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WILL EU BE LESS PRODUCTIVE IN THE TIMES OF AGING POPULATION?

Valdas ANDRIULIS, Mindaugas BUTKUS, Kristina MATUZEVIČIŪTĖ[1]

Vilnius University, Šiauliai Academy, Institute of Regional Development, Vytautas str. 84, Šiauliai, Lithuania

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Abstract. *The paper aims to evaluate the impact of aging labour force on productivity, measured as a GDP per person employed and total factor productivity (TFP), in the European Union (EU) countries based on models developed by Calvo-Sotomayor et al. (2019), Poplawski-Ribeiro (2020), Feyrer (2008), and Aiyar and Ebeke (2016). We combine different research methods to address previous criticism and use the most recent data to compare our results with previous trends and draw conclusions about the impact of an aging labour force on productivity. Measuring productivity as a GDP per person employed, the study finds that the aging labour force has a negative and statistically significant effect, which differs between the EU-15 and EU-13 countries, on productivity. Our evidence is not entirely robust since the negative effect of aging labour force on productivity measured as TFP was not statistically significant.*

Keywords: *aging labour force, European Union, productivity, panel data models, total factor productivity*

JEL classification: *C33, D24, J11, J14, J21*

1. Introduction

Productivity can be considered one of the most important factors of economic growth. If productivity grows, more taxes are collected, wage raises and additional investment is created. Productivity growth requires a balanced workforce of young and older workers, but the demographic phenomenon called aging population threatens this balance. As society ages, more and more older people remain in the workforce, potentially affecting productivity. Over the last twenty years, the share of the Europeans in the world population has fallen from 11.89 in 2000 down to 9.64 per cent in 2020, so Europe's demographic importance is inevitably declining. One of the reasons for this phenomenon is the declining birth rate, but the rate of population decline is being held back by increasing age. Taken together, these two factors are causing population aging. Worldwide the share of people over 65 increased from 6 in 1990 up to 9 per cent in 2021, and by

[1] Corresponding author: Kristina Matuzevičiūtė, e-mail: kristina.matuzeviciute-balciuniene@sa.vu.lt

2050 it will reach 16 per cent. In the EU, there were 93 million people over 65-year-old, and they accounted for 20.8% in 2021, although in 1999, the older people accounted for only 15.48 per cent of the total population. It is projected that in 2050 the number of older people will increase up to 129.8 million, and they will account for 29 per cent of the total population of the EU.

Previous research has emphasized the negative effects of aging labour force on productivity (Feyrer, 2007; Maestas et al., 2016; Aiyar and Ebeke, 2016; Westelius and Liu, 2016; Adler et al., 2017; Calvo-Sotomayor et al., 2019; Park et al., 2021), but there are studies which identify the positive effects as well (Ilmakunnas and Miyakoshi, 2013; Lee and Song, 2020; Acemoglu and Restrepo, 2017, 2022). Mahlberg et al. (2013) provide results that the effect of the aging population on productivity differs across economic sectors. While a large part of the literature aimed at investigating the impact of society ageing on productivity in a single country: USA (Feyrer, 2008; Maestas et al., 2016); Netherlands (Van Ours and Stoeldraijer, 2011), Canada (Dostie, 2011), Germany (Göbel and Zwick, 2012; Börsch-Supan and Weiss, 2016; Börsch-Supan et al., 2021), Austria (Mahlberg et al., 2013), Hungary (Lovász and Rigó, 2013), Finland (Pekkarinen and Uusitalo, 2012), Japan (Westelius and Liu, 2016), Japan, Korea (Lee and Song, 2020), there are only few research referred to a group of countries: OECD (Feyrer, 2007), 18 advanced economies (Adler et al., 2017), EU-28 countries (Aiyar and Ebeke, 2016); EU-24 countries (Calvo-Sotomayor et al., 2019).

As society ages, the share of older people is increasing, as well as the share of older workers in the total labour force. Various indicators are used to study the impact of aging labour force on productivity. The most commonly used are employment rates of people aged between 55 and 64, and the old-age dependency ratio (the ratio between older people at an age when they are generally economically inactive (i.e., aged 65 and over) and the number of working-age people (i.e., 15-64 years old)). According to the IMF (2016), productivity growth is statistically significantly declining as the share of the 55-64 age group in the total labour force increases. Aiyar and Ebeke (2016) study in the EU found that productivity is declining by 0.1 per cent each year, and projected productivity decline is accelerating to 0.2 per cent every year. It has been concluded that the main channel through which an aging labour force slows output growth per employee is lower productivity, which is often seen as a key driver of economic growth.

There is a lack of recent research on the impact of the aging population on productivity in the EU. Filling this gap, our paper aims to estimate the impact of the aging labour force on productivity in EU countries. This research complements limited empirical evidence estimating the impact of aging population on productivity based not on a single country sample but by applying the panel estimation technique and looking at EU-28 countries. Additionally, the article examines the impact of the aging labour force on productivity, measured as a share of GDP per capita, and on TFP, allowing us to examine whether the aging labour force is affecting productivity.

The rest of the paper is organized as follows: Section 2 provides a theoretical background of how aging population affects productivity, Section 3 presents the developed specification of the model, estimations strategy, and data, Section 4 discusses the main estimation results, and the last section concludes the paper and provides discussion for the future research.

2. Literature review

Workers of different ages have different work experiences and abilities. In this way, workers in different age groups may change or complement each other and productivity in one age group may depend on interactions with workers in other age groups. Such changes in productivity can occur between older and younger workers if, for example, the experience of an older worker increases not only his own productivity but also that of the people who work with him. It is important that the knowledge accumulated by older workers is applied to work activities (Börsch-Supan et al., 2021). Equally important are the knowledge and skills that young workers bring to the labour market. As the population ages and fewer young people enter the labour market, fewer new knowledge, new skills, and competencies will be offered to employers. This may have a negative impact on innovation and productivity growth (Mahlberg et al., 2013).

One of the main research papers on the impact of aging society on productivity is considered to be the study by Feyrer (2007, 2008). Our research is not based on this author's work but relies on the subsequent research that emerged from Feyrer's (2007) study to find the best way to assess the impact of the age structure of the labour force on productivity. It is worth noting that Feyrer (2008) was not categorical in assessing the results obtained for the effects of an aging population. The results are seen as showing a link between demographic change in society and the workforce and changes in productivity. Still, he found that the most productive age group is 40-49 years workers. The increase in this age group's workforce share boosts productivity, but the increase in the share of employees aged 15-39 was related to lower productivity. The increase in the share of employees aged 50-59 years and over 60 also had a negative impact on productivity, but the results were less reliable. The author argued that there is no inverse causal link between demographic changes in the labour force structure and productivity, i.e. fluctuations in productivity do not affect the demographic structure of the labour force.

Previous research on the impact of aging population on productivity is conducted at the level of the enterprise, industry, economic sector, country and group of countries. Studies at the level of the company, group of companies, or one or more industries have found that demographic factor has an impact on productivity, but this impact depends on the technology used, the need for human capital and the specifics of the activity (Sun, 2020; Pekkarinen and Uusitalo, 2012; Börsch-Supan and Weiss, 2016; Martino, 2015). At the country group level, examining the impact of an aging population reveals a decline in productivity (Adler et al. al., 2017; Aiyar and Ebeke, 2016; Calvo-Sotomayor et al., 2019; Poplawski-Ribeiro, 2020), as well as at a one country level (Dostie, 2011; Lovász and Rigó, 2013; Lovász, and Rigó, 2013; Westelius et al., 2016; Maestas et al., 2016; Lee and Song, 2020; Park et al., 2021). Acemoglu and Restrepo (2017) state that they have not identified a negative impact of population and workforce aging on productivity and point out that the potential negative impact of aging population is reduced by process automatization and robotization. No adverse (Acemoglu and Restrepo, 2017; Lee and Song, 2020) effects were observed, or effects were inconclusive in research (Mahlberg et al., 2013; Göbel and Zwick, 2012; Van Ours and Stoeldraijer, 2011; Börsch-Supan and Weiss (2016). Aiyar and Ebeke (2016) also draw attention to the problem of endogeneity in this strand of research, as this problem leads to inaccurate estimation results.

An analysis of previous research has shown that studies analyzing the impact of an aging population on productivity have mostly identified negative effects. A summary of previous empirical studies is provided in Table 1.

Table 1: *Main results of the previous research on the impact of aging population on productivity*

Research period	Research sample	Main results	Methods applied	Authors
2006-2015	Republic of Korea	Significant and negative impact on productivity.	Modified Cobb-Douglas production function and various panel estimators	Park et al. (2021)
1973-2005, 1980-2012	Japan, S. Korea	In Japan and South Korea, aging populations positively impact productivity as older workers work in industries with high information and communication technology (ICT) capital.	Fixed effect, modified Cobb-Douglas production function	Lee and Song (2020)
1985-2014	At least 32 and at most 73 advanced economies and emerging markets	Significant and negative impact on productivity. 1% increase in the share of employees aged 55-64 decreased productivity by 0.7%.	Panel-fixed-effect two-stage least squares	Poplawski-Ribeiro (2020)
1983-2014	24 EU countries	Significant and negative impact on productivity. 1% increase in the share of employees aged 55-64 reduces productivity from 0.106%. up to 0.479%	Fixed effect	Calvo-Sotomayor et al. (2019)
1995-2011	18 advanced economies	Aging could significantly slow TFP growth. 1 per centage point increase in the share of 55–64 years-old age group leads to a statistically significant cumulative decrease in TFP of about 0.7 percentage points over five years (that is, about 0.15 per year).	Decomposition method	Adler et al. (2017)
1950-2014	28 EU countries	Significant and negative impact. Projected workforce aging could reduce TFP growth by an average of 0.2 percentage points every year over the next two decades	Fixed effect	Aiyar ir Ebeke (2016)
1990-2007	Japan	The aging of the labour force has had a significant negative impact on TFP.	Modyfied Feyrer (2007) model and Arellano-Bond GMM estimator	Westelius and Liu (2016)

2003-2006	EU, USA, Asia	A study on the production line in the truck manufacturing industry does not support the view that older workers are less productive, at least up to 60 years old. The result may have been affected because older workers who work productively, show good results, are promoted and do not work in the production line.	Piecewise linear specification	Börsch-Supan and Weiss (2016)
2002-2005	Austria	The positive effect is recorded in the construction and trade sectors. In contrast, in other sectors, the negative effect of the share of older workers on productivity is recorded, but this depends on the age, size, sector and region in which the company operates.	Cobb–Douglas production function	Mahlberg et al. (2013)
1997-2005	Germany	The impact of older workers on productivity has not been confirmed.	Cobb–Douglas production function	Göbel and Zwick (2012)
1986-2008	Hungary	Productivity declines in activities where employees need new skills to do the job.	Cobb–Douglas production function	Lovász and Rigó (2013)
2000-2005	Netherlands	No significant effect on productivity was found in the group of older workers. There was also no difference between the age-related effects on productivity, productivity and wages.	Cobb–Douglas production function	Van Ours and Stoeldraijer (2011)

Source: Own elaboration

A share of GDP per employee (Maestas et al., 2016), value-added per capita (Göbel and Zwick, 2012), the productivity of older workers, the gross factor productivity (Westelius and Liu, 2016; Poplawski-Ribeiro, 2020) are used to measure productivity.

Summarizing the results of empirical research, it can be stated that the topic of the impact of aging labour force on productivity is open in the scientific literature. The studies differ in terms of time periods and research samples because not all data are available to researchers. Our study aims to assess the impact of demographic change on productivity in the EU using the latest available data.

3. Data and model

Our panel data covers EU-28 countries for the period of 1999 – 2019. The choice of the research period depends on the availability of the data in order to cover a sufficiently long period. Based on a study by Poplawski-Ribeiro (2019), the data used in the models will be converted to non-overlapping three-year averages. Since aging is a long-term process, averaging data allows for reducing the impact of economic fluctuations and capturing lagging effects of demographic change. The data is collected from Eurostat, World Bank and Penn World Table 10.1 databases.

Based on the results of the above-mentioned empirical studies presented in Table 1, **Hy-**

pothesis 1 is formulated: population aging has a negative impact on productivity in the EU. To test the first hypothesis, we use two specifications. Eq. (1) is adapted from Calvo-Sotomayor et al. (2019). In this equation, the independent variable is productivity, measured as a real GDP per person employed. Eq. (2) is adapted from the study by Poplawski-Ribeiro (2020) but modified according to Calvo-Sotomayor et al. (2019). In this equation, productivity is measured by TFP, which shows the share of growth in output not explained by growth of labour and capital imputs. Our panel specifications:

$$\Delta \ln Y_{i,t} = \alpha_i + \surd_t + ß_1 W55_{i,t} + ß_2 YADR_{i,t} + ß_3 OADR_{i,t} + \varepsilon_{i,t} \quad (1)$$

$$\Delta \ln TFP_{i,t} = \alpha_i + \surd_t + ß_1 \Delta W55_{i,t} + ß_4 \Delta ADR_{i,t} + \varepsilon_{i,t} \quad (2)$$

where α_i is i-th country's specific constant, $\surd_t$ are dummies fore each year t, $\varepsilon_{i,t}$ is the idiosyncratic error term. Variables included in the equations are presented in Table 2.

Table 2: *Description of the variables*

Variables	Abbreviation	Description	Database
Productivity	TFP	The share of growth in output not explained by growth of labour and capital used in production, with the standard weighting of 0.7 for labour and 0.3 for capital.	Penn World Table 10.1
	Y	GDP per person employed (constant 2017 USD), calculated as the gross domestic product (GDP) divided by total employment in the economy, USD	Penn World Table 10.1
Aging of the labour force	W55	The share of the total workforce aged 55-64 years	EUROSTAT
Old-age dependency ratio	OADR	The ratio of the number of elderly people at an age when they are generally economically inactive (i.e. aged 65 and over), compared to the number of people of working age (i.e. 15-64 years old).	EUROSTAT
Young-age dependency ratio	YADR	The youth dependency ratio is the population ages 0-15 divided by the population ages 16-64.	EUROSTAT
Age dependency ratio	ADR	The ratio of dependents--people younger than 15 or older than 64--to the working-age population--those ages 15-64.	EUROSTAT
Technological development	R&D	Research and development expenditure, per cent of GDP	World bank
Foreign direct investment	FDI	Foreign Direct Investment, per cent of GDP	World bank
Trade openness	OPEN	The ratio of imports and exports, per cent to GDP (2015 prices)	EUROSTAT

Human capital	HC	Based on the average years of schooling and an assumed rate of return to education	Penn World Table 10.1
Technological progress	ICT	Share of ICT goods, percent of total trade	UNCTAD

Source: Own elaboration

In these equations, various age-dependency ratios are used as control variables that include other channels through which an aging population affects productivity. A higher age dependency ratio (lower for young people or higher for elderly people) indicates a longer average age of the population, which may affect age-related public expenditure, saving rates, and investment levels.

Productivity in individual countries is influenced by the existing institutional environment. In the EU, the challenge of aging population was previously addressed, as this demographic change is specific to developed countries. As EU-13 countries join the EU later, they may not be ready for these demographic changes. Our study divided EU-28 countries into two groups according to the date of accession to the EU. The first group of countries joined EU-15 prior 2004. The second group is the EU-13 countries, which joined the EU in 2004 and later. Majority of these countries are post-Soviet countries. This grouping is based on previous research by Poplawski-Ribeiro (2020), who divided countries into two groups according to their level of development (study covered 68 countries, ingluding advanced and emerging market economies). Meanwhile, Thalassinos et al. (2019) analysing impact of aging population (measured as the active ageing index) on economic development of the EU Member States find important dissimilarities between the EU countries, so authors apply panel analysis in EU–15 and EU–13 country groups. Cristea et al. (2020) use four specific panels, according to active ageing index, also confirm significant dissimilarities of the aging population impact on productivity in the EU countries. The previous studies reveale the need of the research not only in the EU as a whole but also designed for each investigated panel. For the above reasons, **Hypothesis 2 is: the aging labour force has a greater negative impact on productivity in the new EU Member states (EU-13) than in the old EU countries (EU-15).** To test that hypothesis, we will use Eq. (1).

Previous research examining the effects of aging population on productivity rarely accounts for other important productivity factors. In order to assess the impact of aging labour force on productivity while controlling other macroeconomic factors affecting productivity, we formulate **Hypothesis 3: aging labour force has a negative impact on productivity even if other productivity determinants, such as technological development, foreign direct investment, trade openness, human capital and technological progress are controlled.** The econometric specification is:

$$\Delta \ln Y_{i,t} = \alpha_i + \surd_t + ß_1 W55_{i,t} + ß_2 ADR_{i,t} + ß_3 \Delta FDI_{i,t} + ß_4 \Delta ICT_{i,t} + ß_5 \Delta R\_D_{i,t} + ß_6 \Delta OPEN_{i,t} + ß_7 \Delta H\_CAP_{i,t} + \varepsilon_{i,t} \quad (3)$$

All terms are explained below Eq. (2) and in Table 2.

Research by Calvo-Sotomayor et al. (2019), Poplawski-Ribeiro (2020) and Aiyar and Ebeke (2016) found that the share of older people in the total number of persons employed is endogeneous. The conventional assumption is that the only endogenous variable in the model is a dependent variable. All other model variables must be exogenous, but they can become endogenous because they are affected by an unobserved variable that is not controlled and becomes part of the error. Endogeneity leads to biased results because the error-correlated independent variable may reflect its own and the effect of an unobserved factor. To address the endogeneity problem, we use two stages least squares estimator (2SLS) with external instrumental variables (IV). The endogeneity problem in this study, as in other studies analyzing the impact of aging population on productivity, arises from the fact that the share of the different age employed population in the labor force depends not only on the size of the age group but also on the share of the employed in that group.

The increase in productivity per person employed may have a direct effect on the number of employees in the relevant age group. Endogeneity arises from the fact that labor force participation rates in some age groups are sensitive to fluctuations in productivity. The participation rate of the 55-64 age group in the labor force increases in response to a positive change in productivity (Aiyar and Ebeke, 2016). This means that the employment rate of this group is more elastic in terms of changes in productivity than that of other age groups. As a result, the share of this group of workers tends to increase in the total workforce as productivity increases. In other words, the value of this variable is affected by the effect of a positive change in productivity on the relative employment rate of the 55-64 age group.

Research suggests addressing the endogeneity problem by including exogenous instrumental variables using the 2SLS estimator. We instrumented the independent variable *W55* by the share of the population in the 45-54 age group 10 years earlier (IV45_54). Calvo-Sotomayor et al. (2019) and Aiyar and Ebeke (2016) addressed this problem through instrumental variables – the birth rates 10, 20 and 30 years earlier (in our research: IV_10, IV_20, IV_30). The suitability of the instrumental variables for the model is assessed by considering the strength of the relationship between the instrumental variable and the potentially endogenous variable using pairwise correlations (see Annex 1). The instrumental variable is suitable for the modelling when pairwise correlations is greater than 0.2 and statistically significant. According to the results of correlation analysis only variable IV45_54 meets the requirements for instrumental variables and will be used in the model. A brief summary statistics of the variables is presented in Table 3.

Table 3: *Summary statistics of the variables*

Variables	Group of countries	Mean	Std. Dev.	Min	Max
Aging of the labour force	EU-28	12.919	3.5133	4.8501	21.704
	EU-15	13.174	3.5508	5.7328	21.704
	EU-13	12.621	3.4518	4.8501	21.279
Young-age dependency ratio	EU-28	24.311	3.0603	19.460	34.228
	EU-15	25.187	3.1345	20.159	33.477
	EU-13	23.300	2.6372	19.460	34.228
Old-age dependency ratio	EU-28	24.955	4.5604	15.159	36.057
	EU-15	26.193	4.3784	15.159	36.057
	EU-13	23.527	4.3506	15.178	33.176

Age dependency ratio	EU-28	49.267	4.5330	38.457	61.795
	EU-15	51.381	3.8385	42.821	61.795
	EU-13	46.828	4.0236	38.457	57.839
Total factor productivity	EU-28	0.79821	0.17242	0.44095	1.4270
	EU-15	0.90488	0.14779	0.53890	1.4270
	EU-13	0.67514	0.10279	0.44095	0.90923
Productivity	EU-28	76838	27623	22508	209111
	EU-15	96510	21342	55610	209111
	EU-13	54139	12472	22508	78545
Technological development	EU-28	1.4534	0.87046	0.22000	3.8700
	EU-15	1.9607	0.81974	0.53000	3.8700
	EU-13	0.87257	0.47360	0.22000	2.5600
Trade openness	EU-28	1.1186	0.65824	0.27631	4.0917
	EU-15	1.0271	0.74317	0.42571	4.0917
	EU-13	1.2245	0.52537	0.27631	3.1126
Foreign direct investment	EU-28	11.593	37.371	-58.323	449.08
	EU-15	7.0216	14.216	-58.323	86.589
	EU-13	16.818	52.117	-40.414	449.08
Technological progress	EU-28	7.9125	8.3899	0.79342	63.636
	EU-15	6.4948	5.5417	1.0714	36.819
	EU-13	9.5482	10.557	0.79342	63.636
Human capital	EU-28	3.1722	0.31496	2.2092	3.8490
	EU-15	3.1463	0.34106	2.2092	3.7736
	EU-13	3.2021	0.27950	2.5247	3.8490
The share of the total population aged 45-54 years ten years earlier	EU-28	13.1	1.34	9.23	16.0
	EU-15	13.0	1.18	9.23	16.0
	EU-13	13.2	1.50	9.86	15.8
Birth rates 10 years earlier	EU-28	1.56	0.250	1.12	2.43
	EU-15	1.60	0.224	1.19	2.14
	EU-13	1.52	0.270	1.12	2.43
Birth rates of 20 years earlier	EU-28	1.75	0.331	1.13	3.14
	EU-15	1.65	0.295	1.19	3.14
	EU-13	1.85	0.337	1.13	2.46

Birth rates of 30 years earlier	EU-28	2.04	0.410	1.32	3.86
	EU-15	1.95	0.506	1.32	3.86
	EU-13	2.14	0.219	1.54	2.83

Source: Own elaboration

Estimation results

Estimations of Eq. (1) and Eq. (2) For the EU-28 sample are presented in Table 4.

Table 4: *Estimations of the impact of aging population on productivity*

Variable	Coef.	Eq. (1)		Eq. (2)	
		FE	2SLS	RE	2SLS
Intercept	α	0.0143	0.0192	0.0491***	0.0053
		(0.0323)	(0.0276)	(0.0141)	(0.0249)
Aging labour force (W55)	ß1	-0.0014	-0.0028**	-0.0050	−0.0093
		(0.0008)	(0.0013)	(0.0043)	(0.0136)
Young-age dependency ratio (YARD)	ß2	0.0013	0.0013*		
		(0.0013)	(0.0007)		
Old-age dependency ratio (OARD)	ß3	-0.0003	-0.0004		
		(0.0011)	(0.0008)		
Age dependency ratio (ARD)	ß4			-0.0098***	−0.0118***
				(0.0033)	(0.0040)
N					
R2		0.5481	0.5449	0.3625	0.6015
R2adj.		0.3965	0.5011	0.3347	0.4997
Test for differing group intercepts(1) [p-value]		[<0.001]		[<0.001]	
Breusch-Pegan (2) [p-value]		[<0.001]		[<0.001]	
Hausman test(3) [p-value]		[0.005]		[0.542]	
Wooldridge test(4) [p-value]		[0.023]		[0.206]	
Wald test for heteroscedasticity(5) [p-value]		[<0.001]		[<0.001]	
Pesaran CD test(6) [p-value]		[0.099]		[0.262]	

Source: Own elaboration

All estimations include time dummies. Heteroscedasticity and serial correlation robust standard errors are presented in parentheses. *, **, *** indicates significance at the 10, 5 and 1 per cent levels, respectively.

(1) A low p-value counts against the null hypothesis that the pooled OLS model is adequate

in favor of the fixed effects alternative.

(2) A low p-value counts against the null hypothesis that the pooled OLS model is adequate in favor of the random effects alternative.

(3) A low p-value counts against the null hypothesis that the random-effects model is consistent in favor of the fixed-effects model.

(4) A low p-value counts against the null hypothesis: no first-order serial correlation in error terms.

(5) A low p-value counts against the null hypothesis: heteroscedasticity is not present.

(6) A low p-value counts against the null hypothesis: cross-sectional independence.

The estimated coefficients on variables have a theoretically justified impact on productivity and are consistent with previous research. We confirm Hypothesis 1 as we find that impact of aging labour force on productivity in the EU-28 is negative and statistically significant. We also find that the rejuvenation of the society, i.e. an increase in the young-age dependency ratio, has a positive effect on productivity. Our results show that in the countries where the share of older people in the total working population is higher by one percentage point, productivity is 0.28 per cent on average lower. This is in line with the results by Calvo-Sotomayor et al. (2019), who found a negative and statistically significant impact of the aging labour force on productivity. Authors found that an increase in the share of older people in the total working population by 1 per cent decreases productivity by 0.106 – –0.479 per cent. It can be concluded that the growing share of older people in the total workforce is having an increasingly negative impact on productivity, meaning that countries' economies are failing to adapt to the demographic changes and are experiencing increasing productivity losses.

We found no statistically significant effect of population aging on productivity as measured by TFP (see estimations based on Eq. (2) in Table 4). However, although the effect is not statistically significant, it is negative. We find that the increasing age dependency ratio has a negative effect on productivity, and this effect is statistically significant. Our results are similar to those of Calvo-Sotomayor et al. (2019) and Poplawski-Ribeiro (2020), who found a negative and statistically significant effect of an aging labour force on productivity measured as TFP. Changes in the TFP are slow, suggesting that in some countries, the effects of aging labour force have been stronger, in others, it had less or no effects, and therefore has become statistically insignificant in terms of impact across the EU, but has remained negative. Assessing the statistically significant results based on Eq. 2, it can be concluded that in the countries where the age dependency ratio is higher by one percentage point, the productivity measured as TFP is 1.2 per cent on average lower. The results suggest that the aging labour force has a negative and statistically significant impact on productivity in the EU, measured as a share of GDP per person employed. The effect on productivity, measured as TFP, is also negative but statistically insignificant.

Estimations based on Eq. 1 (see Table 5) show that the impact of aging labour force in the EU-15 is negative but not statistically significant. The estimated coefficient β_2 is statistically significant and shows that a higher share of younger people in society positively affects productivity in the EU-15 countries. We confirm Hypothesis 2 as we find that the aging labour force significantly impacts productivity in the EU-13 group.

Table 5: *2SLS estimates based on Eq. (1) in EU-15 and EU-13*

Variable	Coef.	EU-13	EU-15
Intercept	α	0.3689***	-0.1168
		(0.1069)	(0.0953)
Aging labour force (W55)	ß1	-0.0096***	-0.0011
		(0.0041)	(0.0027)
Young-age dependency ratio (YARD)	ß2	-0.0055	0.0065*
		(0.0035)	(0.0033)
Old-age dependency ratio (OARD)	ß3	0.0001	-0.0005
		(0.0037)	(0.0022)
N			
R2		0.7637	0.5759
R2adj.		0.6863	0.4449
Wooldridge test(4) [p-value]		[0.061]	[0.112]
Wald test for heteroscedasticity(5) [p-value]		[<0.001]	[<0.001]
Pesaran CD test(6) [p-value]		[0.721]	[0.114]

Source: Own elaboration

All estimations include time dummies. Heteroscedasticity and serial correlation robust standard errors are presented in parentheses. *, **, *** indicates significance at the 10, 5 and 1 per cent levels, respectively. (4), (5) and (6) are explained in Table 4.

It can be concluded that in the EU-13 countries, where the share of older people is one percentage point higher, the productivity is 0.96 per cent on average lower. It was found that the share of older people aged 55-64 increased on average by 1.65 per cent in Bulgaria and Slovakia over the period 1999-2019. It led to decreasing productivity in these countries by 1.58 per cent per year. No significant negative effects on productivity have been identified in the EU-15, leading to the conclusion that the economies of the EU-15 are more adapted to the effects of an aging population. This may be due to the adaptation of jobs to older workers, the increased use of automation solutions, integration programs for older workers, and higher capital investment. Meanwhile, the economies of the EU-13 are more dependent on the physical labour force, and demographic changes have a significant impact on productivity. The impact of an aging labour force on productivity growth will continue to impact in the future. According to projections in the EU, the share of the population aged 55-64 among all employed by 2030 will increase to 20 per cent and should remain at that level until 2070, and the effects identified in our research will have a significant impact on productivity, especially in the EU-13. As a result, countries with the fastest-growing share of older people will face significant productivity losses.

Estimation of specification based on Eq. 3, which considers not only the variables of the aging labour force, but also includes other variables that influence productivity, shows that the impact of an aging labour force on productivity in the EU is negative and statistically significant (see Table 6).

Table 6: *Estimations of the impact of aging population on productivity while controlling other variables affecting productivity based on Eq. (3)*

Variable	Coef.	FE	2SLS
Intercept	α	-0.0114	0.0441
		(0.0387)	(0.0350)
Aging labour force (*W55*)	β_1	-0.0012	-0.0035**
		(0.0007)	(0.0014)
Age dependency ratio (*ARD*)	β_4	0.0008	0.0002
		(0.0007)	(0.0006)
Technological development (*R&D*)	β_5	-0.0172	-0.0181*
		(0.0141)	(0.0096)
Trade openness (*OPEN*)	β_6	0.0255	0.0276*
		(0.0222)	(0.0167)
Foreign direct investment (*FDI*)	β_7	<0.001	<0.001
		(<0.001)	(<0.001)
Technological progress (*ICT*)	β_8	-<0.001	<0.001
		(0.0004)	(<0.001)
Human capital (*HC*)	β_9	0.2236	0.1938
		(0.2383)	(0.2192)
N			
R^2		0.5525	0.5357
$R^2_{adj.}$		0.3986	0.4786
Test for differing group intercepts(1) [p-value]		[<0.001]	
Breusch-Pegan (2) [p-value]		[<0.001]	
Hausman test(3) [p-value]		[0.005]	
Wooldridge test(4) [p-value]		[0.017]	
Wald test for heteroscedasticity(5) [p-value]		[<0.001]	
Pesaran CD test(6) [p-value]		[0.1145]	

Source: Own elaboration

All estimations include time dummies. Heteroscedasticity and serial correlation robust standard errors are presented in parentheses. *, **, *** indicates significance at the 10, 5 and 1 per cent levels, respectively. (1) – (6) are explained in Table 4.

We confirm Hypothesis 3 as we find a statistically significant negative effect of aging labor force on productivity after controlling other productivity factors. We also find a statistically significant impact (at 10% significance) of technological development and trade openness on productivity. Other variables such as technological progress, foreign direct investment and human capital appeared as statistically insignificant. It can be concluded that in the EU-28 countries with a higher share of older people by one percentage point, productivity is 0.35 per cent lower. In countries where technological development is higher by one percentage point, productivity is 0.18 per cent lower, and in countries with trade openness higher by 1 percentage point, productivity is 2.76 per cent higher.

5. Conclusions

Summarizing the results of previous research, it can be concluded that the aging population is a significant factor negatively affecting productivity, therefore, it is necessary to further study its sources and channels in order to identify the factors that can reduce its negative impact on productivity.

Our research confirms the negative and statistically significant impact of aging population on productivity measured as GDP per person employed in the EU-28, which is in line with Calvo-Sotomayor et al. (2019). We found if the share of employees aged 55-64 of all employees is higher by 1 percentage point, the productivity is lower from 0.25 up to 0.28 per cent. So we can draw the conclusion that the growing share of older people in the total labour force is having an increasingly negative impact on productivity. Aiming to evaluate aging population impact on productivity measured as total factor productivity we found that impact is negative but statistically insignificant, which is consistent previous research.

We also performed an assessment to determine the impact of the aging population on productivity in the EU-15 and EU-13 country groups. Our results show that the aging population has a negative impact on productivity in the EU-13. In this group of countries, a statistically significant and negative impact of aging on productivity has been identified. Meanwhile, a negative but statistically insignificant effect was found in the EU-15. It can be concluded that the economies of the EU-15 are more adapted to the productivity effects of an aging population and that economic and social convergence between Member States in the EU can help reduce the productivity gap between the EU-13 and the EU-15. The ongoing implementation of European Union programs in the EU-13 countries, the application of new technologies, and increased capital investment can be an effective means of overcoming the impact of an aging population on national economies, as well as on declining productivity.

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Appendix 1: *Results of correlation analysis*

	Instrumental variable ΔW55			
An instrumental variable	IV45_54	IV_10	IV_20	IV_30
Correlation Coefficient	0.3024	-0.1074	-0.2045	-0.1670
***p*-value**	0.0001	0.1658	0.0078	0.0305

Data is recalculated to non-overlapping three-year averages

	Variable W55			
An instrumental variable	IV45_54	IV_10	IV_20	IV_30

Correlation Coefficient	0.5937	-0.0977	-0.3710	-0.3708
***p*-value**	<0.0001	0.1732	<0.0001	<0.0001

Data is recalculated to non-overlapping three-year averages