

Kotschy, Rainer; Sunde, Uwe

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Aging, Skills, and Economic Performance: Evidence from Panel Data

Rainer Kotschy*

LMU Munich

Uwe Sunde

LMU Munich

IZA, Bonn

CEPR, London

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Preliminary and Incomplete!

Abstract

This paper examines the effects of workforce aging and the concurrent change in the human capital distribution on aggregate economic performance. The analysis is based on a theoretically founded empirical framework that encompasses previously used frameworks. The results suggest that aging as well as the level and distribution of human capital in the population influence economic performance. The findings show little evidence of skill obsolescence in terms of differential effects of age-specific human capital. The estimates allow for projections to gauge the relative importance of changes in the age and skill distribution and provide an upper bound of the the increase in human capital that is required to offset the negative effects of population aging.

JEL-classification: J11; O47

Keywords: Demographic Change; Demographic Structure; Distribution of Skills;
Projections; Skills-Aging-Elasticity

*Corresponding Author: Rainer Kotschy, Rainer.Kotschy@econ.lmu.de.

1 Introduction

The aging of populations is doubtless one of the most important challenges in the twenty-first century. As life expectancy increases, the populations of most countries grow older, resulting in substantial changes in the composition of the workforce and the population at large. At the same time, the demographic transition and the associated shift in the age distribution imply changes in the human capital distribution by age, as relatively large but low skilled cohorts are replaced by relatively small but high skilled cohorts. The effects of aging and changes in human capital have been investigated in isolation, but their interactions have been largely neglected in the existing literature.

This study investigates how changes in the demographic structure of the workforce and in the distribution of human capital affect output and output growth rates using data from a cross-country panel of 134 countries for the time span 1950 to 2010. The investigation is based on an extended development accounting model that illustrates the implications of population aging and encompasses the empirical frameworks used in the existing literature.

The analysis proceeds in steps. First of all, when restricting attention to the effects of population aging, the estimation results reveal that changes in the age composition of the work force affect economic performance. These results mirror the well-known hump-shaped individual productivity patterns with large population shares of intermediate ages revealing the largest effects on income dynamics. Likewise, the levels and dynamics in aggregate human capital are shown to affect economic performance independently from the demographic structure. The level and distribution of human capital is shown to affect output through two channels: on the one hand, an increase in human capital leads to a higher marginal product of other production factors and, thus, to higher output due to the accumulation of factors. On the other hand, human capital alleviates the adoption and diffusion of new technologies and the economy's ability to innovate.

In a next step, the analysis explicitly considers the interactions between aging and changes in the skill composition. This analysis complements the existing literature, which, with few exceptions, has largely focused on population aging or changes in the human capital endowment in isolation. The results largely confirm the findings. In particular, population aging appears to have substantial implications on economic performance, while there is little evidence for eroding productivity of skills in older cohorts.

In a last step, the estimation results are used for several quantitative experiments that shed light on the relative importance of changes in the age and in the skill distribution that occur as consequence of population aging. The findings from projection exercises suggest that aging and slower growth in education will tend to dampen economic performance, particularly in developed economies where aging is becoming a serious issue while the population has attained high levels of human capital in all age cohorts. The estimation

results also provide an upper bound for the elasticity of substitution between the age and human capital composition. This elasticity provides new insights into the change in the distribution of human capital that is necessary in order to offset productivity effects of demographic changes in the workforce. The quantitative estimate for this elasticity suggests that aging-related shifts in the composition of the population require substantial increases in the education of young cohorts.

The findings contribute to the literature in several ways. Earlier contributions in macro-development have focused on the role of the young- and old-age dependency ratio and the demographic dividend (e.g. Bloom and Williamson, 1998, and Bloom, Canning and Sevilla, 2003). More recent contributions on the macro level have analyzed the effects of aging and skills on growth. Feyrer (2007) finds that the demographic structure affects output mainly through total factor productivity. Maestas, Mullen, and Powell (2016) use variation in aging across US states over the period 1980-2010 to estimate the growth effect of aging and find a substantial negative effect. These studies only indirectly account for the changes in human capital and its age composition. Cuaresma, Lutz, and Sanderson (2014) investigate the joint effect of skills and aging. However, they do not conduct a cohort-based analysis that accounts for the distribution of skills and aging and instead look at labor force participation and dependency ratios. On the other hand, Sunde and Vischer (2015) show that human capital affects output growth through the composition of production factors and the potential to innovate (e.g. Aghion and Howitt, 1992), or adopt and diffuse new technologies (Nelson and Phelps, 1966). The approach taken in this paper incorporates these different contributions in a coherent framework and, therefore, allows investigating the relative importance of changes in the age and skill composition of the population. In particular, this study provides a systematic investigation of aging effects through purely demographic composition changes and changes in the human capital distribution that is not extant in the literature so far. The only paper, we are aware of, that goes in similar direction is Lindh and Malmberg (1999). However, their analysis is confined to a cross-section. Our estimates also allow for counterfactual forecasts of economic performance under alternative scenarios of aging and human capital accumulation. Another novelty are the estimates for an upper boundary of the semi-elasticity between demographic structure of age cohorts and shares of skills in the population. This semi-elasticity describes the change of skill distribution in the population that is required to offset the effect of a change in the demographic structure in the most favorable case.

The analysis is also related to, and complementing, work on age-education decompositions of labor earnings on a more disaggregated level. Work by, e.g., Card and Lemieux (2001), has used models with imperfect substitution between similarly educated workers in different age groups to study the dynamics of the college wage premium. More recent work by Acemoglu and Autor (2011) and Autor and Dorn (2013) shows for census data and tasks how skill-biased technological progress and changes in the supply of skill levels across

cohorts has lead to wage polarization in the United States. In analogy to the approach popularized by Card and Lemieux (2001) and applied by Fitzenberger and Kohn (2006), we develop a decomposition that allows estimating elasticities of substitution between demographic aging and changes in the education structure. Our empirical findings also complement recent evidence for the effect of aging on productivity at the micro level. For instance, Börsch-Supan and Weiss (2016) find that there are (almost) no negative aging effects on productivity for production line workers before age 60. The findings for the aggregate level presented in this paper are consistent with these findings.

The remainder of this paper is structured as follows: Section 2 presents our methodology and empirical framework. A data description is provided in Section 3. Section 4 provides estimation results and Section 5 concludes.

2 Methodology

The analysis is based on a simple aggregate production framework that underlies the standard development accounting model as in Benhabib and Spiegel (1994) and Hall and Jones (1999). Output Y is produced as a function of total factor productivity A , physical capital K and human capital H of the form:

$$Y_{it} = A_{it} K_{it}^{\alpha} H_{it}^{1-\alpha} \quad (1)$$

Subscripts i and t denote cross-sectional units (countries) and time units (5-year intervals), respectively. Dividing by the labor force L gives the intensive form of output per worker

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

with $k_{it} = \frac{K_{it}}{L_{it}}$ being capital per worker.

The stock of human capital H is a function of human capital per worker h and the overall quality of the labor force Q as a function of the demographic structure of the workforce and cohort-specific productivity parameters. Quality of the labor force is assumed to take a general constant elasticity of substitution (CES) form

$$H_{it} := h_{it} Q_{it} = h_{it} \left[\pi_1 (L_{it}^1)^{\rho} + \dots + \pi_k (L_{it}^k)^{\rho} \right]^{\frac{1}{\rho}}, \quad (2)$$

where L^1, \dots, L^k denote the labor force of each age cohort in the workforce and π_1, \dots, π_k the respective productivity of each group (cf. Sato, 1967, Hellerstein and Neumark, 1995, and Card and Lemieux, 2001, for similar settings). This general CES specification allows for different productivity parameters across age groups and flexible substitution patterns

between them. The human capital stock per worker is thus given by

$$\frac{H_{it}}{L_{it}} = h_{it} \left[\left(\frac{1}{L} \right)^\rho \sum_{j=1}^k \pi_j (L_{it}^j)^\rho \right]^{\frac{1}{\rho}} = h_{it} \left[\sum_{j=1}^k \pi_j \left(\frac{L_{it}^j}{L_{it}} \right)^\rho \right]^{\frac{1}{\rho}} = h_{it} \left[\sum_{j=1}^k \pi_j (S_{it}^j)^\rho \right]^{\frac{1}{\rho}}$$

with S^j denoting the share of each age cohort in the total labor force such that $\sum_{j=1}^k S_{it}^j = 1$. In order to avoid multicollinearity in the empirical model, a reference category S_{it}^r is chosen so that

$$\begin{aligned} \frac{H_{it}}{L_{it}} &= h_{it} \pi_r \left[(S_{it}^r)^\rho + \sum_{j \neq r} \frac{\pi_j}{\pi_r} (S_{it}^j)^\rho \right]^{\frac{1}{\rho}} \\ &= h_{it} \pi_r \left[\left(1 - \sum_{j \neq r} S_{it}^j \right)^\rho + \sum_{j \neq r} \lambda_j (S_{it}^j)^\rho \right]^{\frac{1}{\rho}}. \end{aligned}$$

The parameters $\lambda^j := \frac{\pi_j}{\pi_r}$ denote the productivity of each age cohort relative to the reference category.

This expression can be simplified further by assuming a substitution elasticity between the different age groups of one, i.e. $\rho = 1$. In this special case, human capital per worker is given by

$$\frac{H_{it}}{L_{it}} = h_{it} \pi_r \left[1 + \sum_{j \neq r} (\lambda_j - 1) S_{it}^j \right]. \quad (3)$$

Inserting the expression for the human capital stock per worker in (3) into the production function in (1) and taking logs yields

$$\begin{aligned} \ln(y_{it}) &= \ln(A_{it}) + \alpha \ln(k_{it}) + (1 - \alpha) \ln \left(\frac{H_{it}}{L_{it}} \right) \\ &= \ln(A_{it}) + \alpha \ln(k_{it}) + (1 - \alpha) \left[\ln(h_{it}) + \ln(\pi_r) \right] + (1 - \alpha) \ln \left(1 + \sum_{j \neq r} (\lambda_j - 1) S_{it}^j \right) \end{aligned}$$

Note that the last term in parentheses can be expected to be close to unity since the term for productivity ratios $\lambda_j - 1$ and the share of each age cohort in the total workforce is close to zero for a sufficiently large number of age groups, and correspondingly also their product. Hence, the last term in logarithms can reasonably be approximated by $\ln(1 + x) \approx x$, i.e.

$$\ln \left(1 + \sum_{j \neq r} (\lambda_j - 1) S_{it}^j \right) \approx \sum_{j \neq r} (\lambda_j - 1) S_{it}^j \quad (4)$$

Human capital per worker h is assumed to be a function of an individual worker's skills which can either be high or low. Correspondingly, each skill group is assigned a skill-specific productivity $\{\pi_h, \pi_l\}$. Averaging over the entire economy, human capital per worker is, thus, the weighted average of the shares of each skill group ($S^h, 1 - S^h$)

multiplied by the respective productivity, or formally

$$h_{it} = S_{it}^h \pi_h + (1 - S_{it}^h) \pi_l. \quad (5)$$

Taking logs and choosing the low skill group as reference, this expression can be rearranged to

$$\ln(h_{it}) = \ln \left[\pi_l \left(1 + S_{it}^h \left(\frac{\pi_h}{\pi_l} - 1 \right) \right) \right]$$

which, using the same arguments as before, can be approximated by

$$\ln(h_{it}) = \ln(\pi_l) + \ln \left(1 + S_{it}^h \left(\frac{\pi_h}{\pi_l} - 1 \right) \right) \approx \ln(\pi_l) + S_{it}^h \lambda^h \quad (6)$$

with $\lambda^h := \frac{\pi_h}{\pi_l}$ being the relative productivity of high-skilled to low-skilled workers.

Log output is, thus, given by

$$\ln(y_{it}) \approx \ln(c) + \ln(A_{it}) + \alpha \ln(k_{it}) + (1 - \alpha) S_{it}^h \lambda^h + (1 - \alpha) \sum_{j \neq r} (\lambda_j - 1) S_{it}^j, \quad (7)$$

where $\ln(c) = (1 - \alpha) [\ln(\pi_l) + \ln(\pi_r)]$ is a constant. By taking log-differences, the model is expressed in terms of growth rates:

$$\Delta \ln(y_{it}) \approx \Delta \ln(A_{it}) + \alpha \Delta \ln(k_{it}) + (1 - \alpha) \lambda^h \Delta S_{it}^h + (1 - \alpha) \Delta \left[\sum_{j \neq r} (\lambda_j - 1) S_{it}^j \right] \quad (8)$$

In order to account for the effect of human capital and skills on innovation and convergence in the level of technology between countries, TFP is assumed to be determined by

$$\ln(A_{it}) = \zeta_t + \xi S_{it-1}^h + \gamma \ln(y_{it-1}) + \varepsilon_{it}. \quad (9)$$

In terms of dynamics, the growth rate of total factor productivity is assumed to take the form

$$\Delta \ln(A_{it}) = \tau_t + \theta S_{it-1}^h + \nu \ln(y_{it-1}) + u_{it}. \quad (10)$$

Consequently, total factor productivity (growth) of a country is determined by the exogenous time trend ζ_t (τ_t) which is equal to countries, the rate of innovation or technological diffusion ξS_{it-1}^h (θS_{it-1}^h) net of a term that controls for the current level of output and an idiosyncratic error component ε_{it} (u_{it}) which serves as the error term for the empirical framework.

Therefore, the empirical model which is used to estimate the effect of the demographic structure of the workforce and the distribution of skills on output is given by

$$\begin{aligned} \ln(y_{it}) = & \ln(c) + \gamma \ln(y_{it-1}) + \alpha \ln(k_{it}) \\ & + (1 - \alpha) \lambda^h S_{it}^h + \xi S_{it-1}^h + (1 - \alpha) \left[\sum_{j \neq r} (\lambda_j - 1) S_{it}^j \right] + \zeta_t + \varepsilon_{it} \end{aligned} \quad (11)$$

The model in levels is estimated with the within-transformation to remove country-specific fixed effects. Analogously, the estimation model in differences (growth rates) rather than levels is given by

$$\begin{aligned} \Delta \ln(y_{it}) = & \nu \ln(y_{it-1}) + \alpha \Delta \ln(k_{it}) \\ & + (1 - \alpha) \lambda^h \Delta S_{it}^h + \theta S_{it-1}^h + (1 - \alpha) \Delta \left[\sum_{j \neq r} (\lambda_j - 1) S_{it}^j \right] + \tau_t + u_{it} \end{aligned} \quad (12)$$

Estimating the model in terms of growth rates also accommodates for the possibility of a unit root in the error term if income follows a random-walk. Correspondingly, the series will be stationary. As will become clear below, coefficient estimates do not differ substantially between both models, but, unsurprisingly, the levels model is more efficient and explains a larger fraction of the variation. Results for both versions of the model are reported in Section 4.

This specification of the estimation framework is very flexible and can be adjusted to obtain the regression models of important other contributions of the literature. For example, the estimation model of Feyrer (2007) is obtained by assuming human capital to be the exponential of a piece-wise linear function of human capital savings and imposing no further assumptions on the structure of TFP growth apart from a common time trend across. Given this set of assumptions, the effect of the demographic structure is contained by total factor productivity.

The specification of Cuaresma, Lutz, and Sanderson (2014) can be obtained under the following assumptions: human capital per worker takes an exponential form as described above; GDP is expressed in terms of per capita instead of per worker terms; and the demographic structure of the workforce is neglected. In this case, the demographic structure enters output through the labor force participation rate and the share of the working-age population in the total population.

Finally, the specification of Sunde and Vischer (2015) is derived by assuming that human capital enters both, productivity and output, in logarithms instead of shares. Further control variables can be included by extending either the TFP residual by lagged level controls or the output by additional terms as an multiplicative or exponential function.

3 Data

Productivity and output data are from Penn World Tables (PWT) version 8.1 by Feenstra, Inklaar, and Timmer (2015). The main dependent variables are log output per worker and growth per worker.

Data for the demographic structure are taken from different sources. Information on the working-age population for age cohorts in five-year intervals from 15 to 69 are taken from Barro and Lee (2013). Cohorts are collapsed to ten-year intervals in order to reduce the number of parameters to be estimated. In order to match the results of Feyrer (2007) for comparability, age cohorts of the workforce are defined as the shares of each cohort in the total workforce for the cohorts 15–19 (< 20), 20–29, 30–39, 50–59, 60–69 (60+). The cohort 40–49 which is most productive according to the data serves as reference group. Different classifications do not affect the results qualitatively. The empirical results are also robust to the use of the young- and old-age dependency ratio by the World Bank (2014). Data on population counts by age and forecasts are taken from the United Nations World Population Prospects and the IIASA–VID database by Lutz, Goujon, KC, and Sanderson (2007).¹

Human capital per worker is proxied by the share of high- and low-skilled individuals in the working-age population. The share of low-skilled workers is defined as the sum of the shares of individuals with either no formal education, or primary or secondary schooling only - the respective shares are taken from Barro and Lee (2013). Correspondingly, the share of high-skilled corresponds to those workers who have received formal tertiary education. As described in Section 2, the share of high-skilled human capital is chosen as reference category. Results do not change when alternatively low- and high-skilled years of schooling are used as measure for the human capital stock.

Data are measured for 130 countries in five-year intervals from 1960 to 2010 (13 time periods in total). Descriptive statistics are reported in Table 1.

4 Results

This section reports the estimation results. The effect of the demographic structure and the distribution of skills are first investigated in isolation. In a second step, evidence for a model that combines both dimensions is shown and a skill-aging elasticity is computed which describes to what extent changes in the demographic structure can *ceteris paribus* be substituted by higher investment in schooling.

Models are estimated either in levels as in equation (11) or first differences as proposed

¹Data from United Nations World Population Prospects are from the 2015 Revision and available at <https://esa.un.org/unpd/wpp/Download/Standard/Population/>. The IIASA–VID projection data are available at http://www.iiasa.ac.at/web/home/research/researchPrograms/WorldPopulation/Projections_2014.html.

in equation (12). Lagged levels of output per worker and the share of high-skilled workers in the population enter both types of models in levels to control for convergence dynamics of output and technological diffusion, respectively. If not stated otherwise, specifications are estimated for a panel of 134 countries in five-year intervals for the time period 1950-2010.

4.1 Demographic Structure

Estimates for the effect of the demographic structure of the workforce on output are reported in Table 2 Column (1) for the model in levels. The reference age group in the levels model is the cohort aged 40 to 49. The results are obtained from a specification of the estimation framework with country fixed effects, period fixed effects, and controls for lagged output per worker and capital per worker.

All estimates for the cohort-specific workforce shares are negative and significant. These results indicate that shifting population mass out of the prime age cohort 40–49 has a negative impact on output. This effect is particularly pronounced for the population group aged 60+, which corresponds to population aging. An increase in the share of the cohort 60+ relative to the excluded reference group of the 40–49 year olds leads to a decrease in output p.w. of roughly 2.1%. Shifts of such size are no exception in the data: across all workforce shares, around 25% of all out-shifts of a cohort are roughly equal to a unit percentage point shift or even larger. The same pattern holds for 25% of all in-shifts into a cohort. Furthermore, the estimated negative point estimates are largest for the age-cohorts which are either at the very beginning or the end of their work-life. These results are consistent with estimates from disaggregate data that suggest that productivity is highest for individuals in their prime working age when they have acquired sufficient work experience and on-the-job training. The results are also in line with a hump-shaped pattern, as for middle-aged cohorts additional productivity gains become smaller as the marginal return from more experience decreases and falls towards zero at some point while the benefits of additional deteriorate with the amortization period. At some point, the depreciation rate of human capital, thus, outweighs additional gains by experience so that individual productivity decreases in many cases towards the end of the work-life. Taken together, the results largely confirm earlier findings on the effects of population aging.

Moreover, the joint Wald test on the coefficients of all workforce shares indicates that the overall demographic structure has a significant impact on output. The only exception is Column (6) where it is marginally insignificant. This joint significance of the age cohort controls primarily suggests that there is substantial heterogeneity in the output contribution of different age groups, consistent with the hypothesis that demographic features, in particular the age structure of the population, has important economic consequences. Therefore, the demographic structure of the workforce is of particular importance for societies which are in demographic terms either very young or old.

Table 3 Column (1) contains the corresponding results for the model in growth rates. To be consistent with the levels model, the difference model uses the change in the age cohort aged 50-59 as reference category.² The results essentially replicate those obtained for the levels model. Coefficient estimates are quantitatively larger, but qualitatively the pattern remains, in particular regarding the result on aging and the importance of heterogeneity in the effect of changes in the age composition of the workforce on output growth.

Unreported results suggest that the estimated coefficient for lagged output per worker is negative, indicating conditional convergence of countries over time.³ The estimated values for the capital income share α is 0.41 for the specification in Column (1).⁴

4.2 Human Capital and Distribution of Skills

As a next step, the analysis replicates studies of the role of the effect of human capital and the distribution of skills on output and growth. Conceptually, human capital influences output through two channels. First, changes in the share of skills account for composition effects of productions factors which can be accrued to the complementarity of human and physical capital in standard growth models (e.g. Solow, 1956, or Lucas, 1988). Second, the accumulation of human capital may alleviate the diffusion and adoption of already existing technologies (Nelson and Phelps, 1966) or spur innovation as in the endogenous growth literature (e.g. Romer, 1990, or Aghion and Howitt, 1992). Not accounting for both channels implies a potential problem of omitting one channel from the estimation, which may lead to severe bias of the estimated effects of human capital as indicated by the results of Sunde and Vischer (2015).

Column (2) of Tables 2 and 3 presents the corresponding estimates for a specification along the lines of Sunde and Vischer (2015) for the model in levels and growth rates, respectively. In both estimation frameworks with the two human capital channels considered in isolation from demographic patterns, the point estimates of levels and changes in human capital are positive and jointly significant, indicating the need for incorporating both channels.⁵ The coefficient for the share of high skilled roughly ranges around 0.5 in

²Taking differences implies a forward shift in the age composition, hence taking the next age bracket as reference group in the difference specification is more consistent than taking the change in the earlier age bracket.

³The estimated values of roughly 0.45 might be slightly downward-biased due to the Nickell (1981). However, this bias is only relevant for the levels models and should not be very severe for 13 time periods.

⁴For comparability, this exercise closely resembles the empirical specification of Feyrer (2007). All point estimates are negative indicating that increases in the size of these age cohorts relative to the prime-age cohort result in reduced output growth. The point estimates are qualitatively very similar to the results for empirical specification proposed in this paper but quantitatively slightly smaller. Similar results are found for regressions for each output channel are shown without and with additional fixed effects which allow for country-specific growth trends.

⁵Strictly speaking the specification of the model in levels that follows from (11) does not contain a term involving the change in the share of skilled in the population, since this term emerges from the

both models. That is, an one percentage point increase in the share of skilled workers in the economy is accompanied by an 0.5% increase in output per worker, or growth, respectively. In light of the literature, this effect works through innovation as well as diffusion and adoption of new technologies. The effect of an increase in the skill share is 0.5 but individually insignificant in the levels specification, and 0.93 and significant in the growth specification. The coefficient for lagged output per worker takes negative values for the differences model, indicating conditional convergence towards the steady state equilibrium. The coefficient of the capital income share is similar to the earlier results.

4.3 Demographic Structure of the Workforce and Distribution of Skills

The remaining columns of Tables 2 and 3 present estimates for a combined model that accounts for both the demographic structure of the workforce and the distribution of skills in the population. Columns (3) show estimates for the same specification of the empirical model as before in the levels and differences specifications, respectively. Columns (4) present results for an extended specification that also accounts for the age-related change in skills by incorporating cohort-specific information on the share of skilled individuals. Columns (5) present the corresponding results when controlling for cohort-specific skill shares rather than changes. Columns (6) include both levels and changes of cohort-specific skill shares as controls.⁶

The qualitative results are unchanged when considering population aging and human capital jointly. The estimated parameters for the shares of workforce cohorts in the total labor force are negative throughout all specifications and reveal a very similar pattern to before for the levels and differences models, respectively. Figure 2 provides a graphical illustration of these estimates. The coefficients are somewhat smaller for the young age cohorts (about 20%) compared to those reported before, but similar for the old cohorts. The results for human capital are essentially unchanged. Hence, an increase in the share of a specific age cohort relative to the prime-age group leads to a reduction in output growth. Moreover, the skill distribution positively affects growth rates through both, the innovation and adoption of technology channel and the composition of production factors. Most importantly, demographic structure of the workforce and human capital both jointly

dynamics of TFP. We nevertheless include this term in the specification of the empirical model of the levels estimation for two reasons. First, this allows us to estimate a symmetric empirical specification in both levels and differences and, thus, provides directly comparable estimates of the coefficients of interest. Second, this specification provides a natural specification test since the coefficient of the change in the skill share is hypothesized to be zero in light of the theoretical model (11). The fact that the coefficient is indeed not significantly different from zero in Column (2) of Tables 2 as well as in all other columns, thus, indirectly supports the empirical model. The estimation results are qualitatively and quantitatively almost identical when estimating a specification of the levels model that does not include the change in the share skilled.

⁶Columns (7) present results from an IV strategy presented below.

affect output which is the first main result of this study. Conceptually, this implies that both channels are relevant for themselves even if they interact substantially. To some extent, this finding contradicts the conclusions of Cuaresma, Lutz, and Sanderson (2014), based on a comparable dataset, that the demographic dividend is mostly the byproduct of increases in education. An explanation that reconciles both results is that Cuaresma, Lutz, and Sanderson (2014) do not specifically control for the cohort-based demographic structure but instead for labor force participation and the relative size of the working-age population to total population (i.e. the inverse of the dependency ratio). Additional unreported results suggest that adding the dependency ratio as further control leaves the results essentially unaffected. Moreover, variation in labor force participation rates is partly driven by cyclical phenomena and less through long-run trends. Therefore, the model of Cuaresma, Lutz, and Sanderson (2014) might not capture adequately the effects of the demographic structure that are presented here.

Point estimates for lagged output per worker indicates conditional convergence in the differences specifications and strong persistence in the output series for the levels regressions. The capital income share again takes values around 0.4.

4.4 Identification Using Aging Dynamics

The identification of the effects of aging and human capital so far was based on the implicit assumption that the current workforce (in terms of age structure and skill composition) is the result of fertility and education decisions in the past. Controlling for past income, capital and country-specific intercepts related to productivity and other time-invariant factors account for country-specific differences in economic performance that might influence, or correlate with, the age and skill composition. Additionally, it is assumed that labor force participation is relatively constant over time so that changes in the workforce are arguably exogenous given the lagged dependent variable, country-fixed effects, and period fixed effects. The finding of rather similar results in the levels and differences models is further reassuring, since similar estimates for the respective coefficients are obtained despite the use of alternative variation for identification.

However, one might still argue that unobserved variables influence the factors of production and lead to problems of endogeneity bias. An alternative way to obtain identification is, therefore, to exploit the fact that the demographic structure of the working-age population follows very stable and predictable dynamics. Concretely, a cohort of individuals aged 40 will be of age 50 ten years later. Likewise, the share of individuals in this cohort that has attained, e.g., tertiary education, is unlikely to change over these ten years. Hence, demographic dynamics lend themselves naturally to an instrumental variables approach in the present setting of panel data. The IV strategy exploits the fact that the size and education attainment of particular cohorts at some point in time

predicts these cohorts' size and education attainment in the future. This correlation is unaffected by economic performance and, thus, exogenous for the purpose of the estimation framework applied here, in particular once conditioning on the lagged dependent variable and country-fixed effects.

Figure 3 illustrates this identification strategy. For a given country-period-cohort cell, the working-age population and skill shares are instrumented using the respective country-period-cohort lag. For instance, the cohort of 30-39 year olds in 1990 within a given country is instrumented using the data for the cohort aged 20-29 years old in 1980. Additional power is obtained by exploiting the fact that the source data are coded in 5-year rather than 10-year cohorts.

Columns (7) of Tables 2 and 3 present the corresponding results for the second stage of the 2SLS framework. The first stage is strong as expected, with values of around 100 for the F -statistic. The estimates for the outcome equation are qualitatively identical and quantitatively somewhat larger than those obtained with the baseline estimation approach. This suggests that endogeneity bias appears not to be a serious issue and, if anything, biases the coefficients towards zero when one has confidence in the IV estimates.

4.5 Robustness and Further Results

Additional unreported results reveal stronger effects of changes in the age structure on economic performance in Non-OECD than in OECD countries. This might be related to the fact that the aging process is more pronounced once the demographic transition is completed and the process of population aging sets in with force. This is also consistent with the finding that population aging has a more pronounced effect on societies with a large share of young people when considering a sample split. Moreover, the importance of population aging appears to have increased in recent decades. Concretely, the effects are stronger when considering a subsample for the period after 1990.

There is only weak evidence for population scale effects. This suggests that the main economic implication of low fertility in the aftermath of the demographic transition appears to be population aging rather than a shrinking (or reduced growth) of the population at large. However, this finding appears to be related mostly to the aging of the workforce. Controlling for the dependency ratio does not affect any of the results.

4.6 Projecting the Effects of Aging and Human Capital

The results so far reveal an important role of demographic dynamics in terms of aging as well as in terms of changes in the human capital embodied in the working population for economic development. While aging appears to be a process that is hard if not impossible to influence, at least in the short and medium run, the skill composition of the population is a possible way for policy to influence the economic prospects of a country. This raises

the question about the relative importance of population aging and changes in the skill composition.

One way to infer the relative importance is to use the estimates to conduct counterfactual experiments using available projections of the age and skill composition of the population in the future. These projections can be conducted under several scenarios. One such scenario is to use the estimates to forecast output per worker (or its growth rate) by inserting population forecasts in terms of age and skill structure and compute output as in equation (7) over the period over which forecasts for age structure and skill composition are available. This approach uses all available information about the evolution of the economy and, thus, provides a best practice projection. Alternatively, one could use only the projection for the human capital structure, but keep the age composition of the population constant. In other words, this corresponds to a simulation that stops the aging process and keeps the population at its current age composition, an “age status quo”. Likewise, one can simulate the model using the age projections, but keeping the composition of human capital in the population constant at the present levels. This corresponds to an “education status quo” scenario that evaluates the consequences of aging in isolation.⁷

Figure 4 presents the corresponding results for different samples Panel (a) looks again at Germany and Japan as prime examples of developed economies with a rapidly aging population. While Japan has already entered a period of prolonged economic stagnation since the early 1990s, German output appears to stagnate only recently. For both countries, the projected simulation using available projections for aging and human capital suggest a dampened economic performance in the decades to come. Obviously, these projections are based on strong assumptions and should not be confused with projected output growth, since important components like capital accumulation, depreciation, etc., are not adequately modeled in these simulations. Nevertheless, they are useful as a benchmark for the counterfactual simulations that freeze the demographic structure or the human capital distribution at their respective current shapes. When considering a constant age structure (“age status quo” scenario), the forecast of the economic performance in both countries is substantially more positive than in the baseline forecast, indicating the negative effect of population aging. Alternatively, keeping the human capital structure unchanged (“education status quo” scenario) does not strongly affect the results. This indicates that population aging is a powerful dampening force for economic performance that is likely to unfold its effects in the future, while the effect of changes in the education composition have limited power in economies where the population is already very skilled.

Panel (b) of Figure 4 presents the corresponding results for OECD and Non-OECD countries. Again, the benchmark projections deliver a rather pessimistic outlook about economic performance in both samples. Freezing the age structure at its current level implies faster development in the OECD countries, suggesting that aging will be a major

⁷The reference year for these counterfactual exercises is 2010.

impediment for economic performance in the future. A potentially more surprising result is that aging appears to have an even stronger negative effect on economic development in Non-OECD countries, as indicated by the simulation that keeps the age structure constant (“age status quo” scenario). To be clear, this positive trajectory is mainly due to improvements in the skill composition of the population. Conducting the alternative scenario with constant skill structure but incorporating the demographic aging process delivers similar results as the baseline for the OECD countries. For the Non-OECD countries, this scenario delivers even worse development than the baseline scenario. This indicates the importance of increasing human capital in the process of the demographic transition and the corresponding aging of the population in developing countries. The results are striking in showing the potential of human capital to counteract negative implications of aging, particularly when there is substantial scope for improvements in the education attainment of the population, as in less developed countries.

4.7 Substitution between Aging and Skill Structure?

The framework and the corresponding estimates also allow to go one step further in the quantification of this finding by allowing for an estimate of an elasticity of substitution between changes in the age structure and changes in the human capital structure of the economy. We finish the analysis by showing how to approximate this substitution elasticity between the demographic structure and the distribution of skills (henceforth skills-aging-elasticity). This elasticity describes to what extent changes in the demographic structure can be offset by changes in the distribution of skills in the economy while keeping output per worker unchanged. An upper bound for this skills-aging-elasticity is given by

$$\eta_{max}^j = \frac{(1 - \hat{\alpha})(\hat{\lambda}^j - 1)}{(1 - \hat{\alpha})\hat{\lambda}^h + \hat{\xi}} < 0 \quad (13)$$

where the corresponding parameters are the structural estimates of the empirical models (11) or (12). Since the elasticity depends on the level of schooling in the previous period and changes in the current skill distribution, an increase in the share of skills in the same period can only work through the composition channel (i.e. the denominator is $(1 - \hat{\alpha})\hat{\lambda}^h$ in this case). In the following period, the skills-aging-elasticity is given by the expression in (13) corrected for additional changes in the distribution of skills which are again weighted by $(1 - \hat{\alpha})\hat{\lambda}^h$. Note that since the denominator is positive and the cohort-effects of the demographic structure are negative as long as the most productive cohort (prime-age group) is chosen as reference group, the elasticity will always exhibit a negative sign. Hence, the semi-elasticity is largest, when the denominator is maximized. This is the case when over in at least two consecutive periods the share of high-skilled workers in the population increases and no human capital is lost due to retirement or emigration in the working-age

population. Consequently, the η^j can never be higher as stated in (13) and is, in fact, lower when the gains in human capital are to some extent lost. Thus, η_{max}^j represents an upper boundary for the skills-aging-elasticity. Moreover, this upper boundary has a natural interpretation: it is the most favorable scenario under which negative feedbacks from changes in the demographic structure on output can be compensated.

The elasticity can be computed for each category, respectively. For example, suppose an aging society where a large fraction workforce (the baby boomer) shift out of the prime-age group into the less productive groups of 60+ or even retirement. Column (3) of Table 2 then gives an upper bound for the skills-aging elasticity of $\eta_{max}^{60+} = -\frac{4.45}{0.80+0.53} \approx -3.4$ for every percentage point shift of workers out of the prime-age group and high-skills into the working-age population. Correspondingly, the share of high-skill workers would have to increase by 3.65 percentage points - assuming constant returns to schooling - in order to offset an one percentage point shift out of the prime-age group. However, since schooling takes place mostly at a young age, the human capital of older workers can at best be raised to a small extent. Changes in the skill distribution must, therefore, come mostly through young cohorts. This is particularly problematic if young cohorts are smaller in size relative to the cohort that is being shifted towards retirements; like it is the case for the baby boomer generation. Therefore, even in the presence of large schooling gains, the demographic structure unfolds an overwhelming effect on the output and future growth rates. This may also explain to some extent why large-scale extensions of schooling in developing countries which have not gone through the demographic transition do not incur the expected strong gain in productivity.⁸

Finally, estimates of the effect of human capital and skills divided into skill cohorts for the working-age population (age 15 to 69) in ten-year intervals deliver little evidence for an important effect of the demographic distribution of skills on output. The corresponding estimates are insignificant in most cases. Also the Wald test for joint significance of the estimated parameter sets fails to reject that estimates are jointly different from zero in many cases.⁹

5 Conclusion

This study investigates how the demographic structure of the workforce and the distribution of skills affect aggregate economic performance in isolation and jointly. On the basis of an extended development accounting model, a flexible empirical specification has been

⁸Another reason may be that schooling quality is generally low. For more information see e.g. Hanushek and Woessmann (2008).

⁹In order to further test whether there might be an interplay between the demographic structure of the workforce and the distribution of skills, interacted models can be estimated. This allows to test the null hypothesis whether the effect of the demographic structure is stronger (or weaker) the larger the share of high-skilled workers in the population is. However, there is only weak evidence (results not shown) that this is the case.

derived that can accommodate empirical models that have been used in the literature. In particular, assuming that the quality of the labor force depends on the demographic structure allows to incorporate workforce demographics into the production function.

The estimation results show that changes in the age structure of the working-age population have a strong effect on output, even when controlling for human capital. The effects of aging in terms of changing relative sizes of the different age cohorts mirror productivity profiles that have been found earlier, in terms of hump-shaped productivity patterns over the age dimension.

Human capital and the distribution of skills is shown to affect output through two channels. On the one hand, an increase in human capital leads to a higher marginal product of other production factors and, thus, to higher output due to the accumulation of factors. On the other hand, human capital alleviates the adoption and diffusion of new technologies and the economy's ability to innovate.

The estimation results can be used to infer the relative importance of aging and human capital accumulation for macroeconomic performance. Projections of future economic development suggest that aging will play an important role by slowing down economic development in developed and less developed countries. Aging is, hence, not a problem of the developed world only. Importantly, the projections indicate an important role of human capital in ameliorating the negative consequences of aging, in particular in countries that are yet underdeveloped in terms of human capital endowments and that have considerable scope for an increase in the human capital endowment of the still largely low-skilled population. This scope appears limited in developed economies. Overall, the results are consistent with an important role of long-run demographic dynamics for future economic development, pointing towards the possibility of more stagnant development in the future. In this sense, the results complement recent findings by Cervellati, Sunde, and Zimmermann (2016).

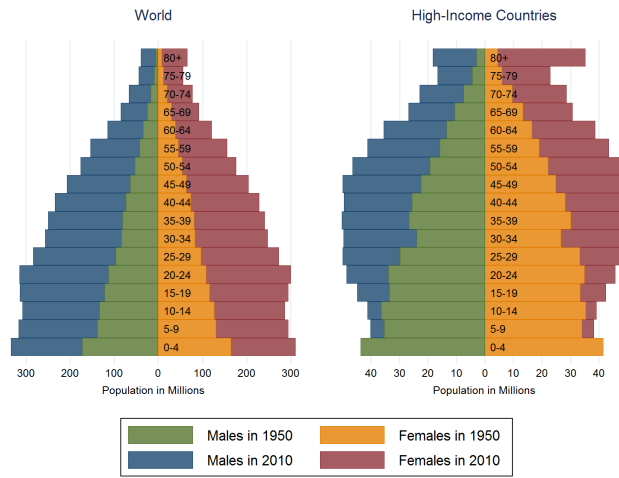
The estimates also deliver an upper bound for the elasticity between the age structure and the distribution of skills. This elasticity allows gauging the change in the distribution of skills that is required to offset the negative effects of aging of the workforce. The quantitative estimates of this elasticity suggest that shifts out of the prime-age group into less productive groups and retirement can only be partly offset by higher investment into schooling, particularly in developed countries.

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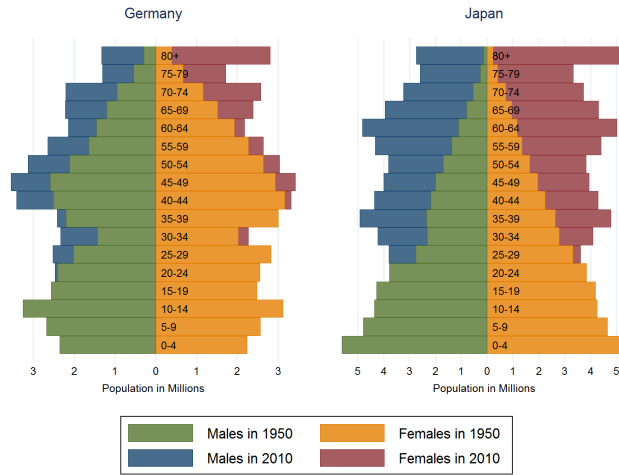
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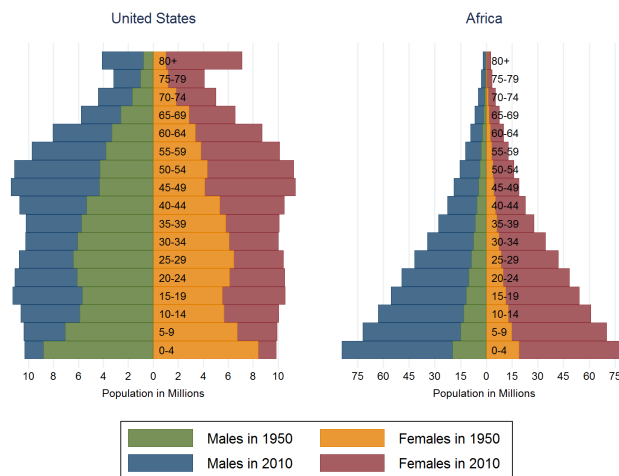
Figure 1: Population Dynamics - Selected Regions and Countries



(a) Population Dynamics: World and High-Income Countries



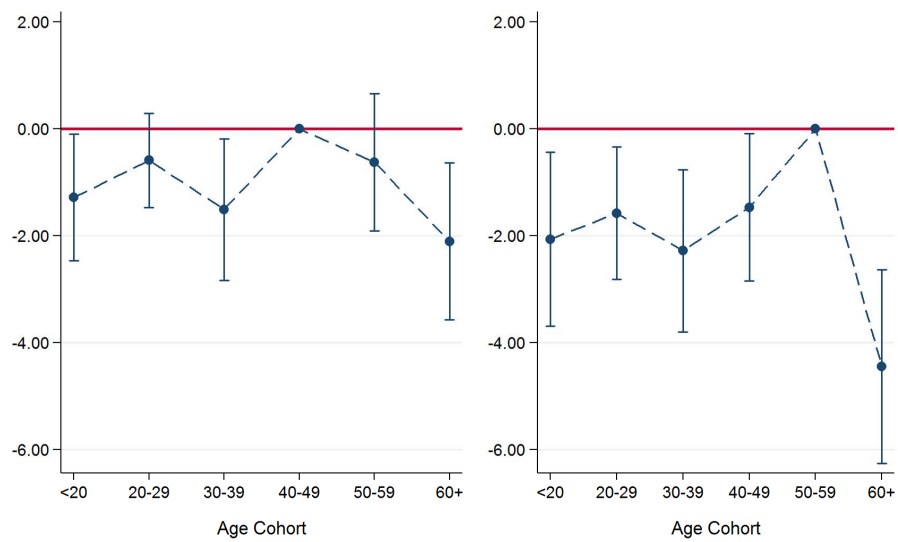
(b) Population Dynamics: Germany and Japan



(c) Population Dynamics: United States and Africa

Source: United Nations, Department of Economic and Social Affairs (2015). World Population Prospects: The 2015 Revision.

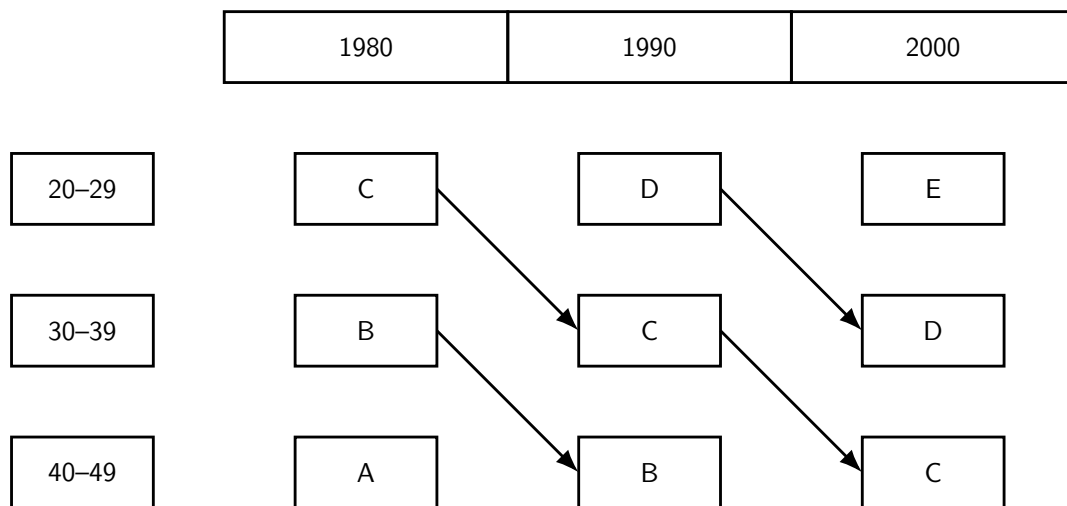
Figure 2: Macro Productivity Profile (Estimates Columns (3) of Tables 2 and 3



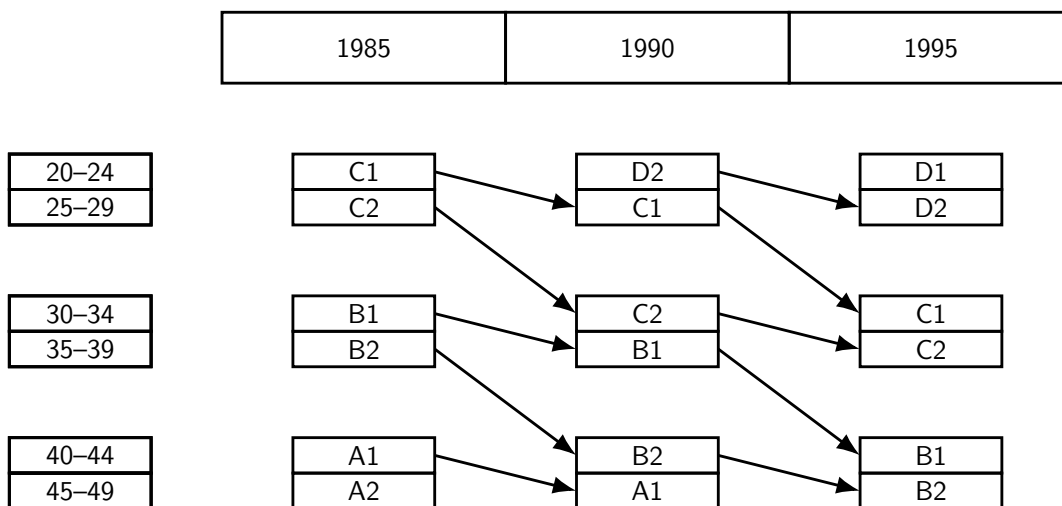
(a) Levels Model

(b) Differences Model

Figure 3: Illustration of Demographic Dynamics as Instrumental Variable

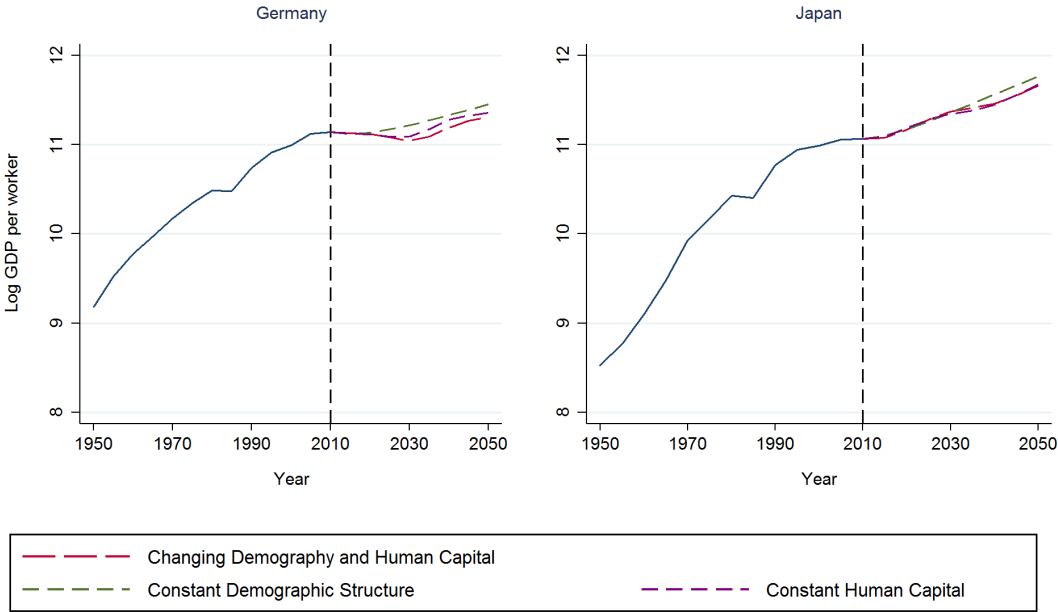


(a) Levels Model

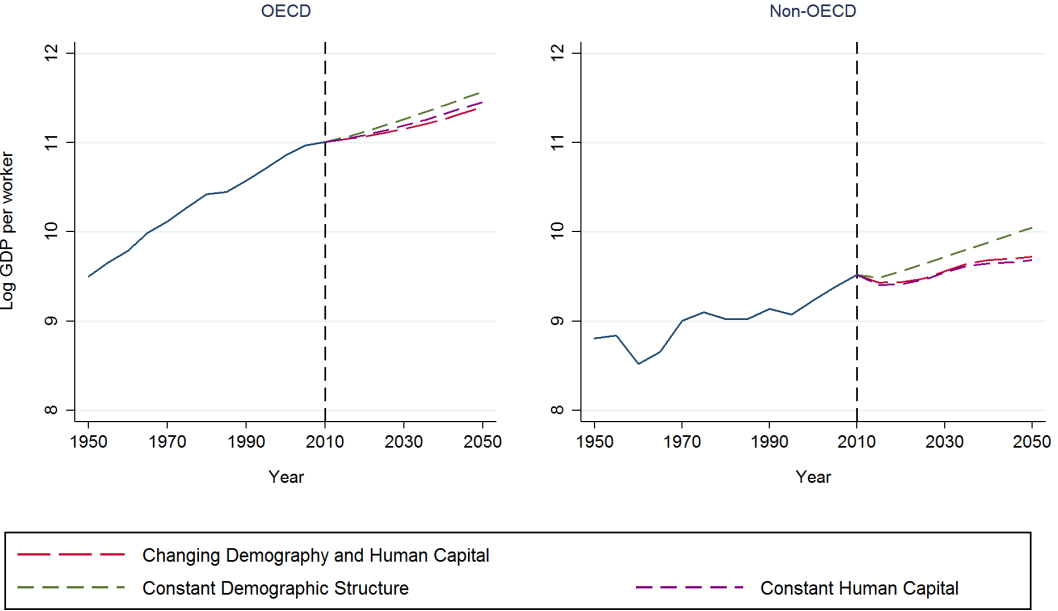


(b) Differences Model

Figure 4: Forecasts under Different Scenarios



(a) Selected Countries: Germany and Japan



(b) Developed vs. Underdeveloped Economies

Table 1: Descriptives Statistics

| | Mean | Std. Dev. | Min | Max | Obs. |
|-------------------------------------|--------|-----------|--------|--------|------|
| Ln(y) | 9.568 | 1.129 | 6.311 | 12.268 | 1176 |
| Ln(y) (t-1) | 9.473 | 1.117 | 6.311 | 12.955 | 1176 |
| Δ Ln(y) | 0.095 | 0.225 | -1.267 | 1.217 | 1176 |
| Ln(k) | 10.337 | 1.391 | 6.549 | 12.993 | 1176 |
| Δ Ln(k) | 0.152 | 0.230 | -1.072 | 2.241 | 1176 |
| Sh. < 20 | 0.155 | 0.044 | 0.063 | 0.251 | 1176 |
| Δ Sh. < 20 | -0.002 | 0.013 | -0.075 | 0.100 | 1176 |
| Sh. 20-29 | 0.264 | 0.047 | 0.145 | 0.402 | 1176 |
| Δ Sh. 20-29 | -0.002 | 0.017 | -0.084 | 0.062 | 1176 |
| Sh. 30-39 | 0.209 | 0.025 | 0.128 | 0.372 | 1176 |
| Δ Sh. 30-39 | -0.000 | 0.016 | -0.059 | 0.103 | 1176 |
| Sh. 40-49 | 0.163 | 0.028 | 0.080 | 0.261 | 1176 |
| Δ Sh. 40-49 | 0.001 | 0.013 | -0.047 | 0.071 | 1176 |
| Sh. 50-59 | 0.123 | 0.035 | 0.058 | 0.217 | 1176 |
| Δ Sh. 50-59 | 0.002 | 0.011 | -0.042 | 0.052 | 1176 |
| Sh. 60+ | 0.086 | 0.035 | 0.019 | 0.201 | 1176 |
| Δ Sh. 60+ | 0.001 | 0.008 | -0.041 | 0.036 | 1176 |
| Sh. high-skill | 0.087 | 0.091 | 0.000 | 0.579 | 1176 |
| Sh. high-skill (t-1) | 0.075 | 0.082 | 0.000 | 0.533 | 1176 |
| Δ Sh. high-skill | 0.012 | 0.017 | -0.078 | 0.146 | 1176 |
| Sh. high-skill <20 (t-1) | 0.022 | 0.039 | 0.000 | 0.328 | 1176 |
| Δ Sh. high-skill <20 | 0.007 | 0.025 | -0.102 | 0.225 | 1176 |
| Sh. high-skill 20-29 (t-1) | 0.104 | 0.113 | 0.000 | 0.745 | 1176 |
| Δ Sh. high-skill 20-29 | 0.016 | 0.040 | -0.209 | 0.172 | 1176 |
| Sh. high-skill 30-39 (t-1) | 0.093 | 0.102 | 0.000 | 0.624 | 1176 |
| Δ Sh. high-skill 30-39 | 0.013 | 0.028 | -0.140 | 0.214 | 1176 |
| Sh. high-skill 40-49 (t-1) | 0.078 | 0.091 | 0.000 | 0.610 | 1176 |
| Δ Sh. high-skill 40-49 | 0.012 | 0.020 | -0.053 | 0.188 | 1176 |
| Sh. high-skill 50-59 (t-1) | 0.061 | 0.078 | 0.000 | 0.574 | 1176 |
| Δ Sh. high-skill 50-59 | 0.011 | 0.018 | -0.054 | 0.186 | 1176 |
| Sh. high-skill 60+ (t-1) | 0.042 | 0.059 | 0.000 | 0.463 | 1176 |
| Δ Sh. high-skill 60+ | 0.010 | 0.016 | -0.037 | 0.189 | 1176 |
| Dependency ratio | 0.634 | 0.209 | 0.165 | 1.089 | 1154 |
| Δ Dependency ratio | -0.021 | 0.042 | -0.227 | 0.132 | 1154 |
| Young-age dependency ratio | 0.566 | 0.242 | 0.154 | 1.048 | 1154 |
| Δ Young-age dependency ratio | -0.025 | 0.041 | -0.221 | 0.128 | 1154 |
| Old-age dependency ratio | 0.067 | 0.044 | 0.006 | 0.234 | 1154 |
| Δ Old-age dependency ratio | 0.004 | 0.007 | -0.020 | 0.039 | 1154 |

Table 2: Effects of Aging and Skills on Economic Performance: Levels Model

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---------------------------------|--------------------|------------------|--------------------|--------------------|--------------------|-------------------|--------------------|
| Share < 20 | -1.61*** (0.58) | | -1.28** (0.60) | -1.34** (0.60) | -1.08* (0.57) | -1.00* (0.57) | -2.11*** (0.68) |
| Share 20–29 | -0.71 (0.44) | | -0.59 (0.45) | -0.60 (0.45) | -0.52 (0.44) | -0.48 (0.44) | -0.42 (0.51) |
| Share 30–39 | -1.59** (0.67) | | -1.51** (0.67) | -1.55** (0.67) | -1.44** (0.66) | -1.46** (0.64) | -1.60** (0.72) |
| Share 50–59 | -0.58 (0.66) | | -0.62 (0.65) | -0.55 (0.65) | -0.57 (0.65) | -0.41 (0.64) | -0.67 (0.75) |
| Share 60+ | -2.08*** (0.72) | | -2.11*** (0.74) | -2.12*** (0.75) | -1.97*** (0.71) | -1.85** (0.73) | -2.92*** (0.82) |
| Share high-skilled | | 0.51 (0.41) | 0.38 (0.42) | 0.39 (0.42) | 0.38 (0.41) | 0.24 (0.39) | 0.35 (0.42) |
| Share high-skilled (t–1) | | 0.53** (0.21) | 0.48** (0.22) | 0.50** (0.22) | 0.53** (0.22) | 0.61** (0.23) | 0.53** (0.24) |
| Output p.w. (t–1) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Capital p.w. | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Time/fixed effects | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Δ Skills by cohorts | | | | ✓ | | ✓ | |
| Skills by cohorts (t–1) | | | | | ✓ | ✓ | |
| First stage <i>F</i> -statistic | | | | | | | 85.8 |
| Joint <i>p</i> -value: | | | | | | | |
| Workforce shares | 0.03 | | 0.07 | 0.06 | 0.09 | 0.12 | 0.00 |
| Skill shares (total) | | 0.04 | 0.09 | 0.07 | 0.06 | 0.04 | 0.09 |
| Δ Skills by cohorts | | | | 0.80 | | 0.06 | |
| Skills by cohorts (t–1) | | | | | 0.00 | 0.01 | |
| Countries | 134 | 134 | 134 | 134 | 134 | 134 | 132 |
| Observations | 1,176 | 1,176 | 1,176 | 1,176 | 1,176 | 1,176 | 1,154 |

Notes: The dependent variable is log output per worker. Lagged output p.w. and capital p.w. are measured in logarithms. The *p*-values for a Wald test whether coefficients of workforce shares (proxied by the working-age population) or human capital measures are jointly different from zero are reported. Standard errors are clustered at the country-level. Stars indicate significance levels: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

Table 3: Effects of Aging and Skills on Economic Performance: Differences Model

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|-----------------------------|--------------------|-------------------|--------------------|--------------------|--------------------|--------------------|--------------------|
| Δ Share < 20 | -2.50*** (0.83) | | -2.06** (0.83) | -2.05** (0.83) | -1.86** (0.84) | -1.77** (0.85) | -3.24*** (1.00) |
| Δ Share 20–29 | -2.03*** (0.65) | | -1.58** (0.63) | -1.57** (0.64) | -1.46** (0.63) | -1.38** (0.64) | -2.16*** (0.76) |
| Δ Share 30–39 | -2.64*** (0.77) | | -2.28*** (0.77) | -2.33*** (0.78) | -2.19*** (0.78) | -2.16*** (0.79) | -2.49*** (0.82) |
| Δ Share 40–49 | -1.76** (0.71) | | -1.47** (0.70) | -1.52** (0.71) | -1.42** (0.71) | -1.44** (0.72) | -1.58* (0.81) |
| Δ Share 60+ | -4.49*** (0.91) | | -4.45*** (0.92) | -4.53*** (0.93) | -4.56*** (0.92) | -4.60*** (0.92) | -4.43*** (1.04) |
| Δ Share high–skilled | | 0.93** (0.45) | 0.80* (0.44) | 0.77* (0.43) | 0.80* (0.43) | 0.75* (0.42) | 0.72 (0.46) |
| Share high–skilled (t–1) | | 0.53*** (0.19) | 0.52*** (0.18) | 0.53*** (0.18) | 0.52*** (0.18) | 0.54*** (0.18) | 0.56*** (0.19) |
| Output p.w. (t–1) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Capital p.w. | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Time/fixed effects | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Δ Skills by cohorts | | | | ✓ | | ✓ | |
| Skills by cohorts (t–1) | | | | | ✓ | ✓ | |
| First stage F -statistic | | | | | | | 103.4 |
| Joint p -value: | | | | | | | |
| Workforce shares | 0.00 | | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Skill shares (total) | | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| Δ Skills by cohorts | | | | 0.47 | | 0.57 | |
| Skills by cohorts (t–1) | | | | | 0.03 | 0.26 | |
| Countries | 134 | 134 | 134 | 134 | 134 | 134 | 132 |
| Observations | 1,176 | 1,176 | 1,176 | 1,176 | 1,176 | 1,176 | 1,154 |

Notes: The dependent variable is output per worker growth. Lagged output p.w. and capital p.w. are measured in logarithms. The p -values for a Wald test whether coefficients of workforce shares (proxied by the working-age population) or human capital measures are jointly different from zero are reported. Standard errors are clustered at the country-level. Stars indicate significance levels: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.