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Abstract

Most industrialized countries today are facing historical demographic changes, paring increasing retirement with a declining labor force. We study the consequences of an increasing pensioner-worker ratio in a macroeconomic framework, which suggests a negative effect on total factor productivity. Using newly collected longitudinal data on pensioners, we quantify this effect by exploiting variation in the pre-determined component of retirement. We find that a 10-point increase in the pensioner-worker ratio decreases factor productivity by 5-6%. The effect is stronger when production is labor intensive and automation potential is low. Economic aging also impedes the creation of innovation at the technological frontier.

JEL-Codes: C230, C260, D240, J110, J140, O400.

Keywords: aging, retirement, factor productivity, secular stagnation, demographic transition.

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1 Introduction

Technological progress is widely considered the main source of long-run economic growth and well-being (Galor and Tsiddon, 1997; Galor and Weil, 2000; Mokyr et al., 2015). The development of innovation and new technologies was proceeding at an unparalleled pace after World War II, but it experienced a sudden decline after the turn of the millennium in most of the advanced economies. Falling productivity growth rates have led researchers to speculate whether the epoch of major technological progress is over (Cowen, 2011; Vijg, 2011; Gordon, 2015). The fall in factor productivity comes at a time when demographic change, another landmark trend, is beginning to cast its shadow over most developed economies. By 2030, the baby boom generation in the United States will be age 65 or older, meaning that one in five US citizens will have reached retirement age (USCB, 2021). An important question persistently raised in the political and academic discourse is how these demographic dynamics impact well-being and productivity.

Previous studies on the productivity effects of population aging have focused on *demographic* aging. A popular thesis is that older workers are less productive than their younger peers, which would result in a decline in average per-worker productivity when societies get older. Recent research, however, challenges the conventional wisdom that aging reduces labor productivity (e.g. Börsch-Supan and Weiss, 2016; Börsch-Supan et al., 2021), arguing that the decline in creativity caused by aging is often offset by an increase in experience. A different but related argument is that demographic aging creates "labor scarcity", which may boost or depress growth depending on whether labor shortages result in declining R&D activity or increased adoption of new technologies (Acemoglu, 2010; Acemoglu and Restrepo, 2017, 2022). An implicit assumption underlying this strand of literature is that older workers drop out of the workforce. However, this assumption and the resulting consequences for productivity have never been tested directly, partly reflecting a lack of cross-nationally comparable data on the development of the number of pensioners relative to the labor force.

In this paper, we provide first empirical evidence on the aggregate productivity effects of retirement, a phenomenon which we refer to as *economic* aging. We move beyond previous studies in three steps. First, we set the stage for our empirical analysis by deriving the impact of economic aging on factor productivity based on an aggregate production framework. The model predicts that a larger number of pensioners relative to the working population reduces factor productivity, particularly when production is labor intense and when the productivity of the workers entering retirement is high, which impedes the replacement of retired workers by automation. The productivity loss caused by economic aging also limits a country's potential to innovate, which is detrimental to factor productivity, especially in industrialized countries at the technological frontier, which depend on new ideas and technologies to increase factor productivity.

Quantifying the size of the predicted effect with empirical data is complicated by the lack of cross-national data on the number of pensioners. Our innovation is to manually compile a dataset on the number of pensioners for 29 OECD countries from 1944 to present. The numbers have been assembled in an extensive data-collection project with the help of a large group of colleagues from 26 OECD countries, who helped us gather, process, and translate multiple sources from national statistical offices, governments, and social security offices. Our newly compiled dataset reveals a striking increase in the number of pensioners relative to the working-age population. Over the last six decades, the pensioner-worker ratio almost tripled, increasing from 16.6% in 1960 to 41.1% in 2019. Our data also uncover large heterogeneity in economic aging across industrialized countries that can be exploited for empirical estimation.

In the second step, we estimate the causal effect of aging on productivity using an instrumental variable strategy that allows us to tackle threats to identification caused by unobserved confounding factors or reversed causation, e.g. when new technologies force workers into early retirement. Our empirical strategy takes advantage of the fact that some of the cross-national variation in retirement was determined many years before, following a logic similar to previous studies of demographic aging (e.g. Maestas et al., 2023). The historical age and retirement structure impact pensioning patterns far into the future. We use these pre-determined components of retirement ratios as instrumental variables for realized pensioning patterns, which enable estimation of the causal effect of economic aging on aggregate productivity. The central assumption underlying this analysis is that the historical retirement structure of a country influences future changes in factor productivity only through its impact on the subsequent retirement structure. In order to meet the exclusion restriction, the instrument drawing on past retirement structures must be sufficiently pre-determined, ensuring that it is not influenced by long-term trends that can predict future factor productivity. To address this requirement, we utilize the "initial" retirement structure of each country ten years prior to the observation year and employ cross-national retirement ratios to predict the proportion of pensioners relative to workers ten years later. We also run many additional analyses to account for the independent effects of prior retirement structures. Our main estimates show that a 10-point increase in the pensioner-worker ratio decreases factor productivity by 5-6%.

Finally, we examine the transmission mechanisms through which economic aging translates to factor productivity. This analysis verifies our theoretical predictions, showing that the effect of economic aging on factor productivity depends on the importance of labor as an input factor and the potential to replace labor inputs by automation. We also show that economic aging is associated with a decline in both the inputs and the outputs of the technology production function. Regarding inputs, we find that economic aging is associated with a decrease in R&D personnel. Economic aging also increases public pension spending, which crowds out expenditure for R&D and other productivity-enhancing spending categories. The reduced input into research that goes in hand with economic aging directly translates to a decline in research output. As the number of pensioners relative to workers increases, patent applications and articles in scientific journals decrease. The effect is only visible for residents and not for non-residents, which is consistent with the effect being driven by the aging of the population and not by other fundamental factors of the economy.

Although causal identification in a cross-country setting is notoriously difficult compared to settings that exploit variation within countries or states, we are interested in the effect of economic aging on the national level for three reasons. First and foremost, the goal of our analysis is to better understand the macroeconomic consequences of population aging and retirement, which are often seen to create major challenges for advanced economies over the next several decades. These macroeconomic effects will, by nature, affect countries as a whole and are not confined to specific sub-national regions within countries. Second, pensioning systems usually differ much less within than between countries. Finally, policy responses targeted to tackle the potential adverse effects of aging are predominantly conducted on the national level.

Our results have important policy implications. Most industrialized countries are at the dawn of facing a severe transition process from the working population to retirement. As the baby boomers of the 1950s and 1960s enter retirement, the adverse effects of economic aging will intensify. This process is seen as *"one of the most dangerous economic ills of the next several decades"* (Acemoglu and Restrepo, 2017). Our estimates imply that the increasing retirement of the population will have a significant impact on factor productivity in the coming years and thus pose major challenges to maintaining living standards. Exploring how policy measures could be designed to dampen the effects of economic aging is an important task for future research.

Contribution to the literature: The main contribution of our study is to provide first empirical evidence on the effect of economic aging via retirement on aggregate productivity. Our study is related to the empirical literature studying how demographic dynamics impact production and productivity (e.g. Kögel, 2005; Feyrer, 2007; Börsch-Supan and Weiss, 2016; Kotschy and Sunde, 2018; Börsch-Supan et al., 2021; Maestas et al., 2023). Previous studies focused on *demographic* aging, i.e. a shift in the distribution of a country's population towards older ages. In these models, aging impacts productivity and output in two ways, either via decreased productivity of older workers relative to younger cohorts (e.g. Kotschy and Sunde, 2018) or via a decrease in the labor force, which is often termed labor scarcity (Acemoglu, 2010; Acemoglu and Restrepo, 2017, 2022). Regarding productivity differentials across age cohorts of the labor force, the more recent literature has challenged the notion of declining per-worker productivity levels when workers get older (Börsch-Supan and Weiss, 2016; Börsch-Supan et al., 2021), arguing that decreasing creativity is offset by productivity gains through experience. A necessary assumption of the literature on labor scarcity, in turn, is that aging leads to retirement and thus a dropout of workers from the labor force. Although these studies provide many insights on productivity shifts through aging, the empirical applications of these models rely on the old-age dependency ratio or the ratio of old workers versus young workers. Much less is known about the aggregate productivity effects of retirement, reflecting a lack of a cross-national dataset on pensioners. Our innovation is to compile such a dataset, which enables us to estimate the productivity effect of economic aging rather than demographic aging.

We also connect to the literature that examines the post-2000 productivity decline (e.g. Cowen, 2011; Gordon, 2015; Summers, 2015) that led to a cross-national slowdown of long-run GDP growth (Antolin-Diaz et al., 2017). Previous studies discussed the role of interest rates (e.g. Eichengreen, 2015; Eggertsson et al., 2019), "headwinds" in the form of global trends that led to stalling innovation activity (Gordon, 2015) and unfavorable labor market outcomes (Summers, 2015). As hypothesized by some authors (e.g. Gordon, 2015), demographic trends may be a major driver *behind* the proximate factors that caused the productivity decline. Our analysis provides empirical evidence that is consistent with this hypothesis. An implication of our results is that the increase in pensioning in industrialized countries over the next decades will contribute to a further decline in factor productivity growth. Closing the gap in productive human capital caused by the retirement of an aging population will be a major challenge for policymakers in the coming years and decades.

Our research also contributes to the literature that discusses tools to project long-run macroeconomic variables, in particular projections of the long-run development of GDP (Duval and de la Maisonneuve, 2010; Müller and Watson, 2016; Werding et al., 2020). These projections play an important role in policy evaluations and assessments of the sustainability of public finances. Long-run projections usually depend on official population forecasts, which are then used to estimate the trajectory of other macroeconomic variables. While assumptions about the relationship between population dynamics and productivity are often critical inputs for long-run projections, they are usually formed using rules of thumb. Our results contribute to this literature by delivering more reliable estimates on how the response of factor productivity to predicted pensioning patterns can be modeled.

Organization: In the next section, we derive our estimation design based on a macroeconomic production function framework. To bring this framework to the data, we compile a new dataset on the number of pensioners relative to workers, which is introduced in section (3). Section (4) discusses factor productivity and other input variables of our framework. We present our main results in section (5) and provide evidence on possible mechanisms in section (6). We conclude in section (7).

2 Methodology

2.1 The basic macroeconomic model

The starting point of our analysis is a standard growth accounting model with human capital (e.g. Benhabib and Spiegel, 1994; Hall and Jones, 1999), which has been used to study the impact of *demographic* aging on production (e.g. Kotschy and Sunde, 2018). Output Y_{it} in country i and year t is produced as a function of productivity A_{it}, physical capital K_{it}, and human capital H_{it}

$$Y_{it} = A_{it} K_{it}^{\alpha} H_{it}^{1-\alpha}, \tag{1}$$

with $\alpha \in (0,1)$. The working age population L_{it} is a subset of the total population N_{it}. Without loss of generality, we assume full employment. By expressing equation (1) in terms of output per worker, that is dividing by L_{it}, we arrive at

$$y_{it} = A_{it} k_{it}^{\alpha} \left(\frac{H_{it}}{L_{it}} \right)^{1-\alpha}, \tag{2}$$

where k_{it} denotes capital per worker.[1] Taking natural logarithms yields

$$\ln(y_{it}) = \ln(A_{it}) + \alpha \ln(k_{it}) + (1-\alpha) \ln\left(\frac{H_{it}}{L_{it}} \right). \tag{3}$$

The total stock of human capital in the economy aggregated over the population, H_{it}, is a function of human capital per capita h_{it} and the overall qualification of the population Q_{it}, which can be expressed as an average of the productivity of each age group in the population $\pi_1, \ldots, \pi_{\mathcal{J}}$ weighted by their size $N_{it}^1, \ldots, N_{it}^{\mathcal{J}}$ (see Kotschy and Sunde, 2018)

$$H_{it} \equiv h_{it} Q_{it} = h_{it} \Big[\pi_1 N_{it}^1 + \ldots + \pi_{\mathcal{J}} N_{it}^{\mathcal{J}} \Big]. \tag{4}$$

Age-dependent productivity may reflect differences in physical strength, experience, and mental ability. In terms of per-worker units, equation (4) can be re-arranged via

$$\frac{H_{it}}{L_{it}} = h_{it} \left[\sum_{j=1}^{\mathcal{J}} \pi_j \frac{N_{it}^j}{L_{it}} \right] = h_{it} \left[\sum_{j=1}^{\mathcal{J}} \pi_j S_{it}^j \right], \tag{5}$$

where S^j is the share of each age cohort of the total labor force such that $\sum_{j=1}^{\mathcal{J}} S_{it}^j = 1$. Equation (5) allows for analyses including varying numbers of cohorts and thus different degrees of complexity. Our model of productivity loss due to retirement can be expressed in a simple two-cohort framework consisting of the working age population L_{it} and a second cohort, $R_{it} = N_{it} - L_{it}$, that has entered retirement. Equation (5) then simplifies to

$$\frac{H_{it}}{L_{it}} = h_{it} \left[\sum_{j=1}^{2} \pi_j S_{it}^j \right] = h_{it} \Big[(\pi_L S_{it}^L) + (\pi_R S_{it}^R) \Big] = h_{it} \pi_L + h_{it} \pi_R S_{it}^R. \tag{6}$$

Output in this framework is produced using the productivity of the workforce, which

[1] Under the standard assumption that knowledge is a public good, the available production technology per worker is not reduced by an increase in the working force.

is

$$\pi_L S_{it}^L \equiv \pi_L (L_{it}/L_{it}) = \pi_L. \tag{7}$$

For a given population size, retirement (e.g. a shift from the L to R) results in a decrease in the working population. This effect is similar as in Acemoglu and Restrepo (2017), who describe that population aging reduces the labor force and creates "labor scarcity". In our model, this scarcity depends on the relative size of cohorts L and R, which is reflected by the metric

$$S_{it}^R = \frac{R_{it}}{L_{it}} = \frac{N_{it} - L_{it}}{L_{it}} = D_{it}, \tag{8}$$

and which denotes the ratio between pensioners and workers. We refer to an increase in S_{it}^R as *"economic aging"*. There are key differences regarding the effects of economic aging and demographic aging on output and productivity. While demographic aging changes the age composition of the labor force, its effects on productivity depend on productivity differentials across cohorts within the working population. As recent research shows, the conventional wisdom of older workers being less productive is probably unjustified (Börsch-Supan and Weiss, 2016; Börsch-Supan et al., 2021). Most importantly, the relative size of age cohorts (e.g. the ratio of individuals above a certain age threshold relative to the younger population) tells us little about the proportion of workers leaving the labor force through retirement. This is, however, the essential mechanism reflected in equation (8). Economic aging through retirement gives rise to an irreversible and mechanical loss of the productive human capital of retirees.

Accounting for economic aging, the aggregate human capital stock per worker is given by

$$\frac{H_{it}}{L_{it}} = h_{it}\pi_L \left[1 + \frac{\pi_R}{\pi_L} D_{it}\right]. \tag{9}$$

Inserting equation (9) in equation (3) adjusts the production function to

$$\ln(y_{it}) = \ln(A_{it}) + \alpha \ln(k_{it}) + (1-\alpha)(\ln h_{it} + \ln \pi_L) + (1-\alpha)\ln\left[1 + \frac{\pi_R}{\pi_L} D_{it}\right] \tag{10}$$

The ratio $\frac{\pi_R}{\pi_L}$ denotes the productivity of pensioners relative to that of the labor force. As productivity drastically decreases when citizens retire, π_R reflects the "productivity loss" of human capital due to retirement. It is often argued that pensioners may still be productivity-increasing, e.g. by sharing experience or helping with child-care. Compared to the direct effect of the active labor force, the indirect productivity effects of pensioners are small. These differentials allow for the approximation

$$\ln\left[1 + \frac{\pi_R}{\pi_L} D_{it}\right] \approx \frac{\pi_R}{\pi_L} D_{it}. \tag{11}$$

By inserting equation 11 in equation 10 we arrive at

$$\ln(y_{it}) = \ln(A_{it}) + \alpha \ln(k_{it}) + (1-\alpha)\ln \tilde{h}_{it} + (1-\alpha)\lambda D_{it} \tag{12}$$

where the productivity differential between age cohorts, $\frac{\pi_R}{\pi_L}$, is denoted by λ and $\ln \tilde{h}_{it} = \ln h_{it} + \ln \pi_L$ is human capital per worker adjusted by the productivity of the workforce. Re-arranging equation (12) in terms of factor productivity delivers the central equation that relates factor productivity to economic aging

$$\ln(A_{it}) = \ln(y_{it}) - \alpha \ln(k_{it}) - (1-\alpha)\ln \tilde{h}_{it} - (1-\alpha)\lambda D_{it}. \tag{13}$$

What does equation (13) imply regarding the aggregate productivity effects of economic aging? To answer this question, let us differentiate the expression for $\ln(A_{it})$, which yields

$$\frac{\partial \ln(A_{it})}{\partial D_{it}} = (\alpha - 1)\frac{\pi_R}{\pi_L} < 0. \tag{14}$$

Given that $\alpha \in (0,1)$, the term $(\alpha - 1)$ is negative. At the same time, $\frac{\pi_R}{\pi_L}$ is always positive. Hence, equation (14) suggests that the impact of economic aging on aggregate productivity is negative.

As equation (14) shows, the size of the effect depends on two factors. First, the negative effect of economic aging is larger for higher productivity levels of retirees relative to the working population. This mechanism reflects the relative "cost" of losing productive human capital through retirement that could otherwise be used for production and R&D. Second, equation (14) shows that in countries that derive large production gains through additional capital (i.e. α is large), the negative effect of economic aging should be smaller. This suggests that the loss of productivity of the older population is more costly when a country's production is labor-intense. The multiplicative link between both factors is intuitive and shows that the loss of productive human capital of the older generation is particularly costly when a country relies more on labor input.

Equation (14) also suggests some implications regarding possible economic responses to labor scarcity (Acemoglu, 2010 and Acemoglu and Restrepo, 2017, 2022), e.g. when scarcity of labor leads to faster technology adoption and automation. The potential to automate tasks performed by workers who retire should be higher in countries where production is concentrated on routine tasks, i.e. where π_R is smaller. Hence, the negative productivity effect of retirement should be smaller in countries with greater potential of automation, although in our production function framework, the effect cannot become positive.

When examining companies that both innovate and adopt technologies from the global technology frontier, a standard finding is that adoption is optimal for countries at earlier stages of development, whereas economies rely more on innovation and the creation of new technologies when coming closer to the world technology frontier (e.g. Acemoglu et al., 2006). For industrialized countries, the loss of π_R caused by retirement should be particularly productivity-decreasing, because it limits the potential to innovate if this loss cannot be compensated for by π_L. An implication of equation (14) is, therefore, that an increase in the pensioner-worker ratio should hamper innovation and thus aggregate productivity, particularly in highly developed countries such as the OECD member states.[2]

[2]This point can easily be shown when extending the framework to include the basic idea of a distance-to-frontier model with two sources of productivity growth. Consider an economy in which productivity in t depends either on imitating existing world frontier technologies $\ln(\bar{A}_{it})$ or on innovation activity (i.e. an expansion of the technological frontier)

$$\ln(A_{it}) = a \ln(\bar{A}_{it-1}) + b \ln(A_{it-1}),$$

where a and b denote the relative weight of imitation and innovation, and the potential to innovate depends on the initial technology level. Replacing $\ln(A_{it-1})$ by the expression of equation (13), the impact of economic aging in equation (14) adjusts to

$$\frac{\partial \ln(A_{it})}{\partial D_{it}} = b(\alpha - 1)\frac{\pi_R}{\pi_L} < 0,$$

implying that the negative effect of population aging should be stronger when a country relies more on innovation activity. It is easy to show in this type of model that the relative importance of innovation (i.e. the parameter b) increases as the country moves closer to the technological frontier, and hence the negative effect of economic aging should be higher in the industrialized countries that depend on innovation to increase factor productivity.

2.2 Estimation

Equation (14) implies that the effect of economic aging on factor productivity is negative, but the size of this effect is difficult to quantify by theory. In the next step, we transform our macroeconomic framework into an empirically estimable model that returns the average effect of economic aging on factor productivity. A challenge of estimating this effect is that countries possess quite different production structures and cohort-specific productivity differentials, and hence the critical parameters in equation (14) that determine the effect size of economic aging might differ across economies. To tackle this challenge, we rely on data from the developed OECD countries and a subset of OECD member states with advanced industries and pension systems, which we refer to as "established democracies".

To further account for systematic cross-national differentials in fundamental factors, we make use of the fact that the level of per worker output at a given year t is determined by output per worker in $t-1$ (e.g. Baumol, 1986; Kotschy and Sunde, 2018). Modeling output in t to be a function of output in $t-1$ allows us to account for long-run cross-national heterogeneity in industries and production structures, institutions, geography, and culture, but it also imposes a degree of imprecision. As part of this imprecision is country-specific and period-specific, we model the GDP process via

$$\ln(y_{it}) = \rho \ln(y_{it-1}) + \eta_i + \zeta_t + \varepsilon_{it}, \tag{15}$$

where η_i and ζ_t denote constants for countries and years. These constants can be accounted for empirically, but we cannot observe the remaining and time-varying part of the identity, ε_{it}.

Inserting equation (15) in equation (13) gives our empirical model which we employ to estimate the effect of economic aging on factor productivity

$$\ln(A_{it}) = \rho \ln(y_{it-1}) - \alpha \ln(k_{it}) - (1-\alpha) \ln \tilde{h}_{it} - (1-\alpha)\lambda D_{it} + \eta_i + \zeta_t + \varepsilon_{it}. \tag{16}$$

We use the within-transformation to estimate equation (16) and to eliminate the country-specific fixed effects η_i.

2.3 Identification

When the unobserved time-varying part of equation (16) does not contain elements that are correlated with the pensioner-worker ratio, empirically estimating equation (16) returns the causal effect of D_{it} on factor productivity. However, when $\mathrm{E}(D_{it}|\varepsilon_{it}) \neq 0$, the parameter estimate is biased. Retirement may depend—in part—on factors related to aggregate productivity. For example, cyclical effects may change the intensive and extensive margin of employment, and hence affect the ratio between pensioners and the labor force that is measured with observable data. To eliminate the confounding influence of labor force dynamics, we account for the average annual hours worked by persons engaged and the labor force participation rate in our baseline specification. Another source of bias comes from early retirement caused by technological progress. For instance, Acemoglu and Restrepo (2022) demonstrate a close entanglement between aging and the adoption of industrial robots. When labor and capital inputs can be substituted, new production technologies might force workers into early retirement. For those, we would observe in the raw data that aging countries have higher levels of factor productivity. On an aggregate level, this source of endogeneity should weaken the negative correlation between economic aging and productivity, and hence the estimated parameters obtained via OLS should be upward biased towards zero.

To tackle these threats to identification, we complement our baseline OLS estimates by an instrumental strategy that exploits variation in the *predetermined* component of retirement across countries over time. This strategy is widely used in empirical studies that aim to identify the causal effect of population aging (e.g.Kotschy and Sunde, 2018; Shelton, 2022; Maestas et al., 2023). The key identifying assumption of this approach for our setting is that the past retirement structure affects future aggregate productivity of a country only by impacting its subsequently realized retirement structure and not through other channels. To satisfy this requirement, we follow the approach of Maestas et al. (2023) using each country's "initial" retirement structure ten years prior to the baseline year t and apply *cross-national* retirement rates to predict the share of pensioners relative to the labor force ten years in the future. The rationale of this approach is that with distant lags, it becomes unlikely that the initial retirement structure of countries could have been influenced by the same trends that drive contemporaneous productivity. Our instrumental variable strategy exploits the fact that the number of pensioners relative to the working population at some point in time predicts this ratio in the future. At the same time, it is unaffected by aggregate productivity in the future and hence exogenous for the purpose of our estimation framework. This assumption is plausible particularly when conditioning on fixed effects for countries and years. We will also show that the results are not sensitive to the chosen lag structure. While more distant lags make it increasingly unlikely that initial retirement is correlated with factors that shape aggregate productivity in t, larger lags also come at the cost of reducing the time horizon that could be used for empirical estimation given notorious restrictions in data availability over time.

More precisely, our baseline models use the composition of retirees and workers in period $t-10$ to predict changes in the pensioner-worker ratio until t. The instrument $Z_{it} = \hat{R}_{it}/\hat{L}_{it}$ is generated using

$$\begin{aligned} \hat{R}_{it} &= \underbrace{R_{it-10}}_{\substack{\text{Total number of} \\ \text{retirees in country } i \\ \text{at time } t-10}} \times \underbrace{\frac{R_t^{\text{OECD}}}{R_{t-10}^{\text{OECD}}}}_{\substack{\text{Cross-national economic} \\ \text{aging rate between} \\ \text{periods } t \text{ and } t-10}} \\ \hat{L}_{it} &= \underbrace{L_{it-10}}_{\substack{\text{Total number of} \\ \text{workers in country } i \\ \text{at time } t-10}} \times \underbrace{\frac{L_t^{\text{OECD}}}{L_{t-10.}^{\text{OECD}}}}_{\substack{\text{Cross-national economic} \\ \text{survival rate between} \\ \text{periods } t \text{ and } t-10}} \end{aligned} \tag{17}$$

To predict the number of pensioners in year t, we use the *cross-national* economic aging rate in the OECD, defined as the ratio of pensioners in t to pensioners in $t-10$. We then multiply the number of pensioners in country i in $t-10$ by the cross-national economic aging rate to arrive at a prediction of the number of pensioners in country i at t. By a similar logic, we predict the labor force using information on the initial number of persons engaged multiplied by cross-national economic survival rates that relate persons engaged in the OECD in the year t to the labor force in $t-10$.

The central idea of our approach is to use the initial retirement composition of countries interacted with cross-national changes in retirement and employment. An advantage of this approach is that it disregards variation resulting from differential country-level retirement laws, mortality, and migration for identification. The construction of our instrument is a specific version of the more general approach conducted by Maestas et al. (2023) to predict demographic change based on 10-year birth cohorts. Our approach is tailored to predicting the pensioner-worker ratio and like the more general approach, it resembles a Bartik-type instrument (Goldsmith-Pinkham et al., 2020). The main source of variation comes from cross-national differentials in the initial retirement structure. As the descriptive analysis of pensioner data will show, these differentials are substantial (section 3.3). Countries with a larger fraction of pensioners in t are predicted to be more likely to be exposed to cross-national trends that drive retirement, e.g. through new technologies or other cross-national events and shocks. We condition our baseline regression specification on fixed effects that should absorb the country-specific independent effect of prior retirement on aggregate productivity.

3 A unique dataset of pensioners in the OECD

Estimating our macroeconomic model requires having precise data on the number of pensioners and the size of the labor force over multiple decades. Covering a sufficiently large time horizon is necessary to capture the demographic transition in the OECD that initiated an increasing decline in the labor force over the past decades. A major data limitation to date is that longitudinal data on pensioners over longer time spans is largely inexistent. We hence conducted a large-scale data-collection project to compile the number of pensioners for 29 OECD countries over the past decades.

3.1 Existing data collections

For some countries, official statistics are available over longer time periods (e.g. for Germany, the United States, or Sweden). For most OECD countries, however, the available official figures predominantly cover the most recent years (e.g. for the Czech Republic, Denmark, or Italy). Pension experts from the OECD informed us that data on the number of pensioners is not collected centrally by the OECD or any other international body. Cross-national information on pension institutions is available in the OECD Pensions at a Glance dataset (OECD, 2021). The Survey of Health, Ageing and Retirement in Europe (SHARE) dataset (Börsch-Supan et al., 2013) also includes individual-level data on health, socio-economic status, and social networks of pensioners and other individuals aged 50 and older from 20 European countries. Although these data collections provide very rich information on pension systems and the socio-economic situation of retirees, data on the number of pensioners per country is not available for longer time horizons. This partly reflects the fact that the number of pensioners in many international statistical analyses is approximated by the population aged 65 or above. Given the substantial differences in retirement laws and conventions across OECD countries, the old-age dependency ratio does not sufficiently proxy the effect of economic aging. This is also reflected by the large heterogeneity in the average effective age of retirement across OECD countries, ranging from 59.5 years in Luxembourg to almost 68 years in South Korea (OECD, 2021).

3.2 Compilation of the dataset

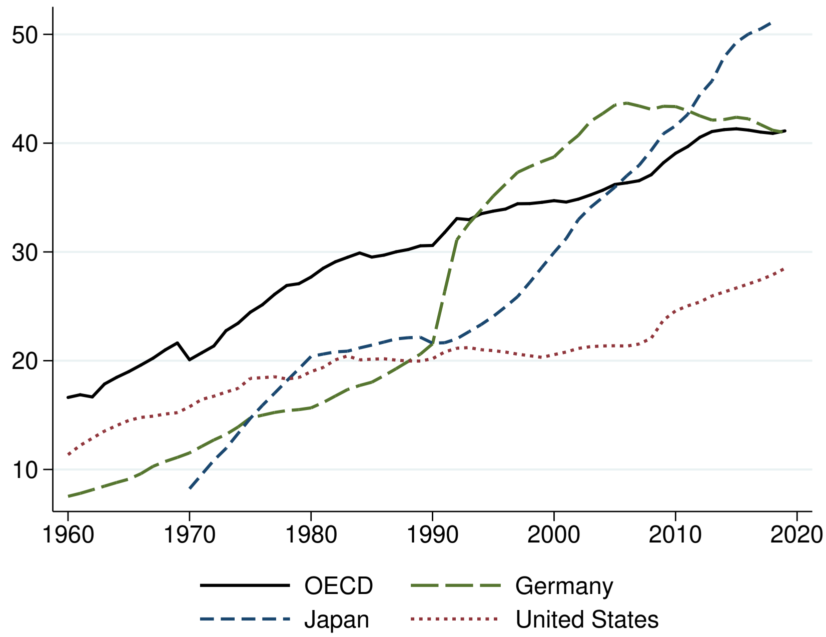
We launched a large-scale data collection process to obtain longitudinal data for 29 OECD countries that covers the number of pensioners over the largest possible time span. In the first step, we obtained all freely available data sources from official sources. In the second step, we collaborated with 26 colleagues from OECD countries to fill as many of the country-year observations without officially available data as possible. The collaboration involved communication with multiple bureaus and contact persons at statistical offices, governments, and social security offices in national language, translation of documents, and, in some instances, collection of printed data that are available in national archives. The complete list of data sources is documented in Appendix C (Table C1).

For most countries, data on the number of public pensioners stem from multiple sources. We conducted a series of plausibility checks to ensure that the time series are comparable within countries. For cross-national comparisons, some differences in the definition of pensioners may require a certain degree of caution. For the majority of countries, these definitional differences are minor. In some countries, however, it is possible for individuals to receive payments from more than one pension. Whenever possible, we eliminate additional pension sources to maximize comparability also between countries. In our empirical estimation, these and any other systematic cross-country differences in the definition of pensioners are eliminated by the country-level fixed effects, exploiting the within variation in economic aging.

Our final dataset covers the time period 1944 to present, but for most countries, our time series start in the 1950s and 1960s. We obtained data for 29 OECD member states, including Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Italy, Japan, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovakia, South Korea, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States. The dataset includes a total of 1,513 country-year observations.

We relate the number of pensioners to the number of individuals in the labor force,

Figure 1 TRENDS IN ECONOMIC AGING (PENSIONER-WORKER RATIO)



Notes: The figure shows trends in economic aging, defined as the pensioner-worker ratio, in selected countries and the OECD from 1960 to 2019. The series labeled "OECD" is the (unweighted) average per year over all countries. Data on the number of pensioners comes from our manually collected cross-national database on retirement. Data on the number of persons engaged is taken from the Penn World Tables, Version 10.0 (see Feenstra et al., 2015b for details).

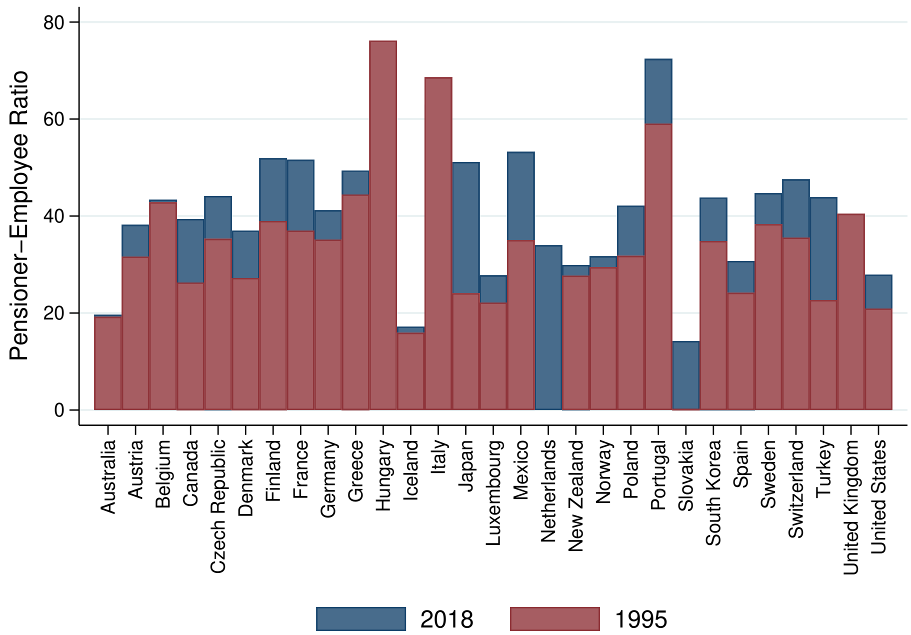
which we obtain from the Penn World Tables, version 10.0 (see Feenstra et al., 2015a for an overview of the general construction). The dataset includes the number of persons engaged, defined as the sum of employees and self-employed individuals. The ratio between the number of pensioners and the number of persons engaged precisely reflects the pensioner-worker ratio of our methodology framework.

3.3 Economic aging in the OECD

Our dataset allows for detailed documentation of the level of economic aging in the OECD and its development over the past six decades.

Trends in economic aging: Figure (1) shows trends in economic aging, defined as the pensioner-worker ratio, in selected countries and the OECD from 1960 to 2019. On

Figure 2 ECONOMIC AGING IN THE OECD (PENSIONER-WORKER RATIO)



Notes: The figure shows levels of economic aging, defined as the pensioner-worker ratio, across the countries included in our pensioner database for the years 1995 and 2018. Years are selected to maximize data availability over the longest possible time period for all countries in our sample. Data for 1995 is missing for the Netherlands and Slovakia. Data on the number of pensioners comes from our manually collected cross-national database on retirement. Data on the number of persons engaged is taken from the Penn World Tables, Version 10.0 (see Feenstra et al., 2015b for details).

average, we observe a substantial increase in the pensioner-worker ratio in the OECD countries. In 1960, pensioners in the OECD were equivalent to 16.6% of the labor force. This ratio almost tripled to 41.1% in 2019. We also find immense heterogeneity in the pace of economic aging between countries. While the pensioner-worker ratio sky-rocketed in Japan over the observation period, economic aging proceeded much slower in the United States, were the ratio of pensioners relative to the working population increased from 11.4% in 1960 to 28.5% in 2019.

Cross-national heterogeneity: Heterogeneity in the level of economic aging is particularly pronounced when examining the full set of countries included in our pensioner database. Figure (2) shows the ratio of pensioners relative to the working population for all countries in our dataset in the years 1995 and 2018. The figure uncovers large

Figure 3 ECONOMIC AGING AND DEMOGRAPHIC AGING

Notes: The figure shows the relationship between economic aging (defined as the ratio of pensioners to the labor force) and demographic aging (defined as the ratio of the population older than 64 to the labor force) for the year 2018. The black dashed line represents the 45-degree line where both metrics of aging are equal. Data on the number of pensioners comes from our manually collected cross-national database on retirement. Data on the number of persons engaged is taken from the Penn World Tables, Version 10.0 (see Feenstra et al., 2015b for details).

cross-national differentials in both the level and the change of the pensioner-worker ratio. The number of pensioners relative to the working population is particularly high in Hungary, Portugal, and Italy. At the other end of the spectrum, we observe low pensioner-worker shares in Australia, Iceland, and Slovakia. This heterogeneity emphasizes rich variation in the initial retirement structure, which is key for the construction of our instrumental variable (section 2.3). It also offers large variation that can be exploited to empirically estimate the effect of economic aging on productivity.

Relation to demographic aging: The momentous changes brought about by the demographic transition and its economic consequences have been extensively discussed (e.g. Poterba, 1998; Greenwood and Seshadri, 2002; Lee, 2003; Bloom et al., 2003; Murtin, 2013; Cervellati and Sunde, 2015; Cervellati et al., 2017). Starting with declining mortality rates in Europe around 1800, the demographic transition was characterized first by falling mortality rates and later by falling fertility rates. These developments initially caused population growth rates to accelerate and then to slow down, moving toward a state of low fertility, long life, and an old population. The transition has now spread to all parts of the world and is projected to be completed by about 2100 (Lee, 2003).

Naturally, the demographic transition should also lead to a higher fraction of pensioners relative to the labor force, but differences in economic institutions, retirement laws, and cultural norms result in sizable differentials between demographic aging and economic aging. Figure (3) shows these differences, relating the pensioner-worker ratio to demographic aging. Aging of the population is usually measured by the share of the population older than 64 to the working age population (old-age dependency ratio). Comparing this ratio to economic aging is uninformative because differentials might be driven by labor market dynamics that result in disparities between the working-age population and the labor force. We hence relate the population aged 65 or above to the number of persons engaged, which is equivalent to comparing the number of pensioners to the number of individuals older than 64.

While Figure (3) shows that demographic and economic aging is correlated (coefficient of correlation is 53.7%), it also reveals substantial differences in both metrics of aging. In countries below the 45-degree line—like the United States, Spain, South Korea, or Greece—the number of individuals aged 65 or above is larger than the number of pensioners. Put differently, older individuals in these countries are disproportionately often still part of the labor force and hence contribute to aggregate productivity. On the other end of the spectrum, individuals in Italy, Mexico, Turkey, or Portugal tend to retire early, and hence the number of pensioners is larger than the number of individuals older than 64.

Importantly, our hypothesis of productivity loss due to retirement suggests that many individuals in countries below the 45-degree line are still working, and hence relating aggregate productivity to demographic aging would ignore the fact that many individuals aged 65 or older are still productive. Similarly, early retirement in countries above the 45-degree line leads to an overestimation of the productive fraction of the population.

4 Productivity and other input data

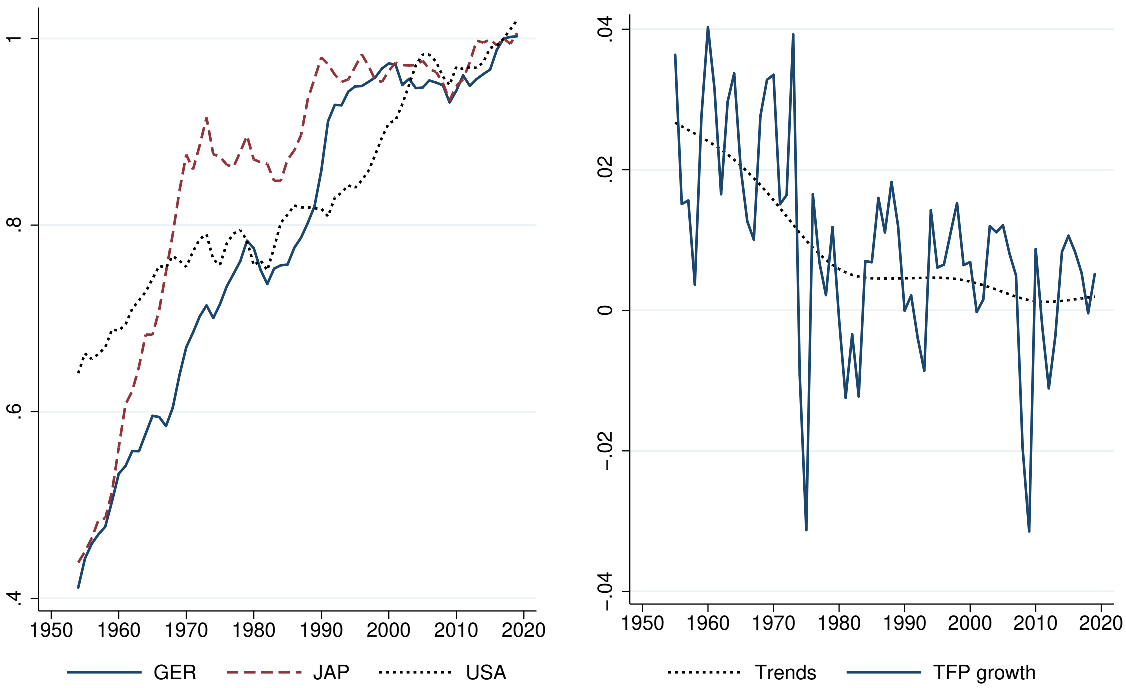
4.1 Total factor productivity

Aggregate productivity in our production function framework reflects a scaling parameter that is usually measured in growth accounting frameworks ("Solow residual"). For our benchmark estimates, we use data from the Penn World Tables (PWT), version 10.0, which is documented in detail by Feenstra et al. (2015b). Version 10.0 of the PWT dataset includes data for a total of 183 countries between 1950 and 2019.

Figure (4) shows trends in total factor productivity in the OECD over the past seven decades, 1950–2019. The left panel shows productivity gains in the Top-3 countries in terms of patent applications, serving as a proxy for the development of the global technological frontier. The figure shows that there have been substantial productivity gains between the 1950s and the mid-1990s, which materialized with major fluctuations over time. These fluctuations are consistent with the theory on general purpose technologies (GPTs), i.e. substantial technological innovations that triggered a series of accompanying technologies in the form of adoptions and improvements (see, e.g. Aghion et al., 2002; Crafts, 2004; Moser and Nicholas, 2004). These general GPT-induced productivity cycles can be observed at least since the 18th century (e.g. Berthold and Gründler, 2015).

Starting in the early 2000s, Figure (4) suggests a substantial decline in aggregate productivity gains. This slowdown is visible for Germany, Japan and the United States, but is also present in the full sample of established OECD countries, which is illustrated on the right-hand side of Figure (4). The decline in factor productivity growth has been shown to affect almost all OECD countries in a similar fashion (Berthold and Gründler, 2015), and has led to a renaissance of Hansen (1939)'s theory of "secular stagnation" (e.g. Eichengreen, 2015; Summers, 2015; Eggertsson et al., 2019). The supply-side interpretation of secular stagnation attributes the productivity growth decline to diminishing returns in the digital revolution, which gave rise to productivity leaps until the late 1990s but caused few fundamentally new applications since (e.g. Gordon, 2015).

Figure 4 TRENDS IN PRODUCTIVITY.



(a) Key innovating countries

(b) OECD countries.

Notes: The figure shows trends in total factor productivity (TFP) from 1950 to 2019. The figure on the left-hand side shows how TFP has developed in Germany, Japan and the United States, representing the most innovative countries in terms of patent applications. The figure on the right-hand side shows trends in TFP growth for the subsample of OECD countries that includes established democracies. The line labeled "Trend" reflects the trend in TFP growth in the OECD and has been computed using the Hodrick-Prescott filter. Data on total factor productivity comes from PWT, version 10.0 (see Feenstra et al., 2015b for details).

4.2 Data for other input variables and sample

Data for most of the remaining input variables of our empirical model specified in equation (16) also comes from the PWT, version 10.0. Since version 8.0, the PWT includes an index of human capital that includes two components: (i) the average years of schooling and (ii) returns to education based on Mincer equation estimates around the world (an extension of the estimates initially provided by Psacharopoulos, 1994).

The PWT includes measures of the capital stock and real GDP, along with figures on the total population (in millions) and the working population (in millions), defined as individuals that are employed or self-employed. The comparison between the population, the working-age population, and the number of persons engaged allows us to construct labor force participation rates, which account for the extensive margin of labor market dynamics. For the intensive margin, we use data on the number of average annual hours worked by persons engaged from the Total Economy Database (TED) collected by The Conference Board (2022). Following our macroeconomic methodology, we convert the input variables in per-worker terms using data on the number of persons engaged from the PWT.

Sample: Our benchmark estimates are obtained using data on OECD countries for three reasons. First, production structures and productivity differentials, key ingredients of the aging effect implied by our macroeconomic framework, are more comparable across the developed OECD countries than among the countries in the rest of the world. Second, pension systems in many developing countries are much less developed compared to the OECD. Third, the dominant strategy for countries farther away from the technological frontier would be to adopt technology developed elsewhere rather than pushing the technological frontier (e.g. Acemoglu et al., 2003; Acemoglu et al., 2006).

To further homogenize the sample, we also provide complementary evidence for a sub-sample of OECD countries which we refer to as "established democracies". These are democratic countries that joined the OECD before the fall of the Iron Curtain. The sub-sample of established democracies is more homogeneous regarding the composition of age structures, retirement laws and pension systems, per capita income, education, and other structural variables than the full sample of OECD countries.

Summary statistics: Summary statistics for the variables used in our analysis are reported in Table (B1) in the appendix, and for the sample of established democracies in Table (B2) in the appendix.

5 Effect of economic aging on aggregate productivity

5.1 Benchmark estimates

We begin with an ordinary least squares (OLS) estimation of the empirical model (Equation 16), which serves as a benchmark estimate. Table (1) presents the OLS coefficients summarizing the relationship between the pensioner-worker ratio and aggregate productivity. We report estimates for the full sample of OECD countries for which we were able to collect data on the number of pensioners (Columns I–II) and the subset of established democracies with highly developed public pension systems (Columns III–IV). For both samples, the table shows coefficients obtained in a parsimonious model and the full model specification derived in our methodological section.

The point estimates indicate that aggregate productivity is lower in countries with a higher ratio of pensioners to employees. We estimate that an increase in the pensioner-worker ratio by 10 points, equivalent to one-fourth of the ratio in the OECD in 2018, is associated with a decline in aggregate productivity by 4.7%. Limiting the sample to the more homogeneous sample of established democracies, we estimate a decline of 2.7%.

Figure (A1) in the appendix presents a graphical illustration of our OLS results using 10-year averages. Each data point represents an observation of the decadal average in a country, with the size of the dots representing population size. The figure visualizes the strong negative association between the pensioner-worker-ratio and aggregate productivity found in Table (1). Importantly, the figure reveals that this relationship is not driven by outliers or by particularly large or small counties in terms of population size.

5.2 Instrumental variable results

As noted above, there are multiple reasons for why aggregate productivity itself may impact pensioning. Most importantly, new production technologies may force workers into early retirement, which should result in upward biased OLS parameter estimates. We next employ predicted retirement structures in an instrumental variable framework to estimate the causal effect of economic aging on factor productivity.

5.2.1 First stage

Figure (5) relates the pensioner-worker ratio to predictions of this ratio obtained via pre-determined components of the retirement structure and cross-national retirement rates (see section 2.3). The figure reveals a strong positive association between realized and predicted numbers of economic aging. Panel B of Table (2) presents the estimated first-stage coefficients. When we predict the pensioner-worker ratio using retirement structures ten years before, we find that an increase in the predicted pensioner-worker

Table 1 ECONOMIC AGING AND PRODUCTIVITY—OLS RESULTS

Dependent variable: Log of total factor productivity, $\ln(A_{it})$

	OECD countries		**Established democracies**	
	(I) Parsimonious	(II) Full	(III) Parsimonious	(IV) Full
Economic aging, $\left(\frac{R}{L}\right)$	-0.0047*** (0.000)	-0.0009*** (0.000)	-0.0027*** (0.000)	-0.0016*** (0.000)
Observations	1,442	1,442	1,182	1,182
Units (# of Countries)	29	29	22	22
R-Squared	0.813	0.926	0.858	0.938
F-Stat	132.3	493.3	115.0	315.5
Prob. > F-Stat	0.000	0.000	0.000	0.000
Country FE	Yes	Yes	Yes	Yes
Period FE	Yes	Yes	Yes	Yes
Controls	No	Yes	No	Yes

Notes: The table reports OLS regression results on the relationship between the pensioner-worker ratio, D_{it}, and factor productivity $\ln(A)_{it}$, estimating the model of equation (16). Robust standard errors adjusted for arbitrary heteroskedasticity are reported in parentheses. The results reported in Columns (I)–(II) are obtained based on the full sample of OECD countries for which comparable data on the legal framework necessary for retirement is available in the OECD database. Columns (III)–(IV) report results based on the sub-sample of established Western democracies that have joined the OECD before the fall of the Iron Curtain and that had developed pension systems over the sample period.

*** Significant at the 1 percent level

ratio by ten points increases the actual ratio by 3.8 points in the OECD, and by 4.5 points in the subsample of established democracies.

Table (2) reports a series of instrument diagnostics. These tests all suggest that predicted pensioning patterns provide a strong and valid instrument for the realized pensioner-worker ratio. The first-stage F-statistic robust to non-*iid* errors (denoted by "Kleibergen-Paap F statistic") greatly exceeds the Stock-Yogo threshold of a maximum 10% IV bias and is also substantially larger than all other conventionally applied thresholds. Further robustness checks on underidentification (Kleibergen-Paap LM test) and weak-instrument-robust inferences (Stock-Wright LM test) underscore that the model is identified and that inferences are informative.

Finally, we also assess the validity of our results under the assumption that our instrumental variables are not *fully* but *plausibly* exogenous. To this end, we employ the union of confidence intervals (UCI) test proposed by Conley et al. (2012) and

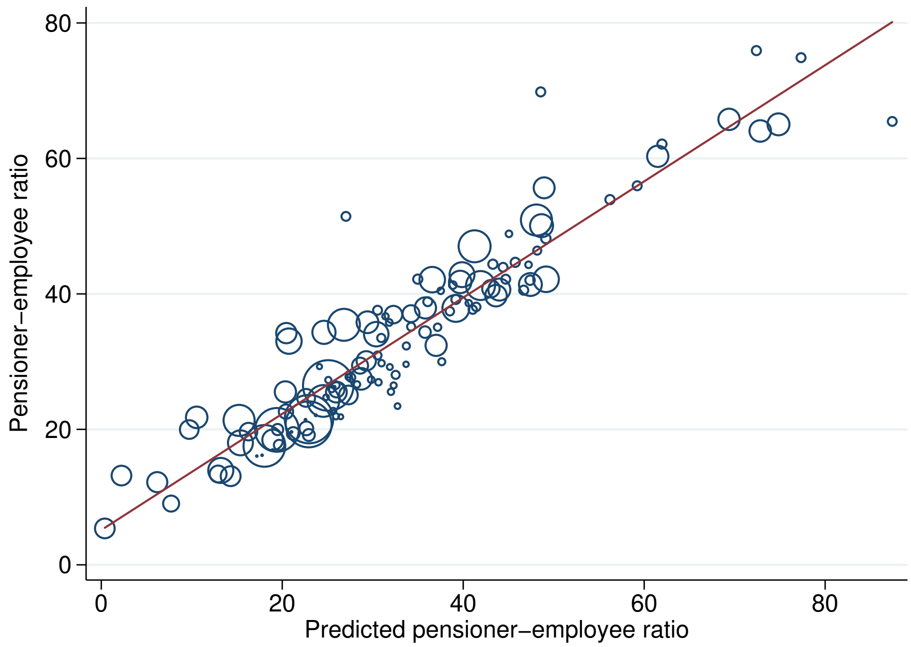
Table 2 ECONOMIC AGING AND PRODUCTIVITY—INSTRUMENTAL VARIABLE RESULTS

Dependent variable: Log of total factor productivity, $\ln(A_{it})$				
	OECD countries		**Established democracies**	
	(I) Parsimonious	(II) Full	(III) Parsimonious	(IV) Full
	Panel A: Second-stage regression results			
Economic aging, $\left(\frac{R}{L}\right)$	-0.00625***	-0.00288***	-0.00516***	-0.00258***
	(0.001)	(0.001)	(0.001)	(0.001)
	Panel B First-stage regression results			
Predicted aging, $\left(\frac{\hat{R}}{\hat{L}}\right)$	0.3841***	0.3265***	0.4445***	0.4302***
	(0.0257)	(0.0284)	(0.0221)	(0.0249)
Observations	1,152	1,152	959	959
Units (# of Countries)	29	29	22	22
R-Squared	0.332	0.735	0.126	0.638
F-Stat (χ^2)	122.4	499.1	40.65	231.7
Prob. > F-Stat	0.000	0.000	0.000	0.000
Kleibergen-Paap F-Stat	222.8	131.9	405.9	298.0
Stock-Yogo 10% max. IV	16.38	16.38	16.38	16.38
Country FE	Yes	Yes	Yes	Yes
Period FE	Yes	Yes	Yes	Yes
Controls	No	Yes	No	Yes

Notes: The table reports IV regression results on the effect of the pensioner-worker ratio, D_{it} on factor productivity $\ln(A)_{it}$, empirically employing the model of equation (16). Robust standard errors adjusted for arbitrary heteroskedasticity are reported in parentheses. The results reported in Columns (I)–(II) are obtained based on the full sample of OECD countries. Columns (III)–(IV) report results based on the sub-sample of established Western democracies that joined the OECD before the fall of the Iron Curtain and that had developed pension systems over the sample period. "Kleibergen-Paap F-Stat" reports the F-statistic of the first stage (which is valid when errors are not iid), with critical values for a maximum 10% IV bias compiled by Stock et al. (2005) denoted as "Stock-Yogo 10% max. IV".

*** Significant at the 1 percent level

Figure 5 REALIZED AND PREDICTED PENSIONER-WORKER RATIO



Notes: The figure visualizes the relationship between the realized and predicted pensioner-worker ratio. Our procedure to predict the pensioner-worker ratio using pre-determined retirement structures ten years before and cross-national retirement figures is described in detail in Section (2.3). Each data point represents an observation of the countries and years included in our sample, with the size of the dots representing population size.

van Kippersluis and Rietveld (2018). We find that inferences from our models are informative even if the exclusion restriction would be relaxed.[3]

5.2.2 Main estimates

Panel A of Table (2) reports second-stage results on the effect of economic aging on factor productivity. Across the board, the IV estimates are larger in size than the OLS estimates, consistent with an upwards bias in the OLS estimates initiated by early retirement due to technological progress. Instrumenting the pensioner-worker ratio with predicted retirement structures, we estimate that an increase in the pensioner-

[3]The UCI test considers an augmented version of our baseline specification that includes the term γZ_{it}. The exclusion restriction requires $\gamma = 0$. The UCI tests for $\gamma \neq 0$ and returns the union of all interval estimates of λ conditional on a grid of possible values for γ. We obtain estimates for the grid by using the 95% confidence interval borders of the reduced form parameter estimate obtained via the model $\ln(A_{it}) = \gamma Z_{it} + \varepsilon_{it}$.

worker ratio by 10 points decreases aggregate productivity by 6.25%. As one would expect, the differences in the estimated parameters between the OECD and the sub-sample of established democracies are smaller compared to the OLS estimates. This result is consistent with a larger upward bias in advanced industrial countries, where the potential for technology-induced early retirement is larger. Countries that have joined the OECD more recently (particularly those joining after the fall of the Iron Curtain) also had less developed pension systems at the beginning of our sample period.

5.3 Dynamic effects

Regarding the dynamic effects of economic aging, we re-specify our baseline empirical model in terms of growth rates, linking changes in the pensioner-worker ratio to growth rates in aggregate productivity. We follow the approach of Maestas et al. (2023) using changes between year t and $t + 10$ for our specification in growth rates to capture fundamental changes in productivity and aging rather than short-lived cyclical effects.

The model in growth rates allows us to estimate dynamics in the effect of economic aging on factor productivity. Consistent with our baseline model, we predict changes in the retirement structure using pre-determined components of economic aging multiplied by average retirement patterns in OECD countries (see section 2.3 for details). We then use these predictions as instrumental variables for realized economic aging. The key identifying assumption underlying the dynamic variant of our empirical model is that prior retirement structures do not predict *changes* in aggregate productivity between t and $t + 10$ through channels other than their relationship with realized retirement patterns during that period. The specification in growth rates also eliminates the potentially confounding impact of prior retirement structures and other unobserved cross-country differences on aggregate productivity. Estimating the model in terms of growth rates also addresses the possibility of a unit root in the error term.

Table (3) presents estimates of the dynamic effect of economic aging on productivity. Our estimates suggest that a 10% increase in the pensioner-worker ratio decreases factor productivity growth by 6.3% in the parsimonious model and by 10.1% in the fully specified model.

Table 3 ECONOMIC AGING AND PRODUCTIVITY—DYNAMIC EFFECTS

Dependent variable: Log difference of total factor productivity, $\Delta \ln(A_{it})$

	OLS Estimates		**IV Estimates**	
	(I) Parsimonious	(II) Full	(III) Parsimonious	(IV) Full
	Panel A: Second-stage regression results			
Economic aging (growth), $\nabla\left(\frac{R}{L}\right)$	-0.0102***	-0.0122***	-0.0634**	-0.101***
	(0.003)	(0.002)	(0.032)	(0.027)
	Panel B First-stage regression results			
Predicted aging (growth), $\nabla\left(\frac{\hat{R}}{\hat{L}}\right)$	–	–	0.0778***	0.0853***
	–	–	(0.0074)	(0.0100)
Observations	124	124	97	97
Units (# of Countries)	29	29	29	29
R-Squared	0.485	0.836	0.158	0.650
F-Stat (χ^2)	6.681	60.65	7.965	31.24
Prob. > F-Stat	0.000	0.000	0.000	0.000
Kleibergen-Paap F-Stat	–	–	72.78	109.8
Stock-Yogo 10% max. IV	–	–	16.38	16.38
Country FE	Yes	Yes	Yes	Yes
Period FE	Yes	Yes	Yes	Yes
Controls	No	Yes	No	Yes

Notes: The table reports OLS and IV regression results on the effect of an increase in the pensioner-worker ratio $\dot{D}_{it}$ on aggregate productivity growth $\Delta \ln(A)_{it}$, empirically employing a dynamic variant of the model of equation (16). Robust standard errors adjusted for arbitrary heteroskedasticity are reported in parentheses. The results reported in Columns (I)–(II) are obtained based on ordinaly least squares estimations. Columns (III)–(IV) report results based on our instrumental variable approach, which predicts changes in the pensioner-worker ratio using the same instrumental variables approach as in our levels estimation. "Kleibergen-Paap F-Stat" reports the F-statistic of the first-stage (which is valid when errors are not iid), with critical values for a maximum 10% IV bias compiled by Stock et al. (2005) denoted as "Stock-Yogo 10% max. IV".

*** Significant at the 1 percent level,
** Significant at the 5 percent level

5.4 Robustness

In this section, we explore the robustness of our main results to confounding trends and differential pension laws, changing strategies to predict retirement patterns for the IV estimates and sensitivity to outliers and weighting.

A. Robustness to confounding trends

OLS estimates of our central specification that we derived from an aggregate production function uncover a strong negative relationship between higher pensioner-worker ratios and factor productivity. These patterns emerge even when conditioning on fixed effects for countries and years. To separate the causal effect of economic aging on aggregate productivity from a potential reverse effect of technological advancement on retirement, we use predicted retirement structures in an instrumental variable approach. Our IV results imply that the OLS estimates are biased towards zero, as one would expect if technological process would indeed contribute to early retirement.

The key assumption of our instrumental variable approach is that the initial pensioning structure of a country does not predict trends or mean reversion in aggregate productivity except through the narrow causal path of influencing realized pensioning patterns. By conditioning our central equation on fixed effects for countries, we can eliminate those confounding elements that are time-invariant over the sample period. Such factors include differentials in cultural norms (like work ethics), institutions, or education systems, which may correlate with the initial share of retirees and which may impact factor productivity. Most of these variables are changing very slowly, if at all, over the sample period, and hence fixed effects should eliminate most of their confounding impact. Further evidence supporting the identifying assumption is the robustness of our main results to the inclusion of initial economic conditions (through lagged GDP per worker) in our fully specified model. The initial state of the economy should correlate with many of the time-varying confounders on the macro level and also accounts for convergence across countries.

A remaining threat to identification comes from *reforms* of the retirement system, which may be driven by the initial pensioning structure and that may affect productivity levels. In general, the impact of pension reforms on productivity should materialize predominantly via our central mechanisms, i.e. via lowering the availability of productive human capital through pensioning. We nevertheless examine the impact of pension reforms on our central estimates in Table (B3) in the appendix, conditioning on the average legal retirement age provided by the OECD Pensions at a Glance Database OECD (2021). The estimates are qualitatively identical to the main IV results when we account for changes in pension systems.

B. Robustness to changes in the prediction of aging

Our main specification uses ten-year lags in the pensioning structure to predict realized pensioner-worker shares. To test whether the lag structure is driving our results, we alter the time horizon we use for prediction. This test also provides further evidence for the plausibility of the key identifying assumption underlying our instrumental variable approach, as it becomes increasingly unlikely that common trends drive initial pensioning structures and future productivity as the lags grow more distant. However, imposing a longer lag structure also comes at the cost of substantially decreasing the number of country-year observations that can be used for estimation.

In Tables (B4) and (B5) in the appendix, we demonstrate how alternative choices of the lag structure used to predict actual pensioning patterns impact our estimates. Results are reported for the full sample of OECD countries (Table B4) and the subsample of established democracies (Table B5). Given that some of the countries in the full sample had less developed pension systems at earlier stages of our sample, the sample of established democracies may deliver more accurate results when the prediction of pension rates relies on (very) distant lags.

The results underline that our main estimates are not sensitive to the chosen lag of ten years. We first replicate our baseline specification of $t-10$ for each sample we can use when employing a lag of $t-n$ as a benchmark (Panel A). We then present first-stage (Panel B) and second-stage (Panel C) results for the alternative prediction horizons, running from $t-5$ to $t-25$. As expected, the first stage coefficients gradually decrease as we use longer lags to predict future retirement structures: a 10-point increase in the predicted pensioner-worker ratio is related to an increase in the realized ratio of 6.9 points for $t-5$, which decreases to 4.3 points ($t-10$), 2.5 points ($t-15$), 1.8 points ($t-20$), and 1.4 points ($t-25$) when exploiting larger time horizons for prediction. Accordingly, the first-stage F statistic (denoted by "Kleibergen-Paap") decreases for larger lags but still points to reasonably strong instruments across all models.

Regarding the second-stage results, the negative effect of retirement on productivity remains economically and statistically significant across all specifications. The effect size of our instrumental variable estimates increases when predicting pension structures over longer periods (Panel C). As the benchmark estimates of Panel A indicate, the increase in the coefficient size is largely caused by a restriction of the sample. Increasing coefficient sizes for longer time horizons to predict pensioning (i.e. relying on more recent observations in the second stage) also suggest that the negative effect of economic aging on aggregate productivity has *intensified* over time.

A major implication that we draw from altering the lag structure of our instrument is that our main IV estimate is unlikely to be confounded by underlying economic trends. Put differently, the consistency of the results across the time periods used to predict pensioning patterns implies that fixed effects for countries and years are appropriate to account for potential independent effects of the initial pensioning structure. The first- and second-stage coefficients and the associated instrument diagnostics also suggest that the 10-year lag structure strikes a good balance between maximizing the sample size and reducing the threat of confounding trends.

C. Robustness to weighting and outliers

In Table (B6) in the appendix, we present re-estimates of the baseline instrumental variable specifications weighted by population size. When accounting for differentials in size, we estimate a slightly larger change in aggregate productivity of -7.3% (compared to -6.3% in the baseline model) in response to a 10-point increase in the pensioner-worker ratio. The results of the weighting exercise, however, show that the negative impact of pensioning on aggregate productivity is not driven by cross-country differentials in population size.

The added variable plot of our OLS results, shown in Figure (A1), suggests that our estimates are not driven by outliers. Given the substantial differentials in the pensioner-worker ratio documented in section (3.3), however, we inspect whether our results are driven by a particular country. Table (A2) reports results from a jack-knife re-sampling analysis, in which we gradually exclude individual countries from the sample ("leave-one-out"). The results plot leaves little space for our results to be driven by outliers. Each parameter estimate lies within the 95% confidence interval of our main instrumental variable estimates, both for the full sample of OECD countries (Panel a) and the sub-set of established democracies (Panel b).

5.5 Economic aging versus demographic aging

The central argument of our methodological framework is that aging decreases factor productivity via a loss of productive human capital, a mechanism that we refer to as "economic aging". The logic underlying this mechanism is that absent of retirement, human capital of older workers would still be productivity-enhancing. Contrary to other theories of demographic aging that posit dwindling creativity, our mechanism reflects the mechanical loss of productive human capital after retirement. Absent of retirement, older workers would still be productive and may also encourage innovation processes by providing guidance, sharing experience, or serving as role models, even in the face of declining creativity. After retirement, such inputs are lost.

Retirement, however, inevitably goes hand in hand with demographic aging. One possible explanation for our main estimates may be that the estimated coefficients pick up effects from demographic aging, e.g. when the negative productivity effects of declining creativity or physical restrictions exceed the positive effects of experience and foresight.

We next disentangle the effect of *economic* aging from *demographic* aging by including the old-age dependency ratio into our baseline empirical models. To be consistent, we employ the same instrumental variable approach for demographic aging that we use for economic aging, instrumenting the old-age dependency ratio by pre-defined components of demographic aging, multiplied by cross-national aging patterns. We predict the number of individuals aged 65 and above using numbers from $t-10$ and average survival rates in the OECD between $t-10$ and t. By the same logic, we obtain predictions for the working-age population to arrive at predictions for the old-age dependency ratio.

Table (4) presents the results. If our estimates would mainly reflect demographic trends, then we would expect that the parameter estimates for economic aging would go to zero once we include demographic aging, which in turn should negatively affect productivity. Instead, we estimate a small and statistically insignificant coefficient on the demographic aging variable. The negative effect of economic aging re-appears in each specification. The effect size is comparable to our main estimates, indicating that a 10-point increase in the pensioner-worker ratio decreases aggregate productivity by 7.2%.

The results of Table (4) allow us to draw two important conclusions about the anatomy of our main estimates. First, it is not aging *per se* that triggers negative

Table 4 ECONOMIC AGING VERSUS DEMOGRAPHIC AGING

Dependent variable: Log of total factor productivity, $\ln(A_{it})$

	OECD countries		**Established democracies**	
	(I) Parsimonious	(II) Full	(III) Parsimonious	(IV) Full
Economic aging, $\left(\frac{R}{L}\right)$	-0.00729***	-0.00258**	-0.00749***	-0.00184**
	(0.001)	(0.001)	(0.001)	(0.001)
Demographic aging, $\left(\frac{L^{65+}}{L^{15-64}}\right)$	0.00009	-0.00004	0.0008	-0.0004
	(0.001)	(0.000)	(0.001)	(0.000)
Observations	1,152	1,152	959	959
Units (# of Countries)	29	29	22	22
R-Squared	0.239	0.687	0.109	0.642
F-Stat (χ^2)	122.4	499.1	40.65	231.7
Prob. > F-Stat	0.000	0.000	0.000	0.000
Kleibergen-Paap F-Stat	80.57	49.32	142.7	107.7
Stock-Yogo 10% max. IV	7.03	7.03	7.03	7.03
Country FE	Yes	Yes	Yes	Yes
Period FE	Yes	Yes	Yes	Yes
Controls	No	Yes	No	Yes

Notes: The table reports IV regression results on the effects of economic aging and demographic aging on factor productivity. The specifications are based on equation (16), augmented by the old-age dependency ratio to disentangle the effect of pensioning from the effect of aging *per se*. The instrumental variable for the old-age dependency ratio is constructed based on the same logic as the instrument for the pensioner-worker ratio. Robust standard errors adjusted for arbitrary heteroskedasticity are reported in parentheses. The results reported in Columns (I)–(II) are obtained based on the full sample of OECD countries. Columns (III)–(IV) report results based on the sub-sample of established Western democracies that joined the OECD before the fall of the Iron Curtain and that had developed pension systems over the sample period. "Kleibergen-Paap F-Stat" reports the F-statistic of the first-stage (which is valid when errors are not iid), with critical values for a maximum 10% IV bias compiled by Stock et al. (2005) denoted as "Stock-Yogo 10% max. IV".

*** Significant at the 1 percent level,
** Significant at the 5 percent level

productivity effects, but rather the dropout of productive workers from the production function caused by pensioning. Second, the fact that the estimated effects of economic aging hardly change when including demographic aging provides additional evidence for the validity of our identification strategy.

6 Mechanisms

Our theory suggests that a decrease in the working population created by retirement lowers productive human capital and hence decreases aggregate productivity compared to a counterfactual in which the retired workers would still be part of the workforce. Our macroeconomic framework also predicts that the effect of economic aging depends on the labor intensity of production and cohort-specific differentials in worker productivity, which determine the potential to offset the negative productivity effects of retirement through automation. Finally, our framework predicts that a loss of productive human capital should limit the potential to innovate, which is particularly important for productivity gains in the sample of developed OECD economies that are close to the technological frontier. In this section, we provide evidence supporting these predictions.

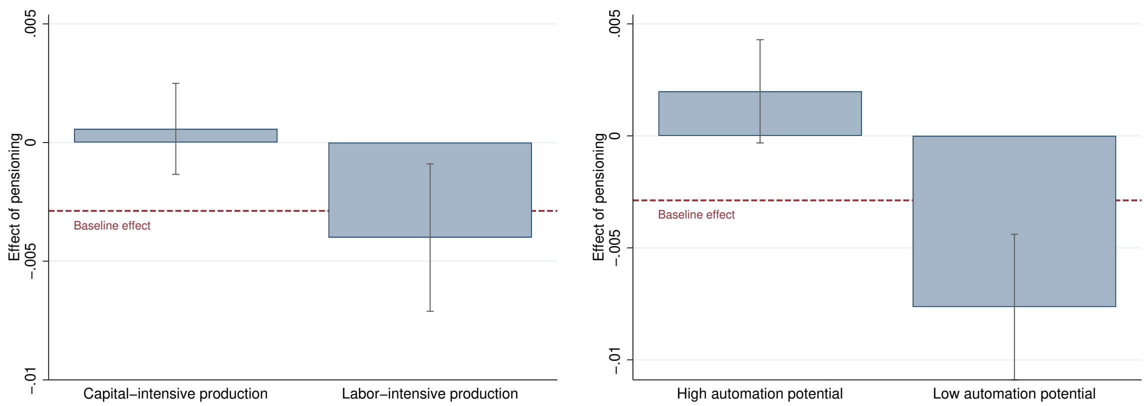
6.1 Labor intensity and automation

The production function framework in section (2) implies that economic aging should be particularly negative for productivity when a country's production is labor-intense and when the workers who retire have high productivity, limiting the potential to substitute their loss by automating tasks (see equation 14). As a first step of our analysis of the mechanisms underlying our main estimates, we examine whether these predictions are reflected in the data.

Figure (6) shows the results of our main IV model, differentiating between countries with high (low) labor intensity in production and high (low) potentials to automate tasks. Data on labor intensity is obtained from the Penn World Tables.[4] For the potential to automate tasks, we take the numbers computed by Nedelkoska and Quintini

[4]To identify labor-intensive and capital-intensive countries, we relate a country's capital stock to GDP and define those observations as capital-intensive that have a share of capital relative to GDP above the median in our sample. Production in the remaining countries is classified to be labor-intensive. By using the median as a cut-off point, we allow countries to switch between regimes.

Figure 6 THE PRODUCTIVITY EFFECT OF ECONOMIC AGING, BY CAPITAL INCOME SHARE AND AUTOMATION POTENTIAL



(a) By labor intensity. **(b)** By automation potential.

Notes: The figure visualizes the regression results on the relationship between the pensioner-worker ratio, D_{it}, and total factor productivity depending on the labor income share and the potential to automate tasks. Data on labor income shares is obtained by the OECD's Compendium of Productivity Indicators (OECD, 2019). For the potential to automate tasks, we use the numbers computed by Nedelkoska and Quintini (2018). Vertical lines represent 95% confidence intervals.

(2018), who collect expert assessments regarding the automatability of a wide range of occupational classes and then match these figures with industrial structures of OECD countries.

Our empirical results are consistent with the predictions of our macroeconomic framework. We find that the negative effect of economic aging is stronger for the subset of countries with labor-intensive production (Panel a) and a high automation potential (Panel b). The results suggest that automation can fill the productivity gap created by retirement when the tasks previously performed by now-retired workers can be automated, i.e. when cohort-specific productivity levels of retirees are low. For more complex tasks that require higher productivity, an increase in the pensioner-worker ratio initiates productivity losses that are harder to replace. These effects are scaled by the degree to which a country relies on labor inputs for production.

6.2 Retirement and the loss of productive human capital

The productivity losses initiated by an increase in the pensioner-worker ratio are potentially most costly for the creation of fundamentally new knowledge at the technological frontier, which requires input from high-ability workers and researchers. Hence, we hypothesize in our theoretical analysis in section (2) that innovation is an important mechanism through which the loss of π_R channels into decreasing productivity levels.

To examine the relationship between economic aging and innovation, we first focus on the *inputs* of the production function for new ideas and technologies. Standard models of innovation production relate innovations and new technologies to the stock and human capital of R&D scientists (e.g. Romer, 1990). An increase in the pensioner-worker ratio implies that the number of older workers that retire exceeds the number of new workers that enter the labor market. Depending on cohort-specific differentials in productivity, economic aging should give rise to a decline in a country's productive human capital that can serve as input factors for the innovation production function.

We use data from the joint OECD-Eurostat international data collection on resources devoted to R&D, which includes information on R&D personnel by sector and major field of R&D for OECD countries from 1981 onward. For estimation, we relate the pensioner-worker ratio to the number of R&D personnel per 1,000 workers, using the same model specifications as in our baseline models for factor productivity.

The results are presented in Table (5). Across all model specifications, we find an economically sizable and statistically significant coefficient of economic aging. We estimate that an increase in the pensioner-worker ratio by 10 points is associated with a decrease in the number of R&D personnel per 1,000 workers of 1.27.

The relationship between the pensioner-worker ratio and the number of R&D personnel suggests that economic aging is associated with a decline in human capital that can serve as an input for the technology production function. Figure (A3) in the appendix provides additional evidence for the plausibility of this interpretation. Panel (a) of Figure (A3) depicts estimation results for sectors of employment. The figure shows that the largest part of the overall effect is triggered by a reduction in R&D personnel employed in the business sector, and much less by a decline in the number of researchers working for the government, in the education sector, or for non-profit companies. Panel (b) provides complementary evidence by examining the field of research. These results show that economic aging is strongly associated with a decline in R&D personnel working in the natural sciences and engineering, where most of the

Table 5 ECONOMIC AGING AND R&D PERSONNEL

Dependent variable: R&D personnel per 1,000 workers

	OECD countries		**Established democracies**	
	(I) Parsimonious	(II) Full	(III) Parsimonious	(IV) Full
Economic aging, $\left(\frac{R}{L}\right)$	-0.127***	-0.125***	-0.0898***	-0.180***
	(0.017)	(0.020)	(0.022)	(0.021)
Observations	693	693	533	533
Units (# of Countries)	29	29	22	22
R-Squared	0.888	0.888	0.867	0.883
F-Stat	56.33	14.84	16.13	22.38
Prob. > F-Stat	0.000	0.000	0.000	0.000
Country FE	Yes	Yes	Yes	Yes
Period FE	Yes	Yes	Yes	Yes
Controls	No	Yes	No	Yes

Notes: The table reports OLS regression results on the relationship between the pensioner-worker ratio, D_{it}, and the number of R&D personnel per 1,000 workers. The specifications follow the basic model of equation (16). Robust standard errors adjusted for arbitrary heteroskedasticity are reported in parentheses. The results reported in Columns (I)–(II) are obtained based on the full sample of OECD countries. Columns (III)–(IV) report results based on the sub-sample of established Western democracies that have joined the OECD before the fall of the Iron Curtain and that had developed pension systems over the sample period.

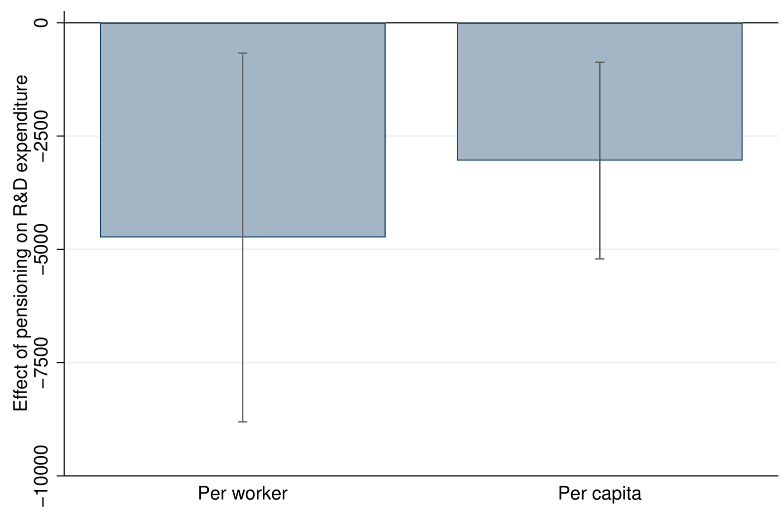
*** Significant at the 1 percent level

productivity-enhancing new technologies are created and improved. By contrast, we find no negative relation between pensioning and the number of researchers working in the social sciences.

6.3 Public expenditure for R&D

Another important input for the innovation production function is the public budget invested in research. A higher pensioner-worker ratio should result in a mechanical increase in public spending due to pension entitlement, which potentially crowds out other spending categories. In Table (B7) in the appendix, we quantify the effect of an increased pensioner-worker ratio on public pension spending. We find that the effects of economic aging on public budgets are sizable. Using the same model specifications as employed for our benchmark estimates, we estimate that an increase in the pensioner-worker ratio by 10 points is associated by an increase in public pension spending relative

Figure 7 ECONOMIC AGING AND R&D EXPENDITURE.



Notes: The figure visualizes the regression results on the relationship between the pensioner-worker ratio, D_{it}, and public expenditure for research and development. Results are obtained based on the full sample of OECD countries. Vertical lines represent 95% confidence intervals.

to GDP by 1.5%. We next examine whether this sizable increase in public spending crowds out other components of public budgets, particularly spending categories that determine the scope of resources channeled into R&D.

We employ data on public R&D expenditure collected by UNESCO's Institute for Statistics, which combines data on researchers, technicians, and expenditure on R&D from multiple sources. Figure (7) shows how the pensioner-worker ratio relates to R&D expenditure, using our full model specification for the OECD. Our estimates show that a 10-point increase in the pensioner-worker ratio is associated with a decrease in public investment in R&D by 4,738 USD per worker and by 3,041 USD per capita.

Is the decline in R&D expenditure driven by a re-prioritization of the spending categories of public budgets? Previous research has shown that the pressure on public finances initiated by demographic aging changes the composition of public budgets (e.g. Razin et al., 2002; Shelton, 2008; Haelg et al., 2022). To quantify the relationship between economic aging and the individual budget components, we use data from the OECD's National Accounts Statistics (OECD, 2021) that distinguishes public expenditure by spending categories. In Table (B8) in the appendix, we present results on the budgetary consequences of pensioning for seven main spending categories, including general public services, defense, public order, economic affairs, health, education, and social protection. We find sizable and statistically significant correlations of the pensioner-worker ratio with several components of public budgets. The results show that economic aging is positively related to public spending on social protection, the category that also includes public pension spending. The results also reveal that economic aging is positively related to spending on public services, and negatively associated with spending on public safety and economic affairs. The results are even stronger for the sample of established democracies (see Table B9 in the appendix). Taken together, the results regarding the composition of public budgets are in line with the hypothesis that with greater economic aging, expenditure on R&D is (mechanically) crowded out by more spending on pensioning and health-related topics.

6.4 Retirement and R&D output

We next examine whether the reduced inputs into research in countries with higher rates of economic aging channels into a decline in research output. For countries at the technological frontier that rely on innovation-based strategies rather than on the adoption of existing technologies, a reduction in R&D personnel and resources should limit the scope for improvements in aggregate productivity.

To estimate the effect of an increasing pensioner-worker ratio on innovation activity, we use data from the World Intellectual Property Organization's (WIPO) statistics on worldwide patent activity (see WIPO, 2021), which is available for residents and non-residents. Patents included in the statistics are filed through the Patent Cooperation Treaty procedure or with a national patent office for exclusive rights for an invention. As a complementary measure for innovation activity, we use data on scientific and technical journal articles compiled by the National Science Foundation (see NSF, 2021). Our indicator refers to the number of scientific and engineering articles published in physics, biology, chemistry, mathematics, clinical medicine, biomedical research, engineering and technology, and earth and space sciences.

Table (6) shows that economic aging is negatively related to innovation activity. The effect is significant both in economic and statistical terms. Regarding patent applications, we find that an increase in the pensioner-worker ratio by 10 points is related to a decrease of roughly 9,000 patents. Compared to the average number of patent applications in the sample of established OECD countries (39,466.56), the effect of pensioning on innovation output is substantial. As a falsification test, we also esti-

Table 6 ECONOMIC AGING AND INNOVATION ACTIVITY

Dependent variable: Proxies of innovation activity (measured in numbers)

	(I) Patents: Residents	(II) Patents: Non-residents	(III) Patents: All	(IV) Scientific Journal Articles
Economic aging, $\left(\frac{R}{L}\right)$	-695.2***	-212.3	-912.0***	-239.4*
	(157.997)	(150.046)	(294.787)	(133.305)
Observations	1,048	1,049	1,048	550
Units (# of Countries)	29	29	29	29
R-Squared	0.925	0.755	0.868	0.988
F Stat	23.85	15.08	18.23	16.96
Prob. > F-Stat	0.000	0.000	0.000	0.000
Controls	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes
Period FE	Yes	Yes	Yes	Yes

Notes: The table reports OLS regression results on the relationship between the ratio of pensioners relative to the working-age population (economic aging), $\frac{R}{L}$, and innovation activity, re-estimating our baseline models of Table (1) with metrics for innovation activity. Robust standard errors adjusted for arbitrary heteroskedasticity are reported in parentheses. All results are based on the full sample of 29 OECD countries used for our baseline estimates on the effect of economic aging on factor productivity. Data on patent applications comes from the World Intellectual Property Organization's (WIPO) statistics on worldwide patent activity (see WIPO, 2021). Data on scientific and technical journal articles is obtained from the National Science Foundation (see NSF, 2021).

*** Significant at the 1 percent level,
** Significant at the 5 percent level

mate the relationship between economic aging and the number of patent applications separately for residents and non-residents. The rationale behind this distinction is that for a patent-decreasing effect of economic aging, the domestic population should be decisive, whereas we would not expect to see an effect for patents that are registered by foreigners. Our results are in line with this prediction, revealing a significantly negative relationship between economic aging and patent applications of residents, but not for non-residents.

As a complementary measure to quantify R&D output, we also examine the relationship between economic aging and the number of scientific research articles published in international journals. Consistent with the previous results, we also find a negative relationship between an increasing pensioner-worker ratio on scientific research output. All results are qualitatively identical in the sample of established democracies (see Table B10 in the appendix).

7 Conclusions

The populations of many industrialized countries are aging rapidly, leading to a historical rise in retirement. This paper has established that economic aging in the form of an increasing pensioner-worker ratio negatively affects total factor productivity, a result which has important policy implications for the next decade when the baby boom generation will enter retirement.

Our main estimate suggests that a 10-point increase in the pensioner-worker ratio leads to a 5-6% decrease in factor productivity in the OECD countries. We also show that this effect depends on the importance of labor input for production and the potential to automate tasks performed by workers retiring.

Arguing that current retirement patterns have long historical roots, our estimates are obtained using the pre-determined components of pensioning in an instrumental variable setting. Instrumenting current pensioner-worker ratios with predictions that are based on historical pensioning rates allows for causal estimation under the assumption that there is no independent effect of the pre-determined pensioning structure on current factor productivity. How plausible is this assumption in a cross-country setting? An important disadvantage of our setting is that there might be unobserved country-specific shocks that impact our results. While we cannot fully rule out the presence of such shocks, we take several steps to address their potential impacts. Our design focuses on the OECD and a homogeneous subset of established democracies. To the extent that this set of countries is uniformly affected, our research design also accommodates the impact of unobserved shocks. To the extent that such shocks are country-specific, they are absorbed by the country-fixed effects. While this strategy does not account for time-varying unobserved factors that correlate systematically with the timing of major increases in retirement, we argue that the time lag of ten years used to predict the pensioner-worker ratio makes it unlikely that unobserved trends and shocks are correlated simultaneously with initial pensioning patterns and future productivity levels. Given the robustness and consistency of our estimates, the degree of confounding would need to be substantial to explain away our results.

An important advantage of our setting over state-level or municipality-level analyses is that we can account for policy responses to population aging, unobserved time-invariant heterogeneity across countries, and systematic differences in pension laws. Also and importantly, our research focus is on the aggregate productivity effects caused by population aging and retirement, a question that inevitably calls for a cross-country research design.

Our findings have important policy implications regarding the future rate of productivity growth. Examining how policy measures could be designed to tackle the momentous macroeconomic challenges caused by population aging and retirement is an important avenue for future research.

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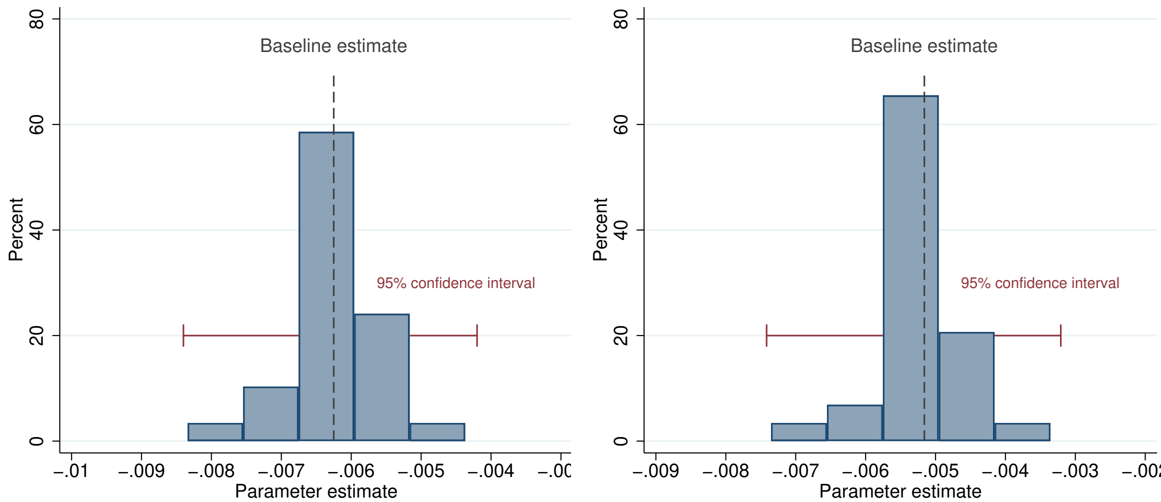
Appendix A: Supplementary Figures

Figure A1 ECONOMIC AGING AND PRODUCTIVITY—OLS RESULTS, ADDED VARIABLE PLOT

Notes: The figure visualizes the benchmark OLS results, presenting an added variable plot that depicts the estimated relation between economic aging (pensioner-worker ratio) and aggregate productivity, conditional on the variables included in the full models specification of Equation (16). Each data point represents an observation of the decadal average in a country, with the size of the dots representing population size.

Figure A2 JACK-KNIFE RE-SAMPLING ANALYSIS ("LEAVE-ONE-OUT").

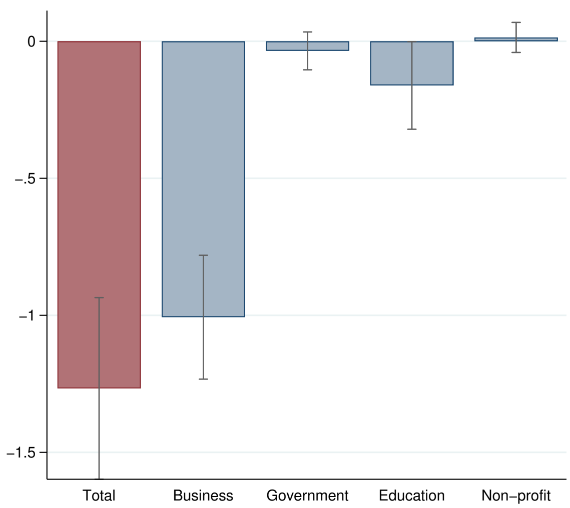


(a) Full sample of OECD countries.

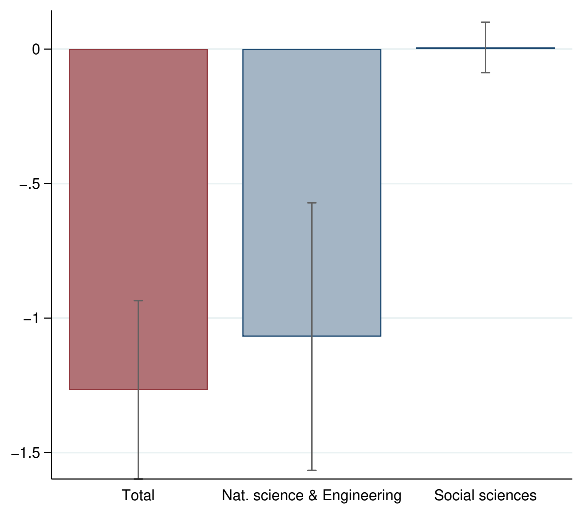
(b) Established democracies.

Notes: The figure shows results from a jack-knife re-sampling analysis ("leave-one-out") of our main instrumental variable results (Table 2). The figure plots the distribution of estimates obtained when gradually excluding single countries from our sample (one by one). The horizontal line graphics the 95% confidence interval of the baseline estimate on the effect of economic aging on aggregate productivity. the grey vertical line marks the baseline regression coefficient. Results are illustrated for the parsimonious model specification for the full sample of OECD countries (Panel a) and the sub-sample of established democracies (Panel b).

Figure A3 ECONOMIC AGING AND R&D PERSONNEL



(a) By sector of employment.



(b) By field of research.

Notes: The figure visualizes the regression results on the relationship between the pensioner-worker ratio, D_{it}, and the number of R&D personnel per 1,000 workers. The figure shows the response of R&D personnel by sector of employment and field of research that is related to an increase in the pensioner-worker ratio by 10 points. Results are obtained based on the full sample of OECD countries (Column I of Table 5). The bar labeled "total" represents the estimated parameter on the total number of R&D personnel as a benchmark. Vertical lines represent 95% confidence intervals.

Appendix B: Supplementary Tables

Table B1 SUMMARY STATISTICS OF VARIABLES—FULL OECD SAMPLE

	Obs.	**Mean**	**Std. dev.**	**Min**	**Max**
	Panel A: Pensioning and aging data				
Pensioner (raw data)	1,563	4786089	6845847	653.614	4.51e+07
Pensioner-worker ratio	1,487	31.33458	14.5862	0.0052335	80.62837
Predicted ratio (instrument)	1,155	34.45959	15.3003	0.0058046	91.65322
Old-age dependency ratio	1,740	6.772111	10.74876	0.0247656	79.66887
Predicted ratio (instrument)	1,450	7.281309	11.28962	0.0311891	76.80508
Average retirement age	1,902	62.422	4.163483	42	70
	Panel B: Production function inputs				
$\ln(A)$	1,790	-0.1345207	0.2119734	-0.9457806	0.4433351
$\ln(Y)$	1,906	10.87417	0.5799501	8.523357	11.80811
$\ln(k)$	1,906	12.50524	0.7294399	9.738612	13.60018
$\ln(h)$	1,906	0.9978853	0.2388586	0.1325792	1.347823
Labor force participation rate	1,906	0.4456119	0.0681275	0.2333487	0.7481585
Hours worked (per worker)	1,793	1868.11	267.3795	1380.608	3039.794
Persons engaged (millions)	1,906	15.63367	23.67338	.0654681	158.2996
Total population (millions)	1,906	35.66691	51.15672	0.1431635	329.0649
Real GDP (2017 prices, millions)	1,906	1029648	2180451	1212.178	2.06e+07
	Panel C: Innovation function inputs and outputs				
R&D personnel per 1,000 worker	717	10.39268	4.648271	0.7864518	23.70131
Patent applications (residents)	1,100	23449.43	67228.22	14	384201
Patent applications (non-res.)	1,101	12056.84	35140.83	3	336340
Patents (total)	1,100	35506.25	94156	24	621453
Scientific journal articles	551	41315.06	72530.31	65.26	433192.3
	Panel D: Public spending categories				
Pension spending	1,067	7.115669	3.385742	0.167	17.45
Public services	624	6.682079	2.346522	2.595325	16.70148
Defense	624	1.754462	1.169878	0.0165645	7.876611
Public order	624	1.607111	0.4866592	0.7402719	4.341982
Economic affairs	624	4.914985	1.523244	1.334702	18.67017
Health	624	5.89393	1.920015	0.188157	9.291896
Education	624	5.19055	0.9357154	3.216046	7.400156
Social protection	624	15.28366	5.733207	0.6686691	27.47935

Notes: The table reports summary statistics for the variables used in our estimations. The sample includes all observations for OECD countries. The tables lists all available information per variable for the OECD countries. "Std. dev." denotes the standard deviation of the variables.

Table B2 SUMMARY STATISTICS OF VARIABLES—SAMPLE OF ESTABLISHED DEMOCRACIES

	Obs.	**Mean**	**Std. dev.**	**Min**	**Max**
	Panel A: Pensioning and aging data				
Pensioner (raw data)	1,200	5042912	7240115	19785	4.51e+07
Pensioner-worker ratio	1,200	30.65764	13.43168	5.293312	80.62837
Predicted ratio (instrument)	962	33.61258	13.88901	6.049207	78.76148
Old-age dependency ratio	1,380	7.409358	11.91011	0.0247656	79.66887
Predicted ratio (instrument)	1,100	8.329207	12.69865	0.0311891	76.80508
Average retirement age	1,500	63.425	3.068872	55	70
	Panel B: Production function inputs				
$\ln(A)$	1,517	-.1548998	0.2057035	-0.9457806	0.3607532
$\ln(Y)$	1,609	10.9825	0.5346964	8.842432	12.25049
$\ln(k)$	1,609	12.65968	0.6092394	10.11352	13.62023
$\ln(h)$	1,609	1.020589	0.2048033	0.2166238	1.328028
Labor force participation rate	1,609	0.4565432	0.059021	0.3063721	0.7481585
Hours worked (per worker)	1,554	1829.73	227.3836	1380.608	2428.279
Persons engaged (millions)	1,609	15.3201	25.40836	0.0654681	158.2996
Total population (millions)	1,609	33.58399	54.36757	0.1431635	329.0649
Real GDP (2017 prices, millions)	1,609	1087254	2354120	1212.178	2.06e+07
	Panel C: Innovation function inputs and outputs				
R&D personnel per 1,000 worker	594	11.42448	4.359379	2.171304	23.70131
Patent applications (residents)	863	26006.25	73087.84	14	384201
Patent applications (non-res.)	864	13458.71	39094.79	3	336340
Patents (total)	863	39466.56	102881	24	621453
Scientific journal articles	437	46958.92	80108.69	65.26	433192.3
	Panel D: Public spending categories				
Pension spending	896	7.448188	3.152974	1.525	17.45
Public services	503	6.924178	2.197733	3.062681	16.70148
Defense	503	1.670514	1.229411	0.0165645	7.876611
Public order	503	1.53787	0.360173	0.7402719	2.518222
Economic affairs	503	4.616702	1.560262	1.334702	25.03866
Health	503	6.32013	1.53249	1.448945	9.291896
Education	503	5.295647	0.9529088	3.165548	7.400156
Social protection	503	16.4341	4.924353	5.484872	27.47935

Notes: The table reports summary statistics for the variables used in our estimations. The sample includes all observations for established democracies in the OECD, which have joined the OECD already before the fall of the Iron Curtain. The tables lists all available information per variable for the sample of established democracies. "Std. dev." denotes the standard deviation of the variables.

Table B3 ECONOMIC AGING AND PRODUCTIVITY—INSTRUMENTAL VARIABLE RESULTS, ACCOUNTING FOR RETIREMENT LAWS

Dependent variable: Log of total factor productivity, $\ln(A_{it})$

	OECD countries		Established democracies	
	(I) Parsimonious	(II) Full	(III) Parsimonious	(IV) Full
	Panel A: Second-stage regression results			
Economic aging, $\left(\frac{R}{L}\right)$	-0.00631***	-0.00232***	-0.00603***	-0.00266***
	(0.001)	(0.001)	(0.001)	(0.001)
	Panel B First-stage regression results			
Predicted aging, $\left(\frac{\hat{R}}{\hat{L}}\right)$	0.3549***	0.3824***	0.4246***	0.4271***
	(0.0245)	(0.0236)	(0.0238)	(0.0216)
Observations	1,152	1,152	959	959
Units (# of Countries)	29	29	22	22
R-Squared	0.377	0.751	0.191	0.646
F-Stat	108.4	490.8	44.39	216.1
Prob. > F-Stat	0.000	0.000	0.000	0.000
Kleibergen-Paap F-Stat	262.9	209.8	389.1	316.9
Stock-Yogo 10% max. IV	16.38	16.38	16.38	16.38
Country FE	Yes	Yes	Yes	Yes
Period FE	Yes	Yes	Yes	Yes
Controls	No	Yes	No	Yes
Retirement Laws	Yes	Yes	Yes	Yes

Notes: The table reports IV regression results on the effect of the pensioner-worker ratio, $\frac{R}{L}$, on factor productivity $\ln(A)$, empirically employing the model of equation (16), augmented by the average effective retirement age to account for (changes in) retirement laws. Robust standard errors adjusted for arbitrary heteroskedasticity are reported in parentheses. The results reported in Columns (I)–(II) are obtained based on the full sample of OECD countries for which comparable data on the legal framework necessary for retirement is available in the OECD database. Columns (III)–(IV) report results based on the sub-sample of established Western democracies that have joined the OECD before the fall of the Iron Curtain and that had developed pension systems over the sample period. "Kleibergen-Paap F-Stat" reports the F-statistic of the first-stage (which is valid when errors are not iid), with critical values for a maximum 10% IV bias compiled by Stock et al. (2005) denoted as "Stock-Yogo 10% max. IV".

*** Significant at the 1 percent level,
** Significant at the 5 percent level

Table B4 ECONOMIC AGING AND PRODUCTIVITY—INSTRUMENTAL VARIABLE RESULTS, DIFFERENT LAG STRUCTURES USED TO PREDICT REALIZED PENSIONING, OECD

Dependent variable: Log of total factor productivity, $\ln(A_{it})$

	Lags (in years) used to predict economic aging				
	$t-5$	$t-10$	$t-15$	$t-20$	$t-25$
	Panel A: Benchmark: Main regressions specification				
Economic aging, $\left(\frac{R}{L}\right)$	-0.00240***	-0.00232***	-0.00320***	-0.00538***	-0.00806***
	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)
	Panel B: First-stage regression results				
Predicted aging, $\left(\frac{\hat{R}}{\hat{L}}\right)$	0.619***	0.355***	0.162***	0.0753**	0.159***
	(0.020)	(0.025)	(0.026)	(0.030)	(0.031)
	Panel C: Second-stage regression results				
Economic aging, $\left(\frac{R}{L}\right)$	-0.00173***	-0.00232***	-0.00610***	-0.0146**	-0.00535***
	(0.001)	(0.001)	(0.002)	(0.007)	(0.002)
Observations	1,275	1,152	1,007	864	727
Units (# of Countries)	29	29	29	29	29
R-Squared	0.638	0.638	0.579	0.500	0.465
F-Stat (χ^2)	249.0	231.7	167.5	112.8	75.54
Prob. > F-Stat	0.000	0.000	0.000	0.000	0.000
Kleibergen-Paap F-Stat	962.5	209.8	37.71	6.387	26.37
Stock-Yogo 10% max. IV	16.38	16.38	16.38	16.38	16.38
Country FE	Yes	Yes	Yes	Yes	Yes
Period FE	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes

Notes: The table reports IV regression results on the effect of the pensioner-worker ratio, $\frac{R}{L}$ on factor productivity $\ln(A)$, empirically employing the model of equation (16). The table shows results for different lags used to construct the instrumental variable of predicted economic aging. Panel A re-estimates the baseline models (with the 10-year lag to predict economic aging) as a benchmark. Panel B reports first-stage results. Panel C reports second-stage results obtained when using varying lags to predict actual aging. All estimates are based on the fully specified model. The results are based on all OECD countries for which we have obtained data on pensioning. "Kleibergen-Paap F-Stat" reports the F-statistic of the first-stage (which is valid when errors are not iid), with critical values for a maximum 10% IV bias compiled by Stock et al. (2005) denoted as "Stock-Yogo 10% max. IV".

*** Significant at the 1 percent level,
** Significant at the 5 percent level

Table B5 ECONOMIC AGING AND PRODUCTIVITY—INSTRUMENTAL VARIABLE RESULTS, DIFFERENT LAG STRUCTURES USED TO PREDICT REALIZED PENSIONING, ESTABLISHED DEMOCRACIES

Dependent variable: Log of total factor productivity, $\ln(A_{it})$

	Lags (in years) used to predict economic aging				
	$t-5$	$t-10$	$t-15$	$t-20$	$t-25$
	Panel A: Benchmark: Main regressions specification				
Economic aging, $\left(\frac{R}{L}\right)$	-0.00259***	-0.00258***	-0.00312***	-0.00417***	-0.00573***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
	Panel B: Second-stage regression results				
Economic aging, $\left(\frac{R}{L}\right)$	-0.00209***	-0.00258***	-0.00470***	-0.00659***	-0.00947***
	(0.000)	(0.001)	(0.001)	(0.002)	(0.002)
	Panel C: First-stage regression results				
Predicted aging, $\left(\frac{\hat{R}}{\hat{L}}\right)$	0.690***	0.430***	0.252***	0.181***	0.139***
	(0.020)	(0.025)	(0.023)	(0.022)	(0.027)
Observations	1,061	959	849	741	636
Units (# of Countries)	22	22	22	22	22
R-Squared	0.638	0.638	0.579	0.500	0.465
F-Stat (χ^2)	249.0	231.7	167.5	112.8	75.54
Prob. > F-Stat	0.000	0.000	0.000	0.000	0.000
Kleibergen-Paap F-Stat	1245.4	298.0	119.8	64.96	26.55
Stock-Yogo 10% max. IV	16.38	16.38	16.38	16.38	16.38
Country FE	Yes	Yes	Yes	Yes	Yes
Period FE	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes

Notes: The table reports IV regression results on the effect of the pensioner-worker ratio, $\frac{R}{L}$ on factor productivity $\ln(A)$, empirically employing the model of equation (16). The table shows results for different lags used to construct the instrumental variable of predicted economic aging. Panel A re-estimates the baseline models (with the 10-year lag to predict economic aging) as a benchmark. Panel B reports second-stage results obtained when using varying lags to predict actual aging. Panel C reports first-stage results. All estimates are based on the fully specified model. The results are based on the homogeneous sub-sample of established Western democracies that have joined the OECD before the fall of the Iron Curtain and that had highly developed pension systems over the sample period. "Kleibergen-Paap F-Stat" reports the F-statistic of the first-stage (which is valid when errors are not iid), with critical values for a maximum 10% IV bias compiled by Stock et al. (2005) denoted as "Stock-Yogo 10% max. IV".

*** Significant at the 1 percent level,
** Significant at the 5 percent level

Table B6 ECONOMIC AGING AND PRODUCTIVITY—INSTRUMENTAL VARIABLE RESULTS, ACCOUNTING FOR POPULATION WEIGHTS

Dependent variable: Log of total factor productivity, $\ln(A_{it})$

	OECD countries		**Established democracies**	
	(I) Parsimonious	(II) Full	(III) Parsimonious	(IV) Full
	Panel A: Second-stage regression results			
Economic aging, $\left(\frac{R}{L}\right)$	-0.00727***	-0.00235***	-0.00734***	-0.00339***
	(0.001)	(0.001)	(0.001)	(0.001)
	Panel B First-stage regression results			
Predicted aging, $\left(\frac{\hat{R}}{\hat{L}}\right)$	0.4320***	0.4360***	0.4887***	0.4340***
	(0.0294)	(0.0266)	(0.0294)	(0.0249)
Observations	1,152	1,152	959	959
Units (# of Countries)	29	29	22	22
R-Squared	0.489	0.869	0.356	0.752
F-Stat (χ^2)	157.9	525.4	18.13	271.1
Prob. > F-Stat	0.000	0.000	0.000	0.000
Kleibergen-Paap F-Stat	267.4	216.0	280.5	275.5
Stock-Yogo 10% max. IV	16.38	16.38	16.38	16.38
Country FE	Yes	Yes	Yes	Yes
Period FE	Yes	Yes	Yes	Yes
Controls	No	Yes	No	Yes
Population weights	Yes	Yes	Yes	Yes

Notes: The table reports IV regression results on the effect of the pensioner-worker ratio, $\frac{R}{L}$ on factor productivity $\ln(A)$, empirically employing the model of equation (16). All regressions are use weighting by population. Robust standard errors adjusted for arbitrary heteroskedasticity are reported in parentheses. The results reported in Columns (I)–(II) are obtained based on the full sample of OECD countries for which comparable data on the legal framework necessary for retirement is available in the OECD database. Columns (III)–(IV) report results based on the sub-sample of established Western democracies that have joined the OECD before the fall of the Iron Curtain and that had developed pension systems over the sample period. "Kleibergen-Paap F-Stat" reports the F-statistic of the first-stage (which is valid when errors are not iid), with critical values for a maximum 10% IV bias compiled by Stock et al. (2005) denoted as "Stock-Yogo 10% max. IV".

*** Significant at the 1 percent level,

** Significant at the 5 percent level

Table B7 ECONOMIC AGING AND PUBLIC PENSION SPENDING

Dependent variable: Public pension spending (in % of GDP)

	OECD countries		**Established democracies**	
	(I) Parsimonious	(II) Full	(III) Parsimonious	(IV) Full
Economic aging, $\left(\frac{R}{L}\right)$	0.149***	0.0770***	0.152***	0.0886***
	(0.010)	(0.007)	(0.014)	(0.008)
Observations	1,032	1,032	832	832
Units (# of Countries)	29	29	22	22
R-Squared	0.925	0.959	0.906	0.959
F-Stat	118.2	127.7	72.46	180.2
Prob. > F-Stat	0.000	0.000	0.000	0.000
Country FE	Yes	Yes	Yes	Yes
Period FE	Yes	Yes	Yes	Yes
Controls	No	Yes	No	Yes

Notes: The table reports OLS regression results on the relationship between the pensioner-worker ratio, $\frac{R}{L}$, and public pension spending (in % of GDP), estimating the model of equation (16) where factor productivity is replaced by pension spending. Robust standard errors adjusted for arbitrary heteroskedasticity are reported in parentheses. The results reported in Columns (I)–(II) are obtained based on the full sample of OECD countries for which comparable data on the legal framework necessary for retirement is available in the OECD database. Columns (III)–(IV) report results based on the sub-sample of established Western democracies that joined the OECD before the fall of the Iron Curtain and that had developed pension systems over the sample period.

*** Significant at the 1 percent level,

Table B8 ECONOMIC AGING AND THE COMPOSITION OF PUBLIC BUDGETS

Dependent variable: Public spending categories (in % of GDP)

	(I) Public Services	(II) Defence Spend.	(III) Public Order	(IV) Econ. Affairs	(V) Health Spend.	(VI) Education Spend.	(VII) Social Protect.
Economic aging, $\left(\frac{R}{L}\right)$	0.103***	-0.00278	-0.00489*	-0.0630***	0.00750	-0.00387	0.126***
	(0.012)	(0.003)	(0.003)	(0.016)	(0.007)	(0.005)	(0.015)
Observations	574	574	574	574	574	574	574
Units (# of Count.)	25	25	25	25	25	25	25
R-Squared	0.887	0.926	0.858	0.574	0.927	0.895	0.963
F Stat	25.41	8.847	34.42	14.85	8.400	1.602	97.15
Prob. > F-Stat	0.000	0.000	0.000	0.000	0.000	0.173	0.000
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Period FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: The table reports OLS regression results on the relationship between the ratio of pensioners relative to the working-age population, $\frac{R}{L}$, and public spending categories. Robust standard errors adjusted for arbitrary heteroskedasticity are reported in parentheses. Data on public spending relative to GDP for spending categories comes from the National Accounts Dataset of the OECD (2021). All results are based on the sample of OECD countries used in the IV model on the effect of aging on factor productivity reported in Table (**??**) for which data is available in the National Accounts Dataset of the OECD.

*** Significant at the 1 percent level,
** Significant at the 5 percent level,
* Significant at the 10 percent level

Table B9 ECONOMIC AGING AND THE COMPOSITION OF PUBLIC BUDGETS—ESTABLISHED DEMOCRACIES

Dependent variable: Public spending categories (in % of GDP)

	(I) Public Services	(II) Defence Spend.	(III) Public Order	(IV) Econ. Affairs	(V) Health Spend.	(VI) Education Spend.	(VII) Social Protect.
Economic aging, $\left(\frac{R}{L}\right)$	0.124***	-0.0104**	-0.00240	-0.0420**	-0.0377***	-0.0180***	0.0664***
	(0.015)	(0.005)	(0.003)	(0.019)	(0.009)	(0.007)	(0.019)
Observations	452	452	452	452	452	452	452
Units (# of Count.)	20	20	20	20	20	20	20
R-Squared	0.903	0.933	0.892	0.540	0.924	0.904	0.967
F Stat	23.00	3.459	10.14	1.757	12.13	5.217	114.8
Prob. > F-Stat	0.000	0.009	0.000	0.137	0.000	0.004	0.000
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Period FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: The table reports OLS regression results on the relationship between the ratio of pensioners relative to the working-age population, $\frac{R}{L}$, and public spending categories. Robust standard errors adjusted for arbitrary heteroskedasticity are reported in parentheses. Data on public spending relative to GDP for spending categories comes from the National Accounts Dataset of the OECD (2021). All results are based on the sample of established democracies (OECD countries that joined the OECD before the fall of the Iron Curtain) for which data is available in the National Accounts Dataset of the OECD.

*** Significant at the 1 percent level,
** Significant at the 5 percent level,
* Significant at the 10 percent level

Table B10 ECONOMIC AGING AND INNOVATION ACTIVITY—ESTABLISHED DEMOCRACIES

Dependent variable: Proxies of innovation activity (measured in numbers)				
	(I) Patents: Residents	(II) Patents: Non-residents	(III) Patents: All	(IV) Scientific Journal Articles
Economic aging, $\left(\frac{R}{L}\right)$	-1138.8***	-403.2	-1543.8***	-1029.8***
	(257.989)	(260.070)	(499.381)	(251.034)
Observations	818	819	818	417
Units (# of Countries)	22	22	22	22
R-Squared	0.932	0.762	0.873	0.989
F Stat	25.58	20.44	23.61	14.09
Prob. > F-Stat	0.000	0.000	0.072	0.000
Controls	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes
Period FE	Yes	Yes	Yes	Yes

Notes: The table reports OLS regression results on the relationship between the ratio of pensioners relative to the working-age population (economic aging), $\frac{R}{L}$, and innovation activity, re-estimating our baseline models of Table (1) with metrics for innovation activity. Robust standard errors adjusted for arbitrary heteroskedasticity are reported in parentheses. All results are based on the sample of established democracies (OECD countries that joined the OECD before the fall of the Iron Curtain). Data on patent applications come from the World Intellectual Property Organization's (WIPO) statistics on worldwide patent activity (see WIPO, 2021). Data on scientific and technical journal articles is obtained from the National Science Foundation (see NSF, 2021).

*** Significant at the 1 percent level,
** Significant at the 5 percent level

Appendix C: Data on the number of pensioners

Table C1 DATA SOURCES AND COLLECTION OF THE PENSIONER DATASET

Country	**Coverage**	**Source**
Australia	1960 - 1980	*Total Age Pensioners.* Yearbooks Australia from the years 1961 to 1981. Bureau of Statistics Australia; missing data for 1974 and 1976 linearly interpolated.
	1981 - 2001	*Total Age Pension Customers.* FaHCSIA Occasional Paper No. 7, Income Support Customers: A Statistical Overview 2001. Australian Government Department of Social Services.
	2002 - 2013	*Total Age Pension Recipients.* FaHCSIA Occasional Paper No. 12, Income Support Customers: A Statistical Overview 2013. Australian Government Department of Social Services.
	2014 - 2020	*Total Age Pensions.* DSS Payment Demographic Data. Australian Government.
Austria	1970 - 2020	*Altersrenten und Invaliditätsrenten ab Volljährigkeit (Old Age Pensions and Invalidity Pensions as of age 60/65).* Pensionsversicherungsanstalt Österreich.
Belgium	1973 - 2021	*Evolutie van het Aantal Pensioengerechtigden (Evolution of the Number of Pensioners).* Service Fédéral des Pensions.
Canada	1976 - 1977	*Old Age Security Program (OAS) recipients.* Canada Income Survey. Statistics Canada.
	1980 - 1999	*Old Age Security Program (OAS) recipients.* Statistics Canada.
	2000 - 2019	*Canada Pension Plan (CPP) and Quebec Pension Plan (QPP) benefits.* Annual Income Estimates for Census Families and Individuals. Statistics Canada.

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Country	**Coverage**	**Source**
Czech Republic	1957 - 1980	*Starobni (Old Age Pension).* Reconstructed data from printed Czechoslovakia Statistical Yearbooks and Slovakia Pension Data records; data between 1957 and 1980 are available in 5-year intervals. Values in between are linearly interpolated.
	1981- 2000	*Starobni (Old Age Pension).* Reconstructed data from printed Czech Republic Statistical Yearbooks; until 1990 Czech Socialist Republic.
	2001 - 2021	*Old Age Pensions.* Cezch Social Security Agency (Ceska sprava socialniho zabezpeceni).
Denmark	1958 - 2012	*Folkepension i alt. Velfaerdsstaaten i tal (State pension in total. The welfare state in numbers).* Printed numbers in Hans Chr. Johansen og Birgitte Holten.
	2012 - 2020	*Folkepensionister i alt. (State pension in total)* Statistikbanken and statistical yearbook (årbog).
Finland	1960 - 2021	*Eläketurvakeskus (ETK), Recipients of an old-age pension.* Statistics on Pensioners in Finland, Finnish Center for Pensions and the Social Insurance Institution of Finland; breaks in the time series in 1980 and 1977 filled with linear interpolation.
France	1956 - 2000	*Number of retirees of the general scheme (métropole).* Évolution du rapport démographique du régime général. Les cotisations et les cotisants.
	2001 - 2021	*Evolution of the number of retirees of the general scheme in payment.* Statistiques, recherches et prospective de la Caisse Nationale d'assurance vieillesse (CNAV), Statistics, research and forecasts of the National Old Age Insurance Fund (CNAV), Septembre 2021.

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Country	**Coverage**	**Source**
Germany	1960 - 2021	*Rentenbestand Renten wegen Alters (Old Age Pension).* Rentenversicherung in Zeitreihen. Deutsche Rentenversicherung, German Pension Insurance.
Greece	1966 - 1997	*Syntáxeis gíratos (Old Age Pensioners).* Statistical Yearbooks of Greece between 1966 - 1997. Ellinikí Statistikí Archí (ELSTAT), Hellenic Statistical Authority.
	1998 - 2011	*Syntáxeis gíratos (Old Age Pensioners).* Pensioners receiving principal pension from the social insurance organizations, by category of pension : 1998-2011. Ellinikí Statistikí Archí (ELSTAT), Hellenic Statistical Authority.
	2016 - 2019	*Syntáxeis gíratos (Old Age Pension Beneficiaries).* Statistics of the Social Protection System. Ellinikí Statistikí Archí (ELSTAT), Hellenic Statistical Authority.
Hungary	1960 - 2020	*Pensioners, annuitants, recipients of other benefits.* Main Long Time Series of Social Services. Központi Statisztikai Hivatal (KSH), Hungarian Statistical Office.
Iceland	1985 - 2021	*Ellilífeyris (Number of Pensioners, Old-Age Pension).* Tryggingastofnun ríkisins, National Insurancy Board.
Italy	1960 - 2012	*Numero di pensioni (Number of Pensions).* Istituto nazionale della previdenza sociale (INPS), National Institute for Social Security; data obtained in 5 year intervals, linear interpolation.

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Country	Coverage	Source
	2013 - 2019	*Tutte le pensioni (All Pensions).* Istituto Nazionale di Statistica (ISTAT), National Statistical Institute, annual data. .
Japan	1970 - 2013	*Rōrei kiso nenkin to rōrei nenkin (Old-Age Basic Pension and Old-Age Pension).* Japanese Social Security Statistics. Kokuritsu Shakai Hoshō Jinkō Mondai Kenkyūjo (IPSS), National Institute of Population and Social Security Research; some of the data obtained with gaps and linearly interpolated for some periods in the 1970s and 1980s.
	2014 - 2018	*Kokumin nenkin jukyūshasū (Number of Beneficial Owners of National Pension).* Sōmu-Shō (MIC), Ministry of Internal Affairs and Communications, Statistical Office.
Luxembourg	1979 - 2020	*Pensions de vieillesse et de vieillesse anticipée (Old Age and Early Old Age Pensions).* Evolution du nombre de pensions par catégorie de pension (Evolution of the number of pensions by category of pension). Assurance Pension, National Pension Insurance Institution.
Mexico	1960 - 2021	*Private Sector (IMSS) Insured (Asegurados) and Public Sector (ISSSTE) Pensioners (Pensionados).* Instituto Nacional de Estadística, Geografía e Informática, National Institute of Statistics and Geography Mexico.

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Country	Coverage	Source
Netherlands	2000 - 2021	*Gepensioneerden (Old Age Pensions).* Gepensioneerden naar leeftijd, Pensioners by Age. Centraal Bureau voor de Statistiek (CBS), Statistics Netherlands; Citizens of 55 years and older whose main source of income is a pension.
New Zealand	1960 - 2007	*Age and Superannuation Pension.* New Zealand Official Yearbooks from 1960 to 2008; Statistics New Zealand (Stats NZ).
	2008 - 2021	*New Zealand Superannuation and Veteran's Pension Recipients.* New Zealand Ministry of Social Development (MSD).
Norway	1967 - 2021	*Alderspensjonister (Old-Age Pensions).* Statistical Yearbooks from 1967 to 2021. Statistisk sentralbyrå (SSB), Statistics Norway.
Poland	1990 - 2020	*Liczba emerytów (Number of Retired People).* Statistical Yearbooks from 1990 to 2020. Główny Urząd Statystyczny (GUS), Central Statistical Office of Poland; numbers linearly interpolated over the periods 1990–1995 and 1995–1999.
Portugal	1970 - 2021	*Pensões totais (Total Pensions).* Social Security and Public Administration Retirement Fund, Pordata. Instituto Nacional De Estatística (INE), Statistics Portugal.
Slovakia	1957 - 1980	*Počet dôchodcov na Slovensku (Number of pensioners in Slovakia).* Sociálna poisťovňa, Social Insurance Agency Slovakia.

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Country	Coverage	Source
	1981 - 2000	*Starobni (Old Age Pension).* Statistical Yearbooks Slovakia from 1981 to 2000. Sociálna poisťovňa, Social Insurance Agency Slovakia; data available in 5-year intervals, values in between linearly interpolated.
	2001 - 2021	*Počet dôchodcov na Slovensku (Number of pensioners in Slovakia).* Sociálna poisťovňa, Social Insurance Agency Slovakia,; annual data.
South Korea	1993 - 2020	*Nolyeong-yeongeum, sugeub-in-won (Old-Age Pension, Number of Beneficiaries).* National Pension Statistical Yearbooks from 1998 to 2020. Gukminyeongeumgongdan (NPS), National Pension Service Korea.
Spain	1955 - 1990	*Pensionsistas Pro Vejez (Old Age Pension).* Statistical Yearbooks from 1955 to 1990. Instituto Nacional De La Seguridad Social, National Institute of Social Security, Spain.
	1991 - 2001	*Pensionsistas Pro Vejez (Old Age Pension).* Informe Estadistico 2000 (Statistical Report 2000). Instituto Nacional De La Seguridad Social, National Institute of Social Security, Spain.
	2002 - 2021	*Old age pension.* Informe Estadistico 2020 (Statistical Report 2000). Instituto Nacional De La Seguridad Social, National Institute of Social Security, Spain.
Sweden	1960 - 2021	*Antal ålderspensionärer (Number of Old Age Pensioners).* Pensionsmyndigheten, Swedish Pensions Agency.

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Country	Coverage	Source
Switzerland	1948 - 2020	*Altersrenten, Bezüger/-innen (Old Age Pensioners, Beneficiaries).* Schweizerische Sozialversicherungsstatistik (SVS). Bundesamt für Sozialversicherungen (BSV). Federal Social Insurance Office; Data between 1970 and 1974 linearly interpolated.
Turkey	2000 - 2020	*Emekli Sayısı Toplam (Number of Pensioners Total).* Türkiye İstatistik Kurumu (TÜİK), Turkish Statistical Institute (TURKSTAT).
UK	1955 - 2011	*State Pensions.* Benefit expenditure and caseload tables. Department for Work and Pensions (DWP); figures include numbers for all regions of Great Britain.
	2012 - 2018	*State Pension.* DWP benefit statistics. Department for Work and Pensions (DWP); figures include numbers for all regions of Great Britain..
USA	1960 - 2020	*Retired workers.* Benefits Paid By Type Of Beneficiary. The United States Social Security Administration (SSA).