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ABSTRACT

Institutional Responses to Aging Populations and Economic Growth: A Panel Data Approach*

Will an aging population lower economic growth? Economists are generally concerned that the increase in life expectancy could lower economic growth, however, theory does not make a prediction. As life expectancy increases, so should household savings, which results in more physical capital per worker. This will stimulate economic growth. However, as the retired population share increases, this may reduce spending on children as more resources are transferred to the elderly. This will likely reduce human capital accumulation and lower growth. The net effect of these competing influences is an empirical question. This paper constructs a stylized endogenous growth model that includes both human capital and government transfers to the elderly. The model is mapped into a linear statistical framework that allows us to estimate each of these potential responses using panel data for a set of OECD countries during the period 1975-2014. We find evidence that households do in fact increase savings in response to a longer retirement period and this effect is associated with a higher realized rate of growth per worker. However, we also find evidence that an aging population reduces spending on children (or other productive investments) placing a drag on growth. These results suggest it is the institutional response to population aging that will determine whether or not an aging population will place a drag on future growth, not population aging itself.

JEL Classification: J11, J18, I21, I28, E66, E37, O43

Keywords: population aging, educational crowding-out, slow secular growth, cross-country panel data

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I. Introduction

The world population is aging. Falling fertility rates, increases in life expectancy at birth, and increases in the conditional life expectancy during the later stages of life has resulted in a major shift in the population age structure for most countries in the world. In 1950 only 5.1% of the world population was 65 or older but by 2000, this percentage had increased to 6.9%. In high-income countries this change was even larger, from 7.7% to 14.3%. There has been opposite movement at the other end of the age distribution. In 1950 the percentage of the population under the age of 15 was 34.3% for the world and 27.4% in high-income countries. By 2000, these percentages decreased to 30.1% and 18.4% respectively. Population projections are even more extreme. The projections for 2050 suggest that those over the age of 64 will reach 15.8% for the world and 26.6% for high-income countries. By 2100 the projections are 22.5% and 29.7% respectively. The percentage of those under the age of 15 will be 21.3% for the world and 15.5% for high-income countries in 2050. By 2100 the projections are 17.7% and 15.1%.[1]

How will this aging population affect economic growth? This is still an open question in economics, but a growing body of literature suggests that the answer rests critically on the institutional response. This paper attempts to address this issue by asking how an increase in the conditional life expectancy beyond the age of retirement affects the long-run growth rate of the economy. We identify two main channels. The first channel is through the *behavioral response*: since households now expect to live longer and spend a longer fraction of life in retirement, the optimal response is to increase savings to smooth-out consumption over their extended lifetimes resulting in capital deepening and additional resources to invest in human capital, which stimulates growth. The second channel is through the *institutional response*: with a defined-benefit pay-as-you-go social security system (and other government transfer programs to the elderly) in place, if the government chooses to fund additional transfers to the elderly by reducing education spending, or any other investment in future productivity, this will reduce growth. Thus, we identify two competing effects. The existence of these channels and the true net effect are the empirical questions we seek to answer in this paper.

We begin by constructing a stylized endogenous growth model in a setting with overlapping generations where agents live for three periods.[2] However, since our objective is empirical in nature, we make a few simplifications. First, we omit bequests, as discussed in Zhang, Zhang, and Lee (2003). Second, we omit survival uncertainty in the earlier stages of life, as discussed in Kalemli-Ozcan (2002) and Ehrlich and Lui (1991). This allows us to concentrate our attention on changes in life expectancy

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[1] United Nations, World Population Prospects (2017)-Medium Variant Projections; Percentage of Broad Age Groups-Both Sexes. Bloom, Canning and Fink (2010) provide an even more detailed decomposition of these demographic trends

[2] Our modeling strategy builds on the work of Dioikitopoulos (2014), Blankenau and Simpson (2004), Zhang, Zhang and Lee (2001, 2003), and Zhang and Zhang (1998).

during retirement. Similar to Zhang and Zhang (2005), we also assume the human capital production function is linear in terms of education spending.[3]

We then map our model into its statistical counterpart. Here we demonstrate that the old-age dependency ratio can be used to measure changes in life expectancy during retirement and the child dependency ratio can be used to measure changes in the fertility rate as we move from theory to data. It is the old-age dependency ratio that allows us to disentangle the two effects previously discussed. To understand our logic, consider the following thought experiment. Assume you observe the growth rate of output over a given period. If forward looking households expect to spend a larger fraction of their life in retirement this should result in an increase in savings which will stimulate growth. The data on the old-age dependency ratio at the end of this growth period will capture this forward-looking behavior. However, the old-age dependency ratio at the beginning of the growth period will capture the potential institutional response. If an increase in the old-age dependency ratio, and the associated increase in government transfers to the elderly "crowds-out" investment in children, then we would expect to see slower growth over this period since new workers have less human capital.

To test our theory, we look at a set of OECD countries over the period 1975-2014. We decompose the sample into 10-year intervals and estimate the model using a series of panel data specifications.[4] Consistent with our theory, we find a positive and statistically significant correlation between the end-of-period old-age dependency ratio and the growth rate of the economy. This result suggests that households do respond in a rational forward-looking way to a longer retirement period. We also find a negative and statistically significant correlation between the beginning-of-period old-age dependency ratio and the growth rate of the economy. This implies that an increase in the old-age dependency ratio, along with the associated increase in transfers to the elderly, does appear to "crowd-out" productive investments in future generations.[5]

All our results are fairly robust to a battery of specifications and additional control variables. The two most important control variables are the child-dependency ratio and the general tax rate. The first variable controls for changes in the fertility rate, which will also likely affect investment in human capital. We find a negative correlation between the child-dependency ratio and economic growth for most

[3] This could be motivated by parental human capital entering the education production function or an externality. The papers by Boldrin and Montes (2005) and Bohn (1997) also provide additional motivation for our choice of institutional design and the underlying assumptions in our framework.

[4] We drop the last 10-year interval (2005-2014) in some cases to control for the possibility that the Great Recession had some unmeasurable effects which may result in biased estimates.

[5] This is consistent with the empirical findings in Poterba (1997, 1998) and the theoretical predictions in Pecchenino and Utendorf (1999) and Zhang et al. (2003) when the mortality rate is already low.

specifications, which is consistent with this argument.[6] However, the crowding-out effect on education, due to the increasing share of elderly in the population, appears to be the dominant effect in our empirical analysis.[7] The other control variable is the total tax rate, which also likely responds to any increase in transfers to the elderly. The importance of this variable in an empirical framework is highlighted in Blankenau, Simpson and Tomljanovic (2007).

Our results suggest that population aging alone is not necessarily bad for economic growth. The behavioral response of households should stimulate growth as households increase savings for retirement. The potential drag on economic growth will likely come from the institutional response by society. This line of reasoning is consistent with Eichengreen's (2014) argument that slower growth and secular stagnation will likely be the result of a self-inflicted wound. These two countervailing forces can potentially offset each other resulting in no growth, which is consistent with the findings in Bloom et al. (2010) where an aging society has only a moderately negative effect on growth. From a policy perspective, entitlement reform would most likely alleviate this negative institutional effect, which would result in higher growth for future generations as people live longer and more productive lives.[8]

This paper also relates to the supply-side secular stagnation literature and labor-force productivity literature. The paper by Aksoy, Basso, Smith and Grasl (2019) demonstrates that demographic change, and in particular population aging, places a drag on long-run economic growth. Our results are consistent with this finding and demonstrate that this pattern in the data is likely the result of the institutional response and the crowding-out of productive investments in future generations. This argument is also consistent with Gordon (2012, 2015) who highlights the importance of the supply-side in the secular stagnation debate. The papers by Maestas, Mullen and Powell (2016), Feyrer (2007), and Lindh and Malmberg (1999) (and the references within) take a more detailed look at how population aging and changes in the composition of the labor-force affect economic growth and age specific productivity. We look at the workforce as a whole, rather than the decomposed labor force, which highlights potential shifts in the distribution itself. Breaking down the institutional response as workers move through their productive years would be an interesting exercise but is beyond the scope of the current paper. However, it is worth noting our results are consistent with the findings in these papers. Our paper explains why the old-age dependency ratio (65+ as a share of the population) places a drag on the growth rate of output per worker in the data.

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[6] This result is also consistent with Zhang and Zhang (1998) who demonstrate that an increase in the social security tax rate can reduce the fertility rate.

[7] This could be the result of political pressure, as suggested by Pecchenino and Utendorf (1999).

[8] Bloom et al. (2010) argue that an increase in the retirement age could also offset the negative effects of population aging. This result would apply to our model as well. Cooley and Soares (1996) describe why these programs might be subject to a political lock-in effect via conditional social security wealth.

The paper proceeds as follows. Section 2 derives the theoretical framework. Section 3 maps the theoretical framework into the statistical model. Section 4 discusses the data. Section 5 presents the results for the demographic variables. Section 6 conducts a series of robustness checks. Section 7 provides some back-of-the envelope calculations. Section 8 concludes.

II. The Theoretical Framework

We begin by constructing a model with overlapping generations that includes changes in the age structure of society and human capital. Our intention is to identify the primary set of demographic variables for our statistical model and relate these variables to the growth rate of the economy. For simplicity we assume individuals live for three periods. In the first period of life a child receives an education and lives with his or her parents. In the second period of life an individual works, saves for retirement, and pays taxes. In the final period of life, the retired individual consumes all savings and transfers from the government. Since the demographic variables are critical to our analysis, we start with the model's population dynamics.

II.A. Demographics

The demographic properties (assumptions) of the model are designed to map our theoretical measures of longevity and fertility into the old-age dependency ratio and the child dependency ratio, respectively. First, we assume each adult worker $N_W(t)$ has $n(t) > 0$ children. Note that $n(t)$ can be less than one, which results in a contracting population.[9] This gives us our first demographic equation,

$$N_Y(t) = n(t)N_W(t), \tag{1}$$

where $N_Y(t)$ is the number of children born in period t. Dividing both sides of equation (1) by the working age population gives us the child-dependency ratio $cdr(t)$,

$$\frac{N_Y(t)}{N_W(t)} = cdr(t) = n(t), \tag{2}$$

which is equal to the fertility rate or the number of children born in the current period.

[9] We assume the fertility rate is exogenous, this simplifies the mapping of our theoretical model into its statistical counterpart. Our objective is to identify patterns in the data to help us better understand the potential interaction between demographic change and long-run growth. See Lee and Mason (2010), Ehrlich and Kim (2005), Kalemli-Ozcan (2002), and Becker, Murphy and Tamura (1990) for a detailed discussion on issues pertaining to endogenous fertility (to cite a few from many papers).

We assume each child survives into adulthood, $N_Y(t) = N_W(t+1)$, and that each working age adult survives into retirement, $N_W(t+1) = N_R(t+2)$, where $N_R(t+2)$ is the number of retirees. That is, there is no uncertainty in the model in terms of moving through each stage of life. However, we do adjust the length of life during the last period (the retirement period) to allow for changes in longevity. Here, we assume each retiree lives the fraction of time $\gamma(t)$ relative to the working period, which we normalize to one.[10] This implies that the "effective" number of retirees alive in period t equals $\gamma(t)N_R(t)$. This assumption, along with equation (1), allows us to express the old-age dependency ratio, $oadr(t)$, in terms of our theoretical measures of fertility $n(t)$ and longevity $\gamma(t)$. Formally, $oadr(t)$ equals,

$$oadr(t) = \frac{\gamma(t)N_R(t)}{N_W(t)} = \frac{\gamma(t)N_W(t-1)}{N_Y(t-1)} = \frac{\gamma(t)}{n(t-1)}, \tag{3}$$

which shows that the current old-age dependency ratio increases when people spend a longer time in retirement and decreases when the fertility rate last period increases, - the children born in the previous period are now working adults and support the transfers to retirees.

II.B. The Household

Given the demographic structure of the model, the next step is to derive the general equilibrium dynamics guiding our empirical specification. Here we start with the household. Assume each household maximizes utility,

$$U(t) = lnc_W(t) + \beta\gamma(t+1)lnc_R(t+1),$$

subject to the following period specific budget constraints (working period and retirement period),

$$c_W(t) + s(t) = w(t)h(t-1)\big(1-\tau(t)\big),$$
$$c_R(t+1) = \gamma(t+1)^{-1}[R(t+1)s(t) + TR(t+1)].$$

[10] This approach is different than the survival rate approach found in Zhang and Zhang (2005), Zhang et al. (2001, 2003), and Ehrlich and Lui (1991). Our approach allows us to focus on the change in time spent in retirement, or longevity during retirement, and how this change interacts with existing social institutions, such as, social security and public education. From a modeling perspective there isn't much difference, but the interpretation that follows does change. An increase in the length of life implies more resources will be transferred to each retiree, now living longer, rather than an increase in transfers to the retired generation (as a group) for a given retirement age.

Lifetime utility includes the working age adult's consumption $c_W(t)$, which we assume includes each child's consumption (that is, $c_W(t)$ is a consumption index), and retirement consumption $c_R(t+1)$. The parameter $\beta \in (0,1)$ is the standard discount factor and the parameter $\gamma(t+1) > 0$ is the relative length of life during retirement.

The period specific budget constraints define the household's choice set during each stage of life. The working period budget constraint equates the household's net income to working period consumption and savings for retirement $s(t)$. Net income is determined by the wage rate $w(t)$ paid to each unit of human capital $h(t-1)$, accumulated during childhood, and the tax rate $\tau(t) \in (0,1)$ on labor income. During the retirement period the retiree consumes savings plus interest, where $R(t+1)$ measures the gross return on capital, and any transfers from the government $TR(t+1)$. All resources are distributed over the relative length of life during the final period.[11]

The solution to the household's optimization problem results in the following savings function:

$$s(t) = \left[\frac{\beta\gamma(t+1)}{1+\beta\gamma(t+1)}\right] w(t)h(t-1)\big(1-\tau(t)\big) - \frac{TR(t+1)}{R(t+1)\big(1+\beta\gamma(t+1)\big)}. \qquad (4)$$

This equation demonstrates that a higher net income stimulates savings either through higher wages, more human capital, or lower taxes. It is also easy to verify that an increase in longevity $\gamma(t+1)$ stimulates savings for retirement holding all other factors constant. However, more transfers from the government will reduce household savings.[12]

II.C. Production, Factor Payments, and Market Clearing

The production function takes on a Cobb-Douglas constant-returns-to-scale form

$$Y(t) = K(t)^{\alpha}\big(N_W(t)h(t-1)\big)^{1-\alpha}.$$

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[11] Since we are assuming $\gamma(t)$ measures the relative length of life during retirement we do not address the structure of annuity markets or bequests in our model. Zhang et al. (2003) discuss some interesting issues surrounding bequests and demographic structure, which we also omit from our framework. We also assume the retirement age is fixed at a given age. Kalemli-Ozcan and Weil (2010) explain why an increase in longevity in the latter stage of life might increase the fraction of a lifetime spent in retirement. They also discuss some empirical evidence supporting this line of reasoning. Lee (2016) demonstrates the major shift in effective age consumption profiles over time towards the elderly, which is our primary concern.

[12] This result is consistent with Feldstein (1996) which finds that social security reduces private savings by roughly 60%. Engen and Gale (1997) provide an excellent summary of social security and savings behavior.

The parameter $\alpha \in (0,1)$ is the capital share of income and $N_W(t)h(t-1)$ measures the aggregate effective labor force. The variables $Y(t)$ and $K(t)$ measure the aggregate output and the aggregate capital stock, respectively. Mapping the aggregate production function into per worker form gives us

$$y(t) = k(t)^{\alpha} h(t-1)^{1-\alpha}, \tag{5}$$

where $y(t) = Y(t)/N_W(t)$ is output per worker and $k(t) = K(t)/N_W(t)$ is the capital stock per worker. Assuming complete depreciation of the capital stock across generations and profit maximizing firms operating in competitive markets, results in the following factor payments:

$$w(t) = (1-\alpha)k(t)^{\alpha} h(t-1)^{-\alpha}\ , \tag{6}$$

$$R(t) = \alpha k(t)^{\alpha-1} h(t-1)^{1-\alpha}, \tag{7}$$

which are equal to the marginal product of the respective factor of production. The market clearing condition equates aggregate savings in the current period $N_W(t)s(t)$ with next period's aggregate capital stock $K(t+1)$. In per worker form, we have

$$k(t+1) = n(t)^{-1} s(t). \tag{8}$$

II.D. Institutional Design and Human Capital Accumulation

To close the model, we describe how each government programs or institution operates and define the initial set of policy restrictions imposed on these programs. We start with transfer programs to the elderly. These programs encompass all transfers to the elderly from the current working generation, that is, all social insurance programs and direct transfers,

$$TR(t) = w(t)h(t-1)\theta. \tag{9}$$

The scale of transfers relative to current earnings is $\theta \in (0,1)$. The next equation assumes these (total) transfer programs operate under a balanced budget,

$$N_R(t)\gamma(t)TR(t) = N_W(t)w(t)h(t-1)\tau_R(t).$$

The left-hand side of the budget constraint measures total outlays on the elderly, based on the number of retirees adjusted for their respective length of life and the individual transfer. The right-hand side measures the total inflow into the program by taxing the current working generation at rate $\tau_R(t) \in (0,1)$. After substituting equation (9) into the budget constraint, we can solve for the social security tax rate necessary to balance the budget

$$\tau_R(t) = \frac{\gamma(t)N_R(t)}{N_W(t)}\theta = \frac{\gamma(t)}{n(t-1)}\theta = oadr(t)\theta. \tag{10}$$

The last equality follows from equation (3). The social security tax rate depends positively on both the old-age dependency ratio and on how the transfers compare to current earnings: the longer people spend in retirement and/or the more generous the transfer system, the higher the social security tax rate must be to balance the budget.

Next, we address expenditures on the young or children in the economy. First, assume that each household spends the fraction $\tau_Y(t) \in (0,1)$ of income on children. We refer to this as a tax rate, but one can conceptualize this value as inclusive of household spending in our empirical specification. Now, assume education expenditures operate under a balanced budget,

$$N_Y(t)e(t) = N_W(t)w(t)h(t-1)\tau_Y(t).$$

The left-had side is total expenditures on children, where $e(t)$ measures expenditure per child. The right-hand side is the total inflow into the education system. Solving for spending per child gives us

$$e(t) = \frac{N_W(t)}{N_Y(t)}w(t)h(t-1)\tau_Y(t) = \frac{1}{cdr(t)}w(t)h(t-1)\tau_Y(t), \tag{11}$$

where the last equality follows from equation (2). One can see from (11) that education spending per child depends positively on household income and the fraction of income spent on children. There is a negative relationship between the child dependency ratio and spending per child, which means that a child benefits if he/she is part of a smaller cohort.

The human capital production function takes on a simple linear form, which results in endogenous growth

$$h(t) = A(\phi_t)e(t). \tag{12}$$

The productivity term $A(\phi_t)$ is a function of time specific (and later potentially group specific) factors that influence the dynamic behavior of the economy. We could derive this linear production function using a model with externalities or add other reproducible inputs, such as parental human capital, but this would only complicate the analysis. As already mentioned, our objective is empirical in nature, so the simplest theoretical framework that captures this potential relationship between demographic change and growth is preferable. This linear approach is similar to the one found in Zhang and Zhang (2005). After substituting (11) into (12) we have

$$h(t) = \left(\frac{A(\phi_t)\tau_Y(t)}{cdr(t)}\right) w(t)h(t-1), \tag{13}$$

which describes the human capital accumulation process.

II.E. Dynamical System

To formalize the dynamic properties of the economy we now map the system of equations above into a two-state variable system. The two state variables we use are the physical capital stock per worker $k(t+1)$ and the amount of human capital per worker $h(t)$, which are both productive inputs in period $t+1$. To derive the law of motion for the physical capital stock, we use the market clearing condition in equation (8), along with the household's optimal savings decision in equation (4),

$$k(t+1) = \left(\frac{\beta\gamma(t+1)\big(1-\tau(t)\big)}{n(t)\big(1+\beta\gamma(t+1)\big)}\right) w(t)h(t-1) - \frac{TR(t+1)}{n(t)R(t+1)\big(1+\beta\gamma(t+1)\big)}.$$

Next, eliminate the transfer payment during the retirement period using equation (9) and then eliminate factor payments using equations (6) and (7). This results in the following closed form solution describing the law of motion for the capital stock per worker

$$k(t+1) = \left(\frac{\alpha\beta(1-\alpha)\gamma(t+1)\big(1-\tau(t)\big)}{n(t)\alpha\big(1+\beta\gamma(t+1)\big)+(1-\alpha)\theta}\right) k(t)^{\alpha} h(t-1)^{1-\alpha} \ . \tag{14}$$

The law of motion for human capital can be found by substituting the effective wage rate paid to each unit of human capital in equation (6) into the human capital production function (13)

$$h(t) = \left(\frac{A(\phi_t)(1-\alpha)\tau_Y(t)}{n(t)}\right) k(t)^{\alpha} h(t-1)^{1-\alpha} \ . \tag{15}$$

These laws of motion determine the (gross) rate of growth for the economy

$$\frac{y(t+1)}{y(t)} = \left(\frac{k(t+1)}{k(t)}\right)^{\alpha} \left(\frac{h(t)}{h(t-1)}\right)^{1-\alpha} . \tag{16}$$

II.F. Balanced Growth Properties of the Model and Tax Rates

The next step is to determine the balanced growth path of the economy. Here, we assume the demographic variables are constant, $\gamma(t) = \gamma$ and $n(t) = n$ for all t. We also assume the tax rates funding the government programs and the total tax rate are constant, $\tau_Y(t) = \tau_Y$, $\tau_R(t) = \tau_R$, and $\tau(t) = \tau$ for all t. Taking the ratio of equations (14) and (15) results in a constant physical to human capital ratio.

$$\frac{k(t+1)}{h(t)} = \frac{n\alpha\beta\gamma(1-\tau)}{A(\phi)\tau_Y(n\alpha(1+\beta\gamma)+(1-\alpha)\theta)} \ . \tag{17}$$

Equation (17) also assumes the productivity term in the education production function is constant. After substituting this ratio (lagged one period) into equations (14) and (15) to determine the growth rate of each input, we can determine the balanced growth path of output for our economy using equation (16),[13]

$$g = \frac{y(t+1)}{y(t)} = (1-\alpha)\left(\frac{A(\phi)\tau_Y}{n}\right)^{1-\alpha} \left(\frac{\alpha\beta\gamma(1-\tau)}{n\alpha(1+\beta\gamma)+(1-\alpha)\theta}\right)^{\alpha} . \tag{18}$$

This equation demonstrates that a larger tax rate funding education stimulates growth, while a larger total tax rate will place a drag on growth. This clearly shows there is a relationship between these two rates within the model.

Thus, our final step is to define the relationship between tax rates in the economy

$$\tau(t) = \tau_Y(t) + \tau_R(t) + \tau_O(t). \tag{19}$$

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[13] See Appendix A for the derivation of this equation.

Along the balanced growth path all the tax rates are constant, $\tau = \tau_Y + \tau_R + \tau_O$, so nothing changes in our balanced growth story. The new tax term $\tau_O(t)$ is the tax rate funding other government expenditures in the economy, which by assumption are not productive. Finally, the additional restriction, $\tau_Y + \tau_R + \tau_O \in (0,1)$, must hold. This tax restriction represents the unified budget constraint.

In a stationary environment this might be the end of the modeling process. We could conduct comparative statics exercises on the parameters of the economy, including the demographic variables and tax rates, to determine how each of these parameters influence long-run growth. However, the objective of this paper is empirical in nature, so we need to map our theoretical model into a statistical counterpart that captures the general features above.

III. The Statistical Model

We now map our theoretical framework into a general linear statistical model. This will allow us to estimate the approximate effects of the demographic variables on growth and to test certain predictions within the model. To accomplish this task, we will need to use some approximation techniques, however these approximations maintain the integrity of the model and the general hypotheses to be tested.

III.A. Building the Empirical Framework

We begin with output per worker. Take the natural logarithm of both sides of equation (5). This gives us the following log-linear form

$$lny(t) = \alpha lnk(t) + (1-\alpha)lnh(t-1). \tag{20}$$

From the dynamical system governing the evolution of the state variables, defined in equations (14) and (15), we have

$$k(t) = \left[\frac{\alpha\beta(1-\alpha)\gamma(t)\big(1-\tau(t-1)\big)}{\alpha n(t-1)\big(1+\beta\gamma(t)\big)+(1-\alpha)\theta}\right]y(t-1),$$

$$h(t-1) = \left[\frac{A(\phi_{t-1})(1-\alpha)\tau_Y(t-1)}{n(t-1)}\right]y(t-1).$$

These equations use last period's output per worker $y(t-1) = k(t-1)^{\alpha}h(t-2)^{1-\alpha}$ to determine the inputs available for current production. Next, take the natural log of both equations above, then substitute these equations into equation (20). This eliminates the direct measure of inputs from the system,

$$y^g(t) = \alpha ln\left[\frac{\alpha\beta(1-\alpha)\gamma(t)\big(1-\tau(t-1)\big)}{\alpha n(t-1)\big(1+\beta\gamma(t)\big)+(1-\alpha)\theta}\right] + (1-\alpha)ln\left[\frac{A(\phi_{t-1})(1-\alpha)\tau_Y(t-1)}{n(t-1)}\right]. \quad (21)$$

The dependent variable is now $y^g(t) = lny(t) - lny(t-1)$, which measures the change in the natural log of output over the period (the approximate growth rate).

So far, no approximations have been required. However, to map the nonlinear system into its linear counterpart we now distribute the logarithm through the denominator of the first component in equation (21),

$$ln\big(\alpha n(t-1)\big(1+\beta\gamma(t)\big)+(1-\alpha)\theta\big) \approx ln\Big(\alpha n(t-1)\big(1+\beta\gamma(t)\big)\Big) + ln\big((1-\alpha)\theta\big).$$

Since the last term is constant, the typical procedure would be to log-linearize the equation around the balanced growth path, or in effect, drop the constant term out of the system. However, we keep this constant term since it may vary across countries and possibly time in the data. After this first approximation (and collecting constants and like terms), we have,

$$y^g(t) = \beta_0 + \alpha\Big(ln\gamma(t) - ln\big(1+\beta\gamma(t)\big)\Big) - lnn(t-1) + \alpha ln\big(1-\tau(t-1)\big) + (1-\alpha)ln\tau_Y(t-1) + (1-\alpha)lnA(\phi_{t-1}). \quad (22)$$

The term $\beta_0 = \alpha(ln\alpha\beta(1-\alpha) - ln\alpha - ln(1-\alpha)\theta) + (1-\alpha)ln(1-\alpha)$.

The next approximation allows us to map the fertility and longevity variables directly into the dependency ratio variables. Specifically, we approximate the term $ln\big(1+\beta\gamma(t)\big) \approx \beta ln\gamma(t)$, which maintains the directional relationship of the longevity variable (an increase in longevity will increase both measures). We also apply this approximation to the total tax rate, $ln\big(1-\tau(t-1)\big) \approx -ln\tau(t-1)$. Finally, we decompose the productivity term into a (potentially) systematic component and a random component,

$$(1-\alpha)lnA(\phi_{t-1}) = \phi_{t-1} + \varepsilon_t. \quad (23)$$

The stochastic component ε_t is unobservable. The systematic components ϕ_{t-1} captures any additional control variables, or secondary variables, in the empirical specification.

Substituting these approximations and the productivity term back into equation (22) gives us

$$y^g(t) = \beta_0 + \alpha(1-\beta)ln\gamma(t) - lnn(t-1) - \alpha \ln \tau(t-1) + (1-\alpha)ln\tau_Y(t-1) + \phi_{t-1} + \varepsilon_t. \quad (24)$$

The final step is to express equation (24) in terms of the old-age dependency ratio and the child-dependency ratio. However, before doing so, we take another look at the relationship between tax rates in our economy.

III.B. Spending on the Elderly and Spending on the Young

The total tax rate in our model incorporates the tax rate funding transfers to the elderly and the tax rate funding education spending on the young (along with other government spending). Here we want to add the possibility that an aging population might crowd out investment in children to our statistical model. To introduce this potential effect, we begin by defining a parametric value that measures the level of educational crowding-out, $\mu \geq 0$. This parametric value determines how much the education tax rate changes in response to a change in the tax rate that funds transfers to the elderly,

$$ln\tau_Y(t-1) = -\mu ln\tau_R(t-1). \quad (25)$$

If $\mu = 0$ then a change in the tax rate funding transfers to the elderly does not affect the tax rate funding investment in children. That is, there is no crowding-out (if the tax rate falls then there is no crowding-in). However, if $\mu > 0$, then an increase in the tax rate funding transfers to the elderly, who are now living longer, will result in a reduction in spending on education and other investments in children. In this case there is crowding-out (or crowding-in if there is a decrease in the tax rate funding transfers to the elderly).

To add this (potential) relationship to our empirical framework, use equation (10), in natural log form, $ln\tau_R(t) = ln\big(oadr(t)\big) + ln\theta$, and write equation (25) as:

$$ln\tau_Y(t-1) = -\mu lnoadr(t-1) - \mu ln\theta.$$

Substitute this relationship into the empirical specification described in equation (24),

$$\begin{aligned} y^g(t) = \beta_0 + \alpha(1-\beta)ln\gamma(t) - lnn(t-1) - \alpha \ln \tau(t-1) \\ -\mu(1-\alpha)lnoadr(t-1) + \phi_{t-1} + \varepsilon_t, \end{aligned} \quad (26)$$

where the constant term β_0 now includes the additional constant term $-\mu(1-\alpha)ln\theta$.

III.C. Empirical Specification

We now rewrite equation (26) in terms of the old-age dependency ratio and the child-dependency ratio. First, add and subtract the term $\alpha(1-\beta)lnn(t-1)$ to and from equation (26):

$$y^g(t) = \beta_0 + \alpha(1-\beta)ln\left(\frac{\gamma(t)}{n(t-1)}\right) - \big(1-\alpha(1-\beta)\big)lnn(t-1)$$
$$- \alpha \ln \tau(t-1) - \mu(1-\alpha)lnoadr(t-1) + \phi_{t-1} + \varepsilon_t.$$

Finally, after reordering the variables of interest, we have our general linear statistical model:

$$y^g(t) = \beta_0 + \beta_1 lnoadr(t) + \beta_2 lnoadr(t-1) + \beta_3 lncdr(t-1) + \beta_4 \ln \tau(t-1) + \phi_{t-1} + \varepsilon_t. \quad (27)$$

The predicted signs for our key demographic variables are as follows: $\beta_1 = \alpha(1-\beta) > 0$ and $\beta_2 = -\mu(1-\alpha) \leq 0$.

The parameter $\beta_1 > 0$ shows that rational forward-looking households should respond to an increase in longevity by increasing savings for retirement during their working years. Note that the end of period old age-dependency ratio captures this forward-looking behavior. This implies an aging population should stimulate economic growth, holding everything else constant.

To help understand this, consider equation (27) for the time period between the years 1995 and 2004:

$$lny(2004) - lny(1995) = \beta_0 + \beta_1 lnoadr(2004) + \beta_2 lnoadr(1995) + \beta_3 lncdr(1995)$$
$$+\beta_4 \ln \tau(1995) + \phi_{1995} + \varepsilon_{2004}.$$

In theory, the working period households increase savings during the time period between 1995 and 2004 because they expect to live longer during retirement. This has two effects. First, the increase in savings increases the capital stock per worker. Second, this increase in the capital stock per worker results in an increase in household earnings, which allows households to spend more on their children. Both effects result in a higher rate of growth. This prediction is consistent with the empirical findings of Zhang and Zhang (2005) and the theoretical results derived in Bloom, Canning and Graham (2003).[14] The key here is

[14] It is important to note that the savings response in our framework is for the working generation and does not represent the aggregate savings response. The latter would include dissavings by the old or retirees. This issue is addressed in Bloom, Canning, Mansfield and Moore (2007), which demonstrates that the aggregate economic response depends on the type and generosity of the social security program in different countries.

that it is the end-of-period old-age dependency ratio that allows us to isolate this behavioral response in the data. The beginning-of-period old-age dependency ratio has a different interpretation or prediction.

The parameter $\beta_2 \leq 0$ measures the potential degree of crowding-out as the population ages. The sign is negative if there is crowding-out, $\mu > 0$, and equals zero if there is no crowding out, $\mu = 0$. In effect, the parameter β_2 tests whether an aging society, and the costs of providing additional resources to the elderly, reduces investment in children. In the example above, the variable $oadr(1995)$ measures the old-age dependency ratio at the beginning of the growth period. If educational crowding-out is present, this will reduce investment in children at the beginning of the period (assuming a higher old-age dependency ratio for this example). In other words, as more funds flow to the elderly through social insurance programs, this will potentially reduce the productivity of the future labor force, which, in turn, will place a drag on economic growth. This variable isolates the potential institutional response in the data.

Our final demographic parameter $\beta_3 < 0$ captures the potential dilution effect that a relatively larger birth cohort will have on education spending per child or the potential increase in education spending per child for a relatively smaller cohort. If this effect is present, then there will be a reduction in human capital per child for relatively larger birth cohorts, placing a drag on growth, or there will be an increase in human capital for relatively smaller cohorts, stimulating growth. This captures the standard quality-quantity tradeoff described in Becker et al. (1990) and some of the papers previously cited.

In summary, our empirical specification allows us to identify patterns in the data that suggest how the society has responded to changes in age structure in the past. Specifically, we can now identify and estimate the *behavioral* and *institutional* response coefficients. Before turning to the description of the data and the estimation of the model above, we conclude this section by presenting equation (27) in general form across time and across countries,

$$y_{it}^{g} = \beta_{0it} + \beta_{1it} oadr_{it} + \beta_{2it} oadr_{it-1} + \beta_{3it} cdr_{it-1} + \beta_{4it} \tau_{it-1} + \beta_{it}' X_{it-1} + \varepsilon_{it}. \qquad (28)$$

The control variables ϕ_{t-1} are now expressed in terms of a set of secondary variables X_{it-1} along with a coefficient vector β_{it}'. The potential country/group specific and time specific intercept may also capture these controls through fixed effects. The subscript i denotes the country and the subscript t denotes time (the end of period). The variables are in their natural log form. After discussing the data, we impose additional restrictions on the parameters of the model to estimate this relationship and to test the hypotheses described above.

IV. Data

We use data from 1975 to 2014 for a set of OECD countries to construct our panel (a list of countries can be found in Appendix C). We decompose this 40-year time period into 10-year intervals for most specifications and use 20-year intervals as a robustness check of our shorter time interval in section 6. We chose this set of countries, and this time period, to ensure a balanced panel for the demographic variables of interest and to capture relatively mature redistribution programs to the elderly for most countries in the sample. This time period also maximizes coverage of the other control variables and is post-Bretton Woods.

Our demographic variables come from the World Development Indicators data set at World Bank. We use the variable "Age dependency ratio, young", which equals the population under 15 divided by the population with ages 15-64, to represent our theoretical child dependency ratio. We use the variable "Age dependency ratio, old", which equals the population 65 and older divided by the population with ages 15-64, to represent our theoretical old-age dependency ratio. We construct our output per worker measure using data from the Penn World Tables (see, Feenstra, Inklaar and Timmer (2015)), which we discuss in Appendix B. This measure also uses the demographic variables above. As a robustness check of our constructed measure of output per worker, we use the variable "Number of Persons Engaged" to derive output per worker. This measure controls for differences in labor-force participation rates. This data also comes from the Penn World Table 9.0 (Groningen Growth and Development Centre (2013)).

We use time fixed effects and group specific fixed effects in our analysis to control for other potential factors that might also influence a country's rate of growth. However, this approach might miss some variables that change over time and across countries, which might also influence our results. Therefore, we add the following variables as additional controls to some specifications. First, we add trade (exports plus imports divided by GDP), taken from the Penn World Tables, to measure potential changes in market integration. Second, we add the debt/GDP ratio, taken from Carmen M. Reinhart's data set (link in footnote below)[15], to measure expenditures that our balanced budget assumptions might miss. Third, we control for net migration using the "Net Migration Rate" variable found in "United Nations: World Population Prospects (2017)".

V. Results (Demographic Variables Only)

[15] The data can be found at http://www.carmenreinhart.com/data/browse-by-topic/topics/9/.

We begin by estimating our model under the following set of restrictions. First, we assume the additional control variables are captured by time specific fixed effects and/or group specific fixed effects (see appendix C for the countries in the two groups). Second, we omit the tax rate variable from the regression to isolate our key demographic variables. Finally, we assume the coefficients are stable across countries and time, excluding the intercept, which gives us the following statistical model:

$$y_{it}^{g} = \beta_{0it} + \beta_1 oadr_{it} + \beta_2 oadr_{it-1} + \beta_3 cdr_{it-1} + \varepsilon_{it}. \tag{29}$$

We report our results in **Table 1**. The first column reports the results with no time specific or group specific fixed effects (pooled data). Column (2) reports the results when we include time specific fixed effects and Column (3) reports the results when we include time specific and group specific fixed effects. Columns (4) through (6) use the same framework as columns (1) through (3), but we restrict the sample to the period 1975-2004 to account for the possibility that the Great Recession influences the results.

The results are consistent with our theory that an increase in longevity during retirement increases the growth rate of the economy. The coefficient on the end-of-period old age dependency ratio $(oadr_{it})$ in Column (1) is positive, although not statistically significant. We find the same sign for columns (2) through (6), but the results are now statistically significant indicating time effects are important. These results demonstrate that this positive relationship is robust to the inclusion of period specific (time) fixed effects, group specific fixed effects, and after removing the Great Recession from the data. The interpretation here is that economic agents rationally respond to an increase in longevity by saving more for their longer period in retirement. This is consistent with Zhang and Zhang (2005) who also find that an increase in life expectancy increases the investment/GDP ratio in the data. Whether this response is optimal in terms of the required amount of savings for the additional retirement years is not identified. However, the key interpretation of this relationship is that the behavioral response will increase, not decrease, the growth rate of the economy as the population ages holding everything else constant. That is, population aging itself is not likely to result in a stagnant/low-growth economy.[16]

The results in columns (1) through (6) find an inverse relationship between the beginning-of-period old age dependency ratio $(oadr_{it-1})$ and the growth rate of the economy. This suggests that if there is an increase in the old-age-dependency ratio then there will be a reduction in education spending per child in our stylized framework. In other words, an aging population appears to crowd-out investment in future working generations by shifting resources to the elderly and away from children. Here we can

[16] The results in Bloom et al. (2007) suggest that aggregate savings decrease as the fraction of the population over the age of 60 increases. Their results look at aggregate savings, whereas our results look at savings per worker. That is, our specification does not include the dissavings by retirees.

see it is the institutional response that will likely place a drag on economic growth. This relationship is consistent with the findings in Maestas et al. (2016) who find that an increase in the share of the population over 60 places a significant drag on growth for U.S. states. This result is also consistent with theoretical findings in Zhang et al. (2003) and Pecchenino and Utendorf (1999) who suggest that as life expectancy increases in the later stage of life there is a reduction in the tax rate funding education. As a final note on this estimate, our results might at first pass appear inconsistent with Zhang and Zhang (2005) who find education (secondary enrollment) increases with life expectancy. However, our measure is capturing the increase in the conditional life expectancy after retirement, whereas they measure life expectancy at birth.

The coefficient on the child dependency ratio is negative for all our specifications, but statistically insignificant in columns (2)-(6). This suggests that education spending per child is inversely related to the size of the generation, however, these estimates are imprecise. In this case, education spending per child tends to increase for smaller generations and decrease for larger generations, which is consistent with the papers previously cited. Thus, a decrease in the fertility rate should stimulate economic growth through an increase in human capital per worker holding everything else constant. We don't belabor this point since our primary focus is on the effect life expectancy during the later stage of life has on growth.

The results above are consistent with the findings in Bloom et al. (2010) who conclude that population aging does not appear to have a large effect on growth. A comparison of the estimates in **Table 1** for the end-of-period old age dependency ratio $(oadr_{it})$ and the beginning-of-period old age dependency ratio $(oadr_{it-1})$ demonstrate the coefficients are very similar. The overall effect is negative, but the data does not reject the restriction that $\beta_1 + \beta_2 = 0$ using the standard Wald Test. We can also see this result in **Table 2**, where we demonstrate the importance of including the beginning-of-period old age dependency ratio and the end-of-period old age dependency ratio in the specification. Our theory suggests that both variables are relevant. In columns (1), (3), and (5) we observe a negative coefficient estimate for the end-of-period old age dependency ratio when the beginning-of-period old age dependency ratio is omitted. However, this is the result of omitted variable bias in our specification. The same reasoning applies to columns (2), (4), and (6), where the coefficient estimate on the beginning-of-period old age dependency ratio is again negative, but smaller than the original estimates. If we only included one measure of the old age dependency ratio the results would suggest that an aging population is always bad for growth. However, as we demonstrated in Table 1 an aging population is only bad for growth if the institutional response is to reduce expenditures on the young. In fact, our results suggest that an aging population will stimulate growth if investment in future generations continues.

One might be concerned about our constructed measure of output per worker. For this reason, in **Table 3** we report results for the basic model estimations using output per engaged worker. Here, the results are basically the same. The coefficient for the end-of-period old age dependency ratio is positive for all specifications and the coefficient for the beginning-of-period old age dependency ratio is negative for all specifications. This again is consistent with the theoretical framework, which suggests that slower economic growth due to population aging is the result of the institutional response rather than the behavioral response. The signs on the beginning-of-period child dependency ratio change across specifications, suggesting this parameter is imprecisely estimated with this data. Given the similarity in findings, we use our constructed measure of output per worker throughout the remainder of the paper.

VI. Robustness of Results

We now check the robustness of our results to variations in the model's specification. Additional robustness checks can be found in appendix D. The first robustness check is to add the general tax rate (tax revenue as a share of GDP) back into the estimation process as an additional control. Our theory suggests this variable should be included. Blankenau et al. (2007) also argues why this additional control should be included in the empirical specification. Column (1) of **Table 4** looks at the period from 1975-2014 with time fixed effects excluding the tax rate, which comes from our initial specification. Column (2) reports the results with the general tax rate. Here we can see the results do not depend on this addition. The coefficient on the end-of-period old age dependency ratio is positive and statistically significant and the coefficient on the beginning-of-period old age dependency ratio is negative and statistically significant as before. The coefficient on the general tax rate is positive and statistically insignificant. This result is a bit of a puzzle but is likely due to the limited additional information contained in the data. Thus, the estimate is imprecise. This estimate could also be capturing the effect of other productive government expenditure not built into our framework. Column (3) controls for government consumption (government consumption as share of GDP) as a proxy for other, possibly productive, forms of government activity in the economy. The results again are roughly the same as before. The key here is that our demographic results are robust to the inclusion of these variables.

Next, we use the same specifications in **Table 5**, but restrict the time period to 1975-2004. This eliminates any potential bias that might result from the Great Recession. Here we once again get the same results. The coefficient estimates for the end-of-period old age dependency ratio are positive and the coefficient estimates for the beginning-of-period old age dependency ratio are negative. In **Table 6** we use the same specifications but look at 20-year intervals rather than the 10-year intervals employed in the previous regressions. The hope here is that we can control for potential generational overlap in the data and the fact that education investment in human capital might take longer than 10 years to enter the labor force. This also introduces greater variation in the data across time. Column (1) shows the results for the initial case where we drop the tax rate (time fixed effects are included in all specifications). Here we observe the effects of population aging are larger than the 10-year interval estimates. The signs are the same. The same applies to Columns (2) and (3) where we control for the tax rate or government consumption (the coefficient estimate for the tax rate is now negative). Columns (4) and (5) add the group fixed effects. As we move to 20-year interval estimates this only strengthens the findings relative to the 10-year interval estimates. Thus, any potential bias that is the result of the shorter interval appears to work against the predictions of the model.

In **Table 7** we control for other potential variables that might directly influence growth and be correlated with our demographic variables. Columns (1) reports our results for the complete model (again, using 10-year intervals). Column (2) controls for debt as a share GDP, Column (3) controls for net migration, and Column (4) controls for trade (exports plus imports as a share of GDP). The variable *debt* seems to have the most influence on our results. We observe a significant decrease in the savings response measured by the end-of-period old-age dependency ratio. The logical interpretation here is that debt is absorbing a significant share of savings by the working generation and is temporarily allowing the economy to expand without increasing taxes. This might also explain the imprecision of our tax rate estimates. The other two variables do not change our results in any significant way. In columns (5) though (8) we estimate the same specifications for the 1975-2004 period, eliminating the great recession. Here we once again find similar results.

VII. Interpreting the Results

To give us some sense of the potential magnitude an aging population might have on growth we now provide some back-of-the-envelope calculations to isolate each potential demographic effect. The first step is to define the long-term growth rate, or structural growth, over the relevant time period:

$$ln\left(\frac{y(t+T)}{y(t)}\right) = ln\left(\frac{y(t)e^{gT}}{y(t)}\right) = gT.$$

Here the period of time between the end-of-period and the beginning-of-period is T and g is the structural (average annual) rate of growth during the period. In difference form, we now have the approximate effects on growth for our demographic variables of interest using equation (28) or (29),

$$\Delta g = \frac{\beta_1}{T}\Delta oadr_{it} + \frac{\beta_2}{T}\Delta oadr_{it-1} + \frac{\beta_3}{T}\Delta cdr_{it-1}.$$

We present our calculations in **Table 8** using the parameter estimates from Table 7-Column 2. These estimates allow debt to absorb some of the savings by the working generation and give us a relatively larger crowding-out effect. Clearly these are just *illustrative calculations* used to demonstrate the potential negative implications of reducing investment in future generations. Different estimates within our own paper would give us different results. For a majority of the estimates the savings and crowding-out effect would roughly offset each other. Finally, we use the percentage change in the old-age dependency ratio and the percentage change in the child-dependency ratio between 2020 and 2050 to measure changes in the population. The same percentage change in the old-age dependency ratio measures the beginning and end-of-period change in population age structure.

The first two columns in **Table 8** report how each component of the age distribution will change over time for each country in the sample. The next three columns decompose the demographic effects on the average annual growth rate for these estimates. Consider the United States in bottom row of the table. The population data indicates that the old-age dependency ratio will increase by roughly 34.8% and the child dependency ratio will fall by 1.39% between the years 2020 and 2050. Using these demographic changes, the predicted savings response accelerates growth by 0.65 percentage points, the crowding-out effect decreases growth by 1.28 percentage points, and the child dependency effect accelerates growth by 0.03 percentage points. The last two columns combine all of the demographic effects to get a sense of the overall (potential) impact on growth. The estimated total effect on growth for the United States is a decrease of 0.59 percentage points. This implies that a 2% trend rate of growth without population aging will fall to 1.41% with population aging. This result is consistent with the secular stagnation literature that suggests an aging population will place a drag on economic growth, as in Aksoy et al. (2019) and Gordon (2012, 2015). However, as our theory and data suggest, this need not be the case. If a country (or government) continues to invest in future generations, then an aging population will likely accelerate long-run growth. As people live longer and save more, this will result in capital deepening and more human capital per worker. The last column of the table suppresses the crowding-out effect, which suggests growth might increase by 0.69 percentage points.

The same reasoning applies to the entire set of countries. For example, France might observe growth declining by 0.65 percentage points, Canada might observe growth declining by 0.87 percentage points, and the UK might observe growth declining by 0.54 percentage points as their populations age. Again, it is important to note that the purpose of this table is to demonstrate how population aging can affect long-run growth through the different channels. The behavioral response clearly accelerates growth and a failure to invest in future generations clearly places a drag on growth. The effect of the child dependency ratio is relatively small for this set of countries. These numerical examples highlight the result that slower growth will be by design. If countries choose to reduce investment in future generations to fund consumption by the elderly, slow growth is the likely result.

As a final note, is important to highlight some of the key assumptions for the table above. First, we assume the parameters are stable across time and thus map into the same values in the future. However, the future behavioral and institutional responses may not be the same as in the historical data. Second, we assume the parameters are the same across countries and can be aggregated. There are likely aggregation issues here, as the different countries in the sample are more than likely going to have different behavioral and institutional responses. It is perhaps best to think of the response coefficients as the sample average across countries. A mean group estimator is problematic given our short time horizon. However, as we demonstrated in the previous section, the results of the paper are for the most part robust to specification changes, different time periods, and additional controls in terms of the overall effects.

VIII. Conclusion

This paper suggests that an aging population will place a drag on growth if a country chooses to fund additional transfers to the elderly by reducing investment in future generations. However, this doesn't need to be the case. Higher growth is possible if investment in future generations is maintained, which will most likely need to be paired with entitlement reform. To demonstrate these results, we construct a model that decomposes the effect a longer retirement period has on growth into two separate components. The first component is the behavioral response. As households live longer and plan to spend a longer time in retirement, they increase savings. This increase in savings stimulates growth through physical and human capital accumulation. The second component is the potential crowding-out effect or the institutional response. If the government increases transfers to the elderly and shifts resources away from the young, then this will place a drag on growth. The failure to invest in future generations will reduce human capital.

We then take the data to the model to determine if these two effects are present, and if so, which effect appears to be the stronger of the two. The data does suggest that both effects are present. The old-age dependency ratio at the end of a growth period appears to stimulate growth and the old age dependency ratio at the beginning of a growth period appears to place a drag on growth. This last effect captures the potential crowding-out effect of productive investment in future generations. We demonstrate these results are robust to different specifications, periods of time, and length of the time being measured. For most cases the crowding-out effect appears to be slightly larger (in absolute value) than the savings response. However, for most cases equality cannot be rejected in the data.

Appendix A

To solve for the balanced growth path of the economy rewrite equations (14) and (15) in terms of input growth rates (gross rates of growth).

$$\frac{k(t+1)}{k(t)} = \left(\frac{\alpha\beta(1-\alpha)\gamma(t+1)\big(1-\tau(t)\big)}{n(t)\alpha\big(1+\beta\gamma(t+1)\big)+(1-\alpha)\theta}\right)\left(\frac{k(t)}{h(t-1)}\right)^{\alpha-1} \tag{14'}$$

$$\frac{h(t)}{h(t-1)} = \left(\frac{A(\phi_t)(1-\alpha)\tau_Y(t)}{n(t)}\right)\left(\frac{k(t)}{h(t-1)}\right)^{\alpha} \tag{15'}$$

Note that the tax rates and demographic variables are constant along the balanced growth path. Equation (17) shows that physical capital-to-human capital ratio is also constant along the balanced growth path.

$$\frac{k(t+1)}{h(t)} = \frac{k(t)}{h(t-1)} = \frac{n\alpha\beta\gamma(1-\tau)}{A(\phi)\tau_Y(n\alpha(1+\beta\gamma)+(1-\alpha)\theta)} \tag{17}$$

Substitute this ratio into equation $(14')$ and $(15')$ and solve for g_h and g_k, the balanced growth rate for each input.

$$g_k = \frac{k(t+1)}{k(t)} = (1-\alpha)\left(\frac{A(\phi)\tau_Y}{n}\right)^{1-\alpha}\left(\frac{\alpha\beta\gamma(1-\tau)}{n\alpha(1+\beta\gamma)+(1-\alpha)\theta}\right)^{\alpha}$$

$$g_h = \frac{h(t)}{h(t-1)} = (1-\alpha)\left(\frac{A(\phi)\tau_Y}{n}\right)^{1-\alpha}\left(\frac{\alpha\beta\gamma(1-\tau)}{n\alpha(1+\beta\gamma)+(1-\alpha)\theta}\right)^{\alpha}$$

These two equations demonstrate that inputs grow at the same rate, which results in balanced growth. Substituting these growth rates into equation (16) gives us the growth rate of output per worker along the balanced growth path, where $g_k = g_h = g$.

$$g_y = \frac{y(t+1)}{y(t)} = (g)^{\alpha}(g)^{1-\alpha} = g = (1-\alpha)\left(\frac{A(\phi)\tau_Y}{n}\right)^{1-\alpha}\left(\frac{\alpha\beta\gamma(1-\tau)}{n\alpha(1+\beta\gamma)+(1-\alpha)\theta}\right)^{\alpha}$$

We can also eliminate the total tax rate defined in equation (19).

$$g = (1-\alpha)\left(\frac{A(\phi)\tau_Y}{n}\right)^{1-\alpha}\left(\frac{\alpha\beta\gamma(1-\tau_Y-\tau_R-\tau_O)}{n\alpha(1+\beta\gamma)+(1-\alpha)\theta}\right)^{\alpha}$$

For the balanced growth path to exist we must also restrict the sum of tax rates, such that, $\tau_Y + \tau_R + \tau_O \in (0,1)$.

Appendix B

To determine output per worker, our dependent variable of interest, we start with Real Gross Domestic Product (RGDP) $Y_i(t)$ where the subscript i denotes the country and t denotes the year. We use the RGDP^e measure in the Penn World Tables as our measure of RGDP (see, Feenstra et al. (2015)). We then divide RGDP by the total population to find RGDP per capita $y_i(t) = Y_i(t)/N_i(t)$, where the total population $N_i(t)$ also comes from the Penn World Table. This gives us the data on output per capita we need to derive our measure.

The next step is to map the value above into our theoretical measure of output per worker. First define output per worker as $y_i^w(t) = Y_i(t)/N_W(t)$ and decompose the total population into each respective age group $N_i(t) = N_{Y,i}(t) + N_{W,i}(t) + \gamma_i(t)N_{R,i}(t)$. Next, define the theoretical measure of RGDP per capita as $y_i^p(t) = Y_i(t)/\big(N_{Y,i}(t) + N_{W,i}(t) + \gamma_i(t)N_{R,i}(t)\big)$ where the superscript p denotes our theoretical measure of RGDP per capita. Now divide the numerator and denominator by $N_{w,i}(t)$.

$$y_i^p(i) = \frac{Y_i(t)/N_{W,i}(t)}{\big(N_{Y,i}(t)/N_{W,i}(t)\big) + 1 + \big(\gamma_i(t)N_{R,i}(t)/N_{W,i}(t)\big)} \qquad \text{(B.1)}$$

Using our definitions of the child dependency ratio and the old-age dependency ratio, defined in equations (2) and (3), along with our definition of output per worker, we map equation (B.1) into

$$y_i^p(i) = \frac{y_i^w(t)}{1 + cdr_i(t) + oadr_i(t)}. \qquad \text{(B.2)}$$

After equating the data value of RGDP per capita with our theoretical measure, $y_i(t) = y_i^p(t)$, and replacing the $cdr_i(t)$ and $oadr_i(t)$ with the data described in section 4 we can solve equation (B.2) for our measure of output per worker.

$$y_i^w(t) = y_i^p(t)\big(1 + cdr_i(t) + oadr_i(t)\big) \qquad \text{(B.3)}$$

We use the values $y_i^w(t)$ as our dependent variable in most of our empirical exercises. Our other measure of output per worker divides $Y_i(t)$ by the number of per engaged workers, also taken form the Penn World Tables. For a description of this measure see: https://www.rug.nl/ggdc/productivity/pwt/pwt-releases/pwt9.0.

Appendix C

This appendix provides detailed information about the data used in our quantitative analysis.

We consider all OECD countries, except the former communist ones in Central and Eastern Europe. The period analyzed is 1975-2014, which is divided in four ten-year intervals (or two twenty-year intervals).

We are left with the following set of countries, which we place in the following categories for group fixed effects: (Group 1): Chile, Greece, Korea, Mexico, Portugal, Turkey. (Group 2): Australia, Austria, Belgium, Canada, Switzerland, Germany, Denmark, Spain, Finland, France, United Kingdom, Ireland, Iceland, Ireland, Israel, Italy, Japan, Luxembourg, Netherlands, Norway, New Zealand, Sweden, United States.

The World Bank classifies economies into four income groups using gross national income (GNI) per capita. The countries in our sample are in the upper middle-income group (Group 1) and the high-income group (Group2). The high-income group was introduced in 1989 and the cut-off was set to $6000 for the year 1987 (GNI per capita). We computed the threshold for 1975 using the SDR deflator (Special Drawing Rights deflator). Based on these computations Spain and Ireland are very close to the threshold in 1975. We therefore move Spain and Ireland into Group 1 and estimate the model with this different grouping. The estimates are almost identical.

Output: Expenditure-side real GDP, using prices for final goods that are constant across countries and over time. Data are expressed at chained PPPs (in mil. 2011US$).
Source: Penn World Tables (PWT) 9.0, www.ggdc.net/pwt

Population: Population in millions.
Source: Penn World Tables (PWT) 9.0, www.ggdc.net/pwt

Number of Workers: Number of persons engaged (in millions).
Source: Penn World Tables (PWT) 9.0, www.ggdc.net/pwt

Child Dependency Ratio: "Age dependency ratio, young (% of working-age population) "- the ratio of younger dependents--people younger than 15--to the working-age population--those ages 15-64. Data are expressed as the proportion of dependents per 100 working-age population.
Source: World Development Indicators, World Bank staff estimates.

Child Dependency Ratio- Alternative Measure: "Child dependency ratio, 2"- Child Dependency Ratio (Age 0-19 / Age 20-64) De facto population as of July 1st of the year indicated.
Source: United Nations, "World Population Prospects: 2017 Revision"

Old Age Dependency Ratio: "Age dependency ratio, old (% of working-age population)"- the ratio of older dependents--people older than 64--to the working-age population--those ages 15-64. Data are expressed as the proportion of dependents per 100 working-age population.
Source: World Development Indicators, World Bank staff estimates.

Output per Worker was obtained as

i. $y^w(t) = y^p(t)\big(1 + cdr(t) + oadr(t)\big)$ or, alternatively,

ii. $y^w(t) = \frac{Output}{\#\ of\ workers}$.

where $y^w(t)$ is output per worker and $y^p(t)$ represents output per capita (output/population).

Tax Rate: Tax revenue (% of GDP) from compulsory transfers to the central government for public purposes. Certain compulsory transfers such as fines, penalties, and most social security contributions are excluded. Refunds and corrections of erroneously collected tax revenue are treated as negative revenue.
Source: World Development Indicators, World Bank.

Government Expenditure: General government final consumption expenditure (% of GDP). General government final consumption expenditure includes all government current expenditures for purchases of goods and services (including compensation of employees). It also includes most expenditures on national defense and security but excludes government military expenditures that are part of government capital formation.
Source: World Development Indicators, World Bank.

Debt: Debt-to GDP Ratio- central government debt as a percent of GDP.
Source: Carmen M. Reinhart' s webpage: http://www.carmenreinhart.com/data/browse-by-topic/topics/9/.

Trade: Trade (% of GDP). Trade is the sum of exports and imports of goods and services measured as a share of gross domestic product.
Source: World Development Indicators, World Bank.

Net Migration: The number of immigrants minus the number of emigrants over a period, divided by the person-years lived by the population of the receiving country over that period. It is expressed as average annual net number of migrants per 1,000 population.
Source: United Nations, "World Population Prospects: 2017 Revision"

Given that Net Migration may be a negative number, in our estimations we employ the following transformation to the raw data: we divide the raw data by a thousand and add 1, so that we can take the natural logarithm.

Appendix D

This appendix conducts a more thorough set of robustness checks on the model. All of the results in the body of the paper are robust to the following modifications. In Tables D1 and D2 we define the child dependency ratio as the ratio of people 19 and under to the number of people between the ages of 20-64. These two tables use the same specifications found in Tables 4 and 5 in the paper. In Tables D3 and D4 we attempt to control for the possibility of serial correlation in the last two columns of the table. The first two columns report the results from the body of the paper that do not control for potential serial correlation. The second to last column clusters by country and allows for serial correlation across time. The last column uses a random effects model to control for potential structural shocks over time. All of the results appear to be robust to these variations in specification. We also estimated the model using country fixed effects, but this resulted in a significant collinearity problem. We therefore chose the grouping method employed in the paper and attempted to control other potentially influential variables in the body of the paper.

Table D1

Estimation of the Basic Model with and without Group Specific and Time Specific Fixed Effects: Dependent Variable: $y^g(t) = lny(t) - lny(t-1)$

Panel: 1975-2014

Variable	(1)	(2)	(3)	(4)	(5)
$oadr_{it}$	0.3948**	0.4305**	0.3876**	0.4184**	0.3585*
	(0.1862)	(0.1913)	(0.1908)	(0.1956)	(0.1971)
$oadr_{it-1}$	-0.4414**	-0.4755**	-0.4509**	-0.4477**	-0.4165**
	(0.1595)	(0.1631)	(0.1592)	(0.1780)	(0.1730)
cdt_{it-1}	-0.0528	-0.0733	-0.0630	-0.0804	-0.0887
	(0.1179)	(0.1324)	(0.1241)	(0.1316)	(0.1218)
τ_{it-1}		0.0137		0.0151	
		(0.0357)		(0.0358)	
g_{it-1}			0.0185		0.0466
			(0.0491)		(0.0524)
Time FE	Yes	Yes	Yes	Yes	Yes
Group FE	No	No	No	Yes	Yes
R^2	0.2691	0.2765	0.2669	0.2801	0.2765
Observations	112	104	111	104	111

Degrees of Freedom	105	96	103	95	102
F-Test: $\beta_1 + \beta_2 = 0$	0.2276 (0.6343)	0.1617 (0.6885)	0.3219 (0.5717)	0.0635 (0.8016)	0.2728 (0.6026)

NOTES: Constructed GDP per worker (see formula in Appendix B). ** significant at 5% and * significant at 10%. Heteroskedasticity Robust standard errors are in parentheses. We report the p-value for the F-test on the coefficient restriction in the last row of the table.

Table D2

Estimation of the Basic Model with and without Country Specific and Time Specific Fixed Effects:
Dependent Variable: $y^g(t) = lny(t) - lny(t-1)$

Panel: 1975-2004

Variable	(1)	(2)	(3)	(4)	(5)
$oadr_{it}$	0.5851** (0.2548)	0.5645** (0.2676)	0.5691** (0.2597)	0.5622** (0.2735)	0.5499** (0.2694)
$oadr_{it-1}$	-0.5598** (0.2038)	-0.5767** (0.2073)	-0.5829** (0.2017)	-0.5721** (0.2237)	-0.5624** (0.2179)
cdr_{it-1}	0.0069 (0.1413)	-0.0358 (0.1604)	-0.0123 (0.1455)	-0.0377 (0.1606)	-0.0299 (0.1464)
τ_{it-1}		0.0200 (0.0420)		0.0202 (0.0426)	
g_{it-1}			0.0481 (0.0480)		0.0633 (0.0536)
Time FE	Yes	Yes	Yes	Yes	Yes
Group FE	No	No	No	Yes	Yes
R^2	0.3174	0.3072	0.3188	0.3073	0.3212
Observations	84	78	83	78	83
Degrees of Freedom	78	71	76	70	75
F-Test: $\beta_1 + \beta_2 = 0$	0.0459 (0.8308)	0.0081 (0.9284)	0.0111 (0.9162)	0.0051 (0.9435)	0.0091 (0.9241)

NOTES: Constructed GDP per worker (see formula in Appendix B). ** significant at 5% and * significant at 10%. Heteroskedasticity Robust standard errors are in parentheses. We report the p-value for the F-test on the coefficient restriction in the last row of the table.

Table D3

Estimation of the Basic Model with and without Country Specific Fixed/Random Effects and Time Specific Fixed Effects and under various assumptions regarding the coefficient covariance method. Dependent Variable: $y^g(t) = lny(t) - lny(t-1)$

Panel: 1975-2014

Variable	OLS	White hetero-skedastic	Cluster by country	Random Effects (OLS)
$oadr_{it}$	0.4090**	0.4090*	0.4090**	0.2039
	(0.1843)	(0.2078)	(0.1920)	(0.1908)
$oadr_{it-1}$	-0.4589**	-0.4589**	-0.4589**	-0.3497**
	(0.1549)	(0.1694)	(0.1744)	(0.1601)
cdt_{it-1}	-0.0864	-0.0864	-0.0864	-0.1799*
	(0.0999)	(0.1204)	(0.0971)	(0.0970)
τ_{it-1}	0.0154	0.0154	0.0154	0.0163
	(0.0368)	(0.0366)	(0.0311)	(0.0396)
Time FE	Yes	Yes	Yes	No
R^2	0.2787	0.2787	0.2787	0.1076
Observations	104	104	104	104
Degrees of Freedom	96	96	96	99
F-Test:	0.3793	0.2668	0.4983	3.004
$\beta_1 + \beta_2 = 0$	(0.5394)	(0.6067)	(0.4820)	(0.0861)

NOTES: Constructed GDP per worker (see formula in Appendix B). ** significant at 5% and * significant at 10%. Heteroskedasticity Robust standard errors are in parentheses. We report the p-value for the F-test on the coefficient restriction in the last row of the table.

Table D4

Estimation of the Basic Model with and without Country Specific Fixed/Random Effects and Time Specific Fixed Effects and under various assumptions regarding the coefficient covariance method. Dependent Variable: $y^g(t) = lny(t) - lny(t-1)$

Panel: 1975-2004

Variable	OLS	White hetero-skedastic	Cluster by country	Random Effects (OLS)
$oadr_{it}$	0.5313** (0.2272)	0.5313* (0.2803)	0.5313** (0.2641)	0.5237** (0.2399)
$oadr_{it-1}$	-0.5618** (0.1871)	-0.5618** (0.2162)	-0.5618** (0.2239)	-0.6330** (0.1982)
cdt_{it-1}	-0.0637 (0.1189)	-0.0637 (0.1497)	-0.0637 (0.1236)	-0.1886* (0.1099)
τ_{it-1}	0.0221 (0.0450)	0.0221 (0.0427)	0.0221 (0.0429)	0.0426 (0.0475)
Time FE	Yes	Yes	Yes	No
R^2	0.3093	0.3093	0.3093	0.2166
Observations	78	78	78	78
Degrees of Freedom	71	71	71	73
F-Test: $\beta_1 + \beta_2 = 0$	0.0973 (0.7561)	0.0636 (0.8016)	0.1042 (0.7478)	1.2485 (0.2675)

NOTES: Constructed GDP per worker (see formula in Appendix B). ** significant at 5% and * significant at 10%. Heteroskedasticity Robust standard errors are in parentheses. We report the p-value for the F-test on the coefficient restriction in the last row of the table.

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Table 1

Estimation of the Basic Model with and without Group Specific and Time Specific Fixed Effects:
Dependent Variable: $y^g(t) = lny(t) - lny(t-1)$

	Panel: 1975-2014			Panel: 1975-2004		
Variable	(1)	(2)	(3)	(4)	(5)	(6)
$oadr_{it}$	0.2185 (0.1978)	0.3748* (0.2015)	0.3690* (0.2053)	0.5402* (0.2774)	0.5472** (0.2676)	0.5442** (0.2721)
$oadr_{it-1}$	-0.3596** (0.1688)	-0.4272** (0.1677)	-0.3945** (0.1815)	-0.6181** (0.2229)	-0.5455** (0.2128)	-0.5368** (0.2269)
cdt_{it-1}	-0.1775* (0.0970)	-0.0655 (0.1056)	-0.0668 (0.1060)	-0.1667 (0.1210)	-0.0260 (0.1318)	-0.0284 (0.1323)
Time FE	No	Yes	Yes	No	Yes	Yes
Group FE	No	No	Yes	No	No	Yes
R^2	0.1125	0.2706	0.2763	0.2083	0.3178	0.3182
Observations	112	112	112	84	84	84
Degrees of Freedom	108	105	104	80	78	77
F-Test: $\beta_1 + \beta_2 = 0$	2.8046 (0.0969)	0.3991 (0.5290)	0.0812 (0.7763)	0.5139 (0.4756)	0.0003 (0.9875)	0.0044 (0.9473)

NOTES: Constructed GDP per worker (see formula in Appendix B). ** significant at 5% and * significant at 10%. Heteroskedasticity Robust standard errors are in parentheses. We report the p-value for the F-test on the coefficient restriction in the last row of the table.

Table 2

Estimation of the Reduced Model with and without Country Specific and Time Specific Fixed Effects
Dependent Variable: $y^g(t) = lny(t) - lny(t-1)$

Variable	(1)	(2)	(3)	(4)	(5)	(6)
$oadr_{it}$	-0.1766** (0.0856)		-0.0932 (0.0866)		-0.0432 (0.0945)	
$oadr_{it-1}$		-0.1945** (0.0706)		-0.1427** (0.0685)		-0.1121 (0.0825)
cdr_{it-1}	-0.2476** (0.0949)	-0.2471** (0.0764)	-0.1318 (0.1093)	-0.1785** (0.0892)	-0.1255 (0.1098)	-0.1780* (0.0906)
Time FE	No	No	Yes	Yes	Yes	Yes
Group FE	No	No	No	No	Yes	Yes
R^2	0.0663	0.1008	0.2129	0.2398	0.2299	0.2466
Observations	112	112	112	112	112	112
Degrees of Freedom	109	109	106	106	105	105

NOTES: Constructed GDP per worker (see formula in Appendix B). ** significant at 5% and * significant at 10%. Heteroskedasticity Robust standard errors are in parentheses.

Table 3

Estimation of the Basic Model with and without Country Specific and Time Specific Fixed Effects

Dependent Variable: $y^g(t) = lny(t) - lny(t-1)$

	Panel: 1975-2014			Panel: 1975-2004		
Variable	(1)	(2)	(3)	(4)	(5)	(6)
$oadr_{it}$	0.2341	0.3500*	0.3410*	0.5108**	0.4604*	0.4575*
	(0.1889)	(0.1854)	(0.1918)	(0.2510)	(0.2429)	(0.2485)
$oadr_{it-1}$	-0.2404	-0.2997*	-0.2494	-0.4716**	-0.3820*	-0.3736*
	(0.1610)	(0.1560)	(0.1756)	(0.2067)	(0.1968)	(0.2136)
cdt_{it-1}	-0.0028	0.0460	0.0440	-0.0044	0.0600	0.0577
	(0.0906)	(0.1012)	(0.1018)	(0.1111)	(0.1243)	(0.1249)
Time FE	No	Yes	Yes	No	Yes	Yes
Group FE	No	No	Yes	No	No	Yes
R^2	0.0320	0.2325	0.2508	0.1200	0.2592	0.2596
Observations	112	112	112	84	84	84
Degrees of Freedom	108	105	104	80	78	77
F-Test:	0.0077	0.4910	1.3257	0.1837	0.7582	0.7724
$\beta_1 + \beta_2 = 0$	(0.9303)	(0.4850)	(0.2522)	(0.6694)	(0.3866)	(0.3822)

NOTES: PWT GDP per engaged worker. **significant at 5% and * significant at 10%. Heteroskedasticity Robust standard errors are in parentheses. We report the p-value for the F-test on the coefficient restriction in the last row of the table.

Table 4

Estimation of the Basic Model with and without Country Specific and Time Specific Fixed Effects:
Dependent Variable: $y^g(t) = lny(t) - lny(t-1)$

Panel: 1975-2014

Variable	(1)	(2)	(3)	(4)	(5)
$oadr_{it}$	0.3748*	0.4090*	0.3656*	0.4031*	0.3464
	(0.2015)	(0.2078)	(0.2082)	(0.2119)	(0.2154)
$oadr_{it-1}$	-0.4272**	-0.4589**	-0.4365**	-0.4342**	-0.4028**
	(0.1677)	(0.1694)	(0.1660)	(0.1844)	(0.1814)
cdt_{it-1}	-0.0655	-0.0864	-0.0766	-0.0870	-0.0903
	(0.1056)	(0.1204)	(0.1128)	(0.1207)	(0.1116)
τ_{it-1}		0.0154		0.0162	
		(0.0366)		(0.0367)	
g_{it-1}			0.0218		0.0474
			(0.0506)		(0.0544)
Time FE	Yes	Yes	Yes	Yes	Yes
Group FE	No	No	No	Yes	Yes
R^2	0.2706	0.2787	0.2686	0.2817	0.2776
Observations	112	104	111	104	111
Degrees of Freedom	105	96	103	95	102
F-Test:	0.3991	0.2668	0.5110	0.0914	0.3201
$\beta_1 + \beta_2 = 0$	(0.5290)	(0.6067)	(0.4763)	(0.7631)	(0.5728)

NOTES: Constructed GDP per worker (see formula in Appendix B). ** significant at 5% and * significant at 10%. Heteroskedasticity Robust standard errors are in parentheses. We report the p-value for the F-test on the coefficient restriction in the last row of the table.

Table 5

Estimation of the Basic Model with and without Country Specific and Time Specific Fixed Effects: Dependent Variable: $y^g(t) = lny(t) - lny(t-1)$

Panel: 1975-2004

Variable	(1)	(2)	(3)	(4)	(5)
$oadr_{it}$	0.5472**	0.5313*	0.5301*	0.5297*	0.5145*
	(0.2676)	(0.2803)	(0.2737)	(0.2854)	(0.2844)
$oadr_{it-1}$	-0.5455**	-0.5618**	-0.5686**	-0.5571**	-0.5467**
	(0.2128)	(0.2162)	(0.2101)	(0.2329)	(0.2284)
cdr_{it-1}	-0.0260	-0.0637	-0.0454	-0.0648	-0.0590
	(0.1318)	(0.1497)	(0.1362)	(0.1502)	(0.1376)
τ_{it-1}		0.0221		0.0222	
		(0.0427)		(0.0431)	
g_{it-1}			0.0518		0.0678
			(0.0494)		(0.0557)
Time FE	Yes	Yes	Yes	Yes	Yes
Group FE	No	No	No	Yes	Yes
R^2	0.3178	0.3093	0.3201	0.3094	0.3230
Observations	84	78	83	78	83
Degrees of Freedom	78	71	76	70	75
F-Test:	0.0003	0.0636	0.1026	0.0466	0.0716
$\beta_1 + \beta_2 = 0$	(0.9875)	(0.8016)	(0.7497)	(0.8298)	(0.7898)

NOTES: Constructed GDP per worker (see formula in Appendix B). ** significant at 5% and * significant at 10%. Heteroskedasticity Robust standard errors are in parentheses. We report the p-value for the F-test on the coefficient restriction in the last row of the table.

Table 6

Estimation of the Basic Model with and without Country Specific and Time Specific Fixed Effects:
Dependent Variable: $y^g(t) = lny(t) - lny(t-1)$

Panel: 1975-2014
(20 Year Intervals)

Variable	(1)	(2)	(3)	(4)	(5)
$oadr_{it}$	0.5999**	0.5691**	0.5689**	0.5663*	0.5524*
	(0.2767)	(0.2802)	(0.2668)	(0.2878)	(0.2749)
$oadr_{it-1}$	-0.6525**	-0.6667**	-0.6754**	-0.6392**	-0.6412**
	(0.2483)	(0.2415)	(0.2636)	(0.2915)	(0.2999)
cdt_{it-1}	-0.0326	-0.1037	-0.0790	-0.1078	-0.1077
	(0.2531)	(0.2824)	(0.2596)	(0.2846)	(0.2494)
τ_{it-1}		-0.0102		-0.0091	
		(0.0610)		(0.0624)	
g_{it-1}			0.0520		0.0911
			(0.0904)		(0.0920)
Time FE	Yes	Yes	Yes	Yes	Yes
Group FE	No	No	No	Yes	Yes
R^2	0.2611	0.2816	0.2646	0.2847	0.2758
Observations	56	52	55	52	55
Degrees of Freedom	51	46	49	45	48
F-Test:	0.0761	0.2164	0.2648	0.0942	0.1665
$\beta_1 + \beta_2 = 0$	(0.7837)	(0.6440)	(0.6092)	(0.7603)	(0.6851)

NOTES: Constructed GDP per worker (see formula in Appendix B). ** significant at 5% and * significant at 10%. Heteroskedasticity Robust standard errors are in parentheses. We report the p-value for the F-test on the coefficient restriction in the last row of the table.

Table 7

Estimation of the Basic Model with and without Country Specific and Time Specific Fixed Effects:
Dependent Variable: $y^g(t) = lny(t) - lny(t-1)$

	Panel: 1975-2014				Panel: 1975-2004			
Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$oadr_{it}$	0.4090* (0.2078)	0.1884 (0.2281)	0.4001* (0.2139)	0.3368* (0.1946)	0.5313* (0.2803)	0.2467 (0.2872)	0.5313* (0.2821)	0.3991 (0.2559)
$oadr_{it-1}$	-0.4589** (0.1694)	-0.3705** (0.1841)	-0.4527** (0.1737)	-0.4061** (0.1650)	-0.5618** (0.2162)	-0.4594** (0.2190)	-0.5619** (0.2177)	-0.4577** (0.2036)
cdt_{it-1}	-0.0864 (0.1204)	-0.2679** (0.1261)	-0.0956 (0.1245)	-0.1195 (0.1111)	-0.0637 (0.1497)	-0.3214* (0.1616)	-0.0635 (0.1511)	-0.1213 (0.1359)
τ_{it-1}	0.0154 (0.0366)	0.0119 (0.0363)	0.0192 (0.0379)	0.0347 (0.0390)	0.0221 (0.0427)	0.0018 (0.0411)	0.0219 (0.0448)	0.0616 (0.0418)
$debt_{it-1}$		0.0226 (0.0211)				0.0514* (0.0280)		
$netmigr_{it-1}$			-2.0483 (3.2531)				0.1009 (3.4579)	
$trade_{it-1}$				-0.0293 (0.0298)				-0.0608 (0.0366)
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Group FE	No	No	No	No	No	No	No	No
R^2	0.2787	0.3436	0.2804	0.2857	0.3093	0.4084	0.3093	0.3355
Observations	104	93	104	104	78	69	78	78
Degrees of Freedom	96	84	95	95	71	61	70	70

NOTES: Constructed GDP per worker (see formula in Appendix B). ** significant at 5% and * significant at 10%. Heteroskedasticity Robust standard errors are in parentheses.

Table 8

A Decomposition of the Potential Effects an Aging Population might have on Growth.
Coefficient Estimates from Table 7-Column 2.

Country	Change in share 65+	Change in share 14-	Estimated Effect (Savings)	Estimated Effect (Crowding Out)	Estimated Effect (Child Dependency)	Estimated Total Effect	Estimated Net Effect
Australia	38.94%	-5.49%	0.73	-1.44	0.14	-0.56	0.88
Austria	59.37%	10.16%	1.11	-2.19	-0.27	-1.35	0.84
Belgium	42.73%	2.9%	0.80	-1.58	-0.07	-0.85	0.72
Canada	44.74%	2.4%	0.84	-1.65	-0.06	-0.87	0.77
Switzerland	54.47%	6.81%	1.02	-2.01	-0.18	-1.17	0.84
Chile	78.38%	-15.3%	1.47	-2.90	0.41	-1.01	1.88
Germany	46.41%	12.05%	0.87	-1.71	-0.32	-1.16	0.55
Denmark	25.41%	4.58%	0.47	-0.94	-0.12	-0.58	0.35
Spain	82.50%	13.29%	1.55	-3.05	-0.35	-1.85	1.19
Finland	17.31%	0%	0.32	-0.64	0	-0.31	0.32
France	33.68%	1.37%	0.63	-1.24	-0.03	-0.65	0.59
UK	33.07%	-2.13%	0.62	-1.22	0.05	-0.54	0.68
Greece	73.69%	9.48%	1.38	-2.73	-0.25	-1.59	1.13
Ireland	65.61%	-6.87%	1.23	-2.43	0.18	-1.01	1.42
Iceland	57.29%	-13.9%	1.07	-2.12	0.37	-0.66	1.45
Israel	31.14%	-20.2%	0.58	-1.15	0.54	-0.02	1.12
Italy	55.24%	17.43%	1.04	-2.04	-0.46	-1.47	0.57
Japan	39.84%	13%	0.75	-1.47	-0.34	-1.07	0.40
ROK	109.8%	15.41%	2.06	-4.07	-0.41	-2.41	1.65
Luxembourg	56.55%	9.11%	1.06	-2.09	-0.24	-1.27	0.82
Mexico	94.93%	-36.8%	1.78	-3.51	0.98	-0.74	2.77
Netherlands	43.49%	1.16%	0.81	-1.61	-0.03	-0.82	0.78
Norway	37.39%	-0.73%	0.70	-1.38	0.02	-0.66	0.72
New Zealand	43.76%	-10.6%	0.82	-1.62	0.28	-0.51	1.11
Portugal	64.82%	9.48%	1.22	-2.40	-0.25	-1.43	0.96
Sweden	23.04%	-1.4%	0.43	-0.85	0.03	-0.38	0.47
Turkey	91.78%	-27.5%	1.72	-3.4	0.73	-0.93	2.46
United States	34.80%	-1.39%	0.65	-1.28	0.03	-0.59	0.69

Notes: The change in share of the population is measured using 2020 and 2050 data for each country. The data comes from United Nations: World Population Prospects (2017), Medium Variant-Old Age Dependency Ratio 1 (Age65+/Age 15-64). Our measure is in terms of percentage changes. We also assume the same value for the old-age dependency ratio for each contributing factor. Thus, the results approximate the potential long-run effect over the next 30 years. The Estimated Net Effect excludes the crowding-out factor to demonstrate the effect an aging population has on growth in our framework if crowding-out does not occur.