and OAD is only marginally significant, as noted by Bayar et al. (2024), technological change, especially in ICT, can affect life expectancy and ageing patterns, which may indirectly influence the fiscal burden of pensions, the loss of statistical significance for the interaction between robotization and unemployment may reflect the institutional rigidity of DB systems, where pension formulas are less responsive to short-term labour market fluctuations. Additionally, Garcia & Da Silva (2023) highlight that unemployment remains a key driver of pension expenditure, whereas structural adjustments primarily attenuate the ageing–expenditure link.

Across all models, the results consistently show that robotization exerts an indirect effect on public pension expenditure. It modifies the strength and direction of the traditional determinants, particularly labour productivity and the benefit ratio. This conclusion is in line with emerging theoretical and empirical research that views technological change not as an isolated fiscal driver, but as a structural force that reconfigures the institutional and economic mechanisms (Graetz & Michaels, 2018; Acemoglu & Restrepo, 2020).

6. Conclusion

This study examined the determinants of public pension expenditure (PE) in all the EU-27 countries over 2016–2024 and assessed whether robotization alters the transmission of those determinants. FE-2SLS indicate that Unemployment rate and Benefit ratio exert a positive and statistically significant effect on PE, whilst labour productivity has a negative and significant effect, consistent with the idea that more productive economies contain pension spending as a share of GDP. Contrary to conventional expectations, the old-age dependency ratio displays a negative and significant coefficient in the full sample.

Introducing interactions with robotization, shows that robotization does not have a stable direct effect on pension expenditure, but moderates it. The $RB \times LP$ interaction is positive and significant, implying that the expenditure-reducing role of productivity weakens as robotization intensifies. In the subsample of countries with predominantly defined benefit schemes, $RB \times BR$ is positive and significant, meaning that generous systems cost even more in more robotized economies. Interactions with UR and OAD are not consistently robust.

In sum, Robotization effect on pensions is indirect, it weakens productivity and strengthens generosity, especially in DB systems.

These findings have important policy implications. Since robotization appears to weaken the cost-containment effects of productivity and amplify the fiscal burden of pension generosity, particularly in defined benefit systems, policymakers may need to re-evaluate the design and adaptability of pension schemes considering ongoing technological change. Measures such as gradually increasing the statutory retirement age, indexing benefits more strictly to economic performance can help mitigate future spending pressures.

Nonetheless, this study has limitations. The time span is relatively short (2016–2024), which may limit the capture of long-term demographic or technological effects.

Future research could extend the time frame and case studies on DB systems could also clarify how fixed pension commitments interact with technological change over time.

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Appendix

Figure A1. Plots for all the variables (unweighted mean for all the countries)



