Ageing, Productivity and Economic Growth: A Macro-level Analysis

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Abstract

Slower growth, or even a decline, of the labour force and an increase in old-age dependency will slow down the growth of aggregrate output and output per capita in many developed countries. However, a major question is whether there is any systematic link between demographics and the productivity of those who will still be active during the up-coming period of demographic ageing. As productivity is difficult to investigate at a micro level, the paper builds on a large macro-data panel covering developed as well as developing countries and explores the impact of the age composition of the labour force on levels and growth rates of output per worker as well as on total factor productivity (TFP). The results point to an inversely *U*-shaped relationship between the share of workers in different age groups and productivity which works mainly through the TFP channel and is effectively much stronger than what can be observed at a micro level. In-depths analyses suggest that cohort effects in human-capital accumulation may contribute to this pattern, but do not explain it. The paper concludes with simulations for a number of OECD countries showing that the impact of projected ageing of the labour force on productivity and per-capita growth could be really substantial in some cases.

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1 Introduction

Over the 20th century, there has been a secular decline in fertility rates in virtually all industrialized countries, with the number of births mostly falling below a "replacement level" during the last three decades. A parallel, strong increase in longevity adds to the picture of demographic ageing as a current mega-trend. However, continuing reductions in age-specific mortality rates now mainly relate to years of age in which individuals are clearly beyond their active life span. As a result, most developed countries will be faced with a considerable slow-down in growth, in many cases even a decline, in their labour force. With an increasing share of older individuals, changes in total population growth tend to exhibit the same patterns, but will be far less pronounced.

The economic implications of these changes are of first-order significance, especially for countries that will be particularly hard hit. Nevertheless, disputes about many of the potential consequences are still unsettled. For example, surprisingly little is actually known regarding the impact of large shifts in the age composition of the labour force on productivity growth, which is what the present paper is going to look at. A major reason is that demographic ageing as it is currently observed in the developed world is largely unprecedented. Hard empirical evidence is thus necessarily lacking. From a theoretical point of view, there are a number of diverging effects for productivity growth: exogenous, age-related differences in productivity at an individual level could matter here; other effects could work via the capital–labour ratio or, more fundamentally, via savings and capital accumulation; also, the demographic structure of the labour force could have effects for average productivity that cannot be traced back to individual workers or their proportion to other factors of production. Some of these effects are rather obvious in their direction, while others are ambiguous or simply unclear. The joint impact on productivity growth and economic performance, including the timing by which it will become effective in the countries affected, is ultimately an empirical question – so that serious research in this area would be at a loss. What remains to be done, therefore, is bringing forth reasonable theoretical conjectures and using data and methods that are in place to assess their relevance in order to push forward the boundaries of our knowledge. This is essentially what the present paper attempts to do.

The paper is organized as follows. In Section 2, I will browse through the body of relevant literature, discussing the main observations that have been made. In Section 3, I take up a simple macroeconomic model of how the age composition of the labour force could affect productivity growth. Section 4 reports on procedures and results of an empirical assessment of the model, based on a large macro-data panel spanning a longer time series and covering developed as well as developing countries. Extending existing work, I also look at the potential role of cohort effects in educational attainments. Section 5 adds illustrative simulations as to what the econometric estimates could mean for future economic performance in a number of developed countries – *viz.*, the US, Japan, Germany, the UK, and France – with diverging demographic prospects. Section 6 concludes, commenting on promising paths for future research in this area.

2 Productivity and demographic ageing: ideas and observations

Note, first of all, that there is a direct, negative impact of demographic change on the growth rates of aggregate output and output per capita. To illustrate this, let us assume for an instant that the growth rate of output per worker – *i.e.*, productivity growth – were exogenously given, hence entirely unaffected by demographic change. If the number of individuals who engage in production grows at a smaller rate than in the past, or even diminishes, the growth rate of aggregate output will slow down correspondingly. Of course, one need not really worry about this reduction in economic growth along its “extensive” margin; people may simply have to get used to smaller growth figures. What is more important from an economist’s point of view is that the “intensive” growth rate of per-capita output, which is sometimes used as a rough indicator of individual well-being, is also likely to decline. The reason is that, whatever the precise trends are, the growth rate of total population will nowhere decelerate as much as that of the working-age population, while the share of the population that is economically inactive, hence the economic dependency ratio, will go up substantially.

Both these effects figure prominently in a number of recent simulation exercises regarding the economic consequences of demographic ageing.[1] They are straightforward from the simple arithmetic of economic growth, so that there is little room to evade them. At the same time, the above considerations imply that the key question arising in this context is really whether there is any systematic impact of demographic change on productivity growth. After all, it is far from clear that, in spite of all the expected shifts in demographic fundamentals and the economic environment, average productivity of those who remain active during the period of overt demographic ageing will be entirely unaffected. Therefore, the present paper mainly focuses on the effects of expected shifts in the age composition of the labour force which are largely driven by the pronounced fertility decline since the mid-1970s on the growth of output per worker.

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[1] See, for example, Martins *et al.* (2005) or European Commission (2005). There, the focus is on ways to increase labour-force participation to counter the wide-spread downward trend in the working-age population. In case this can be accomplished, there will be a positive effect for aggregate and per-capita growth, but the results are still mainly governed by the simple rule of proportion applied above.

2.1 "Capital deepening" in standard growth theory

Neglecting the age composition of the labour force and concentrating on its size, a conventional neoclassical growth model in which output per worker, $q = Y/L = Tf(k)$, is co-determined by the capital–labour ratio, $k = K/L$, predicts an increase in labour productivity if the growth rate of L diminishes. (In standard notation, T measures the current state of technological progress, while the functional form of $f(\cdot)$ represents the generic type of technology that is currently available and may not change so much over time.) In the basic framework suggested by Solow (1956) and Swan (1956), the saving rate is taken to be exogenous, so that capital accumulation is given by $\hat{K} = sY/K - \delta$, where s is the saving rate and δ the depreciation rate.[2] Since the time path of K is governed by s, Y and δ, changes in $\hat{L}$ trigger endogenous adjustments in the model that feed back on k via Y.

To see this, assume that L initially grows at a constant rate $\hat{L}$, that there is no technological progress ($\hat{T} = 0$), and that the economy is on a balanced, "steady-state" growth path on which Y and K grow at the same rate as L, while k and, hence, q remain constant (because $\hat{k} = \hat{K} - \hat{L}$).[3] If, then, L starts persistently growing more slowly than it did before, the immediate response in K is limited to a less than proportional decline in $\hat{K}$ which becomes stronger and stronger until a new steady state is reached. During the entire transition period (with $\hat{k} > 0$) and also in the new steady state, there is thus more capital per worker, and q as a measure of labour productivity increases. This "capital-deepening" effect can be made explicit by calculating the growth rate of output per worker, $\hat{q} = (f'k/f)(\hat{K} - \hat{L})$. The right-hand side of this equation represents capital deepening – "capital dilution" in the case of a reverse change in $\hat{L}$ – which has a positive impact on $\hat{q}$ if $\hat{L}$ declines and vanishes if $\hat{K}$ has adjusted to $\hat{L}$.

The same effect feeds through to changes in output per capita, $y = Y/N = (L/N)\, q$.[4] With respect to $\hat{y} = (f'k/f)(\hat{K} - \hat{L}) + \hat{L} - \hat{N} = (f'k/f)\hat{K} + \big((f - f'k)/f\big)\hat{L} - \hat{N}$, there is an additional "dependency" effect of $\hat{L} - \hat{N}$ which is negative if $\Delta\hat{L} - \Delta\hat{N} < 0$, that is, if $\hat{L}$ is shrinking faster than $\hat{N}$ due to an increasing share of individuals who are out of the labour force. This dependency effect – or, ultimately, a negative "participation" effect of the decline in $\hat{L}$ – always dominates the capital-deepening effect.[5] All in all,

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[2] A hat over a symbol conventionally indicates the growth rate of the respective variable

[3] *With* technological progress, things become a bit more complicated. As long as growth in T does not meet further conditions, a steady-state growth path need not exist (see Section 3 below).

[4] In standard growth models there is often no distinction between the number of workers L and total population N as everyone is assumed to be active in the labour market. Here, I am a bit more careful.

[5] Combining the two effects of changes in $\hat{L}$ as I do above, one can see that their sum is equal to the share of wages in output, $w/f > 0$, in a competitive environment. Therefore, sign ($\Delta\hat{L}$) directly matters for what happens to y as a total effect of changes in the labour force. Keep in mind that $\hat{K}$ moves in the same direction as $\hat{L}$ during the transition to a new steady state.

capital deepening may therefore moderate the direct, quantitative impact of slower growth in the labour force on per-capita growth, but it will not reverse it. Furthermore, capital deepening can be weakened, but also reinforced, if the saving rate s is not exogenous as it is in the neoclassical standard model.[6]

2.2 The empirical evidence thus far

Most of the empirical work on economic growth done prior to the 1990s is now clearly out-dated, due to improvements in both econometric methodology and data availability that have been achieved since then. Brandner and Dowrick (1994) are thus the first to investigate the impact of demographics on economic performance, specifically on per-capita output and per-capita growth, in an up-to-date fashion for a large panel of developed and developing countries. Building on the Solow–Swan model and using population growth as the relevant regressor, they find that, to the extent that they can isolate it, the capital-deepening effect is weak and insignificant. Effectively lumping together the participation and dependency effects, they find a much stronger impact of the working-age share of population which is both positive and significant. The role of investment for output and growth is also positive and significant, as one should expect. Yet, as in many other applied studies on growth, the most important source of variation in output and growth, both across countries and over time, appears to be a productivity indicator taken to reflect the current stage of technological progress in each country.

In a more recent paper, Ahituv (2001) uses an augmented model which includes variables reflecting average qualifications of workers, *i.e.*, human capital accumulation. He concentrates on capital deepening and dependency effects as the two main channels for how demographics could affect output per capita in an even larger panel of countries. Using fertility rates instead of total population growth as a regressor, he finds the former effect to be significant. Still, his estimates suggest that the latter channel is more important in explaining a negative effect of high fertility on output per capita. Like Brandner and Dowrick (1994), Ahituv (2001) looks at contemporaneous relationships only – *i.e.*, effects of current fertility rates on current economic performance[7] – thus neglecting long-term consequences of changes in fertility for economic growth that are currently moving to the fore and should therefore rank high on the research agenda.

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[6] In a Ramsey-type growth model with endogenous saving (Ramsey 1928), the impact of a decline in $\hat{L}$ on s_t is truly ambiguous. Heuristically, there are two opposing effects: individuals may save less as an increasing k puts the rate of return under pressure; they may as well save more to keep up consumption at old age. Ultimately, this is a matter of the intertemporal elasticity of substitution between consumption at different ages, hence an empirical question. See Appendix A.1 for a formal treatment.

[7] Therefore, he also tests for reverse causality, concluding that the negative relation between fertility and output per capita is effectively the result of bi-directional dependence.

An important step in this direction is taken by Lindh and Malmberg (1999) who are the first to investigate the idea that, in developed countries, there may be an impact of the age composition of the population, which is mainly shaped by past birth rates, on the growth rate of output per worker. Their results indicate that, controlling for net investment and labour-force growth within an overall model of transitional growth with gradual adjustments of technology, there is a significant positive effect of the share of those who are currently aged 50–64 years. The share of elderly people (aged 65 and over) has a significant negative effect on productivity growth, while younger age groups have ambiguous and largely insignificant effects. Perhaps, one of the main shortcomings of their study is that the demographic variables used by Lindh and Malmberg (1999) relate to total population, not to the working-age population or the labour force, and therefore do not allow for stronger conclusions regarding the precise mechanisms at work.

Another study dealing with effects of the age composition on productivity and productivity growth that uses data relating to both population *and* labour force is provided by Feyrer (2007). Building on a human-capital augmented growth model and a conventional growth-accounting approach (Solow 1957), his main interest lies with the impact of demographics on the state and dynamics of technological progress. In other words, he mainly looks at the component T in the neoclassical production function, also known as the "Solow residual" or as "total factor productivity", which has often been found to be very important for explaining actual growth processes, respectively, their variation across countries and over time.[8] There is also a number of recent papers, such as Bloom *et al.* (2007), which demonstrate a growing interest in the link between demographics and economic growth in general. Yet, the positive relationship they find between growth of per-capita output and changes in the overall activity rate (*i.e.*, 1 – total dependency ratio) should not be surprising, simply due to the definition of both these variables.

In the empirical part of this paper, I will much build on Feyrer's (2007) work, extending it mainly in two directions. First, I add ten more years of data taken from a period, 1991 to 2000, when growth was certainly more business as usual than in the postwar period until well into the 1960s. Second, I will also look at the role of cohort effects in human-capital accumulation for the link between demographics and productivity.

2.3 Age-related productivity differentials

Another strand of the literature stresses that a given worker's productivity could systematically differ over his or her active period of life for reasons such as differences in experience, depreciation of knowledge or age-related trends in physical and mental ca-

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[8] For an extensive survey of empirical work that backs this conclusion, see Easterly and Levine (2000).

pabilities. Based on the link between productivity and wages, this is often illustrated using micro-level estimates of Mincerian wage equations (Mincer 1974) which measure life-cycle profiles of individual wage rates, usually differentiated by gender, as a function of educational attainments, job experience or age (allowing for non-linear effects) and a number of socio-economic background characteristics. Typically, these profiles exhibit a strong increase until workers are in their 40s and a moderate decline toward the end of the working life. Consequently, if the number of older workers increases *vis-à-vis* that of prime-aged workers, there could be a reduction in average productivity.

There are several objections to interpreting a Mincer-type wage profile as an indicator of age-related differences in productivity. First, in estimates that are based on cross-section data, seemingly age-related trends may effectively be due to cohort effects arising from changes in educational behaviour over time. Levels of qualification are explicitly controlled for in the estimation, yet this may not fully remove the distortion. Second, life-cycle profiles of wages may effectively reflect seniority rules of pay which have little, or nothing, to do with age-related patterns of productivity. Most importantly, however, using data that are suited to avoid these two problems, Börsch-Supan (2003) demonstrates that age-related productivity differentials which show up in individual wage earnings are unlikely to have more than negligible effects for the development of average productivity.[9] Even under extreme assumptions regarding the size of these differentials, he finds that the gradually changing age distribution of the labour force projected for Germany until 2050 (where these changes are rather strong) may reduce productivity growth only by up to 0.15% per year.

An important *caveat* with respect to all kinds of micro-level approaches in this area is that productivity (and its life-cycle profile) is not, at least not fully, an individual characteristic. As the rough tools of macroeconomic growth theory suggest, it is rather the outcome of a complex interaction with other workers and other factors of production which takes place within a certain economic environment constituted by the available technology, public infrastructure, characteristics of a given firm and sector, and many other things beside. This definitely needs to be taken into account when assessing the impact of changes in the size and the composition of the labour force on aggregate economic performance.

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[9] Börsch-Supan (2003) looks at the structure of two different earnings profiles relating to the employees of a major service company in the US (taken from Kotlikoff and Wise 1989), a genuinely longitudinal profile for salesmen whose pay is mainly performance-related and an artificial profile for salarymen who are newly hired at different ages. The restriction to new hires is meant to neutralize the effects of seniority remuneration which may be highly relevant for salaried workers. It turns out that both profiles exhibit more variation than simple cross-section results and that the profile for salaried workers shows an even stronger decline of earnings at higher ages than that for salesmen. This may be partly due to a selection effect between those who stay in a job and those who have to find a new employer.

3 A macroeconomic model

The basic idea which will be put to an empirical test here is the one already pursued by Feyrer (2007), *viz.* that productivity and productivity growth may be influenced by the age composition of the labour force, respectively by changes in this structure. Furthermore, from the literature on age-related productivity differentials (see Section 2.3), one can already infer that such effects, if they exist, may not so much affect productivity that can be directly attributed to the labour input of workers and can be rewarded in terms of wages. Instead, they may mainly work via total factor productivity (TFP), *i.e.*, technological progress and technology dissemination.

To formalize this idea, I start from a particular specification of a neoclassical production function, augmenting it with a variable h representing human capital per worker and assuming technological progress, now measured by a parameter A, to be "labour-augmenting" and the production function to be of the Cobb–Douglas variety. As I want to test the model using annual data for a large number of countries, I add a country index i and a time index t.

$$Y_{it} = K_{it}^{\alpha} (A_{it} h_{it} L_{it})^{1-\alpha} \tag{1}$$

To be sure, none of these are novel features. Equation (1) is essentially taken from Hall and Jones (1999). Taking into account human capital is definitely important as there is a lot of variation across countries and over time in this variable, a major drawback for many older studies being that this has not been measurable in a reliable fashion. The assumption that technological progress is labour-augmenting, or "Harrod-neutral", is necessary for the model to have a steady state (see Uzawa 1961). The assumption that the production function is Cobb–Douglas reconciles this definition with the alternative one of technological progress being "Hicks-neutral" which is needed for growth accounting to be applicable.[10]

Re-writing (1) in terms of output per worker, $q = Y/L$, and re-arranging yields

$$q_{it} = k_{it}^{\alpha} (A_{it} h_{it})^{1-\alpha} = \kappa_{it}^{\alpha/(1-\alpha)} A_{it} h_{it}, \tag{2}$$

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[10] Technological progress is said to be labour-augmenting, or Harrod-neutral (with reference to Harrod 1942), if it does not affect the output shares of capital and labour for a given capital-output ratio. It is called "Hicks-neutral" (after Hicks 1932) if, as in $Y = T K^{\alpha} L^{1-\alpha}$, it does not affect the ratio of marginal productivities of capital and labour for a given capital-labour ratio.

Note that the definitions of Hicks-neutrality and Harrod-neutrality are not mutually exclusive. However, they can only be met simultaneously with a production function that exhibits a constant unit elasticity of substitution. Furthermore, a constant-returns-to-scale Cobb-Douglas function (where the sum of all partial output elasticities is unity and the output shares of all factors of production are simply constant) is the only functional form fulfilling this condition. To see the equivalence, simply assume that the TFP measure A included in (1) is related to T by the monotonic transformation $A = T^{1/(1-\alpha)}$.

with the capital coefficient $\kappa = K/Y = k/q$. Taking natural logarithms leads to a linear decomposition by which A can be isolated. The result is

$$\ln A_{it} = \ln q_{it} - \frac{\alpha}{1-\alpha} \ln \kappa_{it} - \ln h_{it} . \tag{3}$$

Calculating first differences, one obtains (exponential) growth rates of A and the other variables, based on $\ln(x_t/x_{t-1}) = \ln x_t - \ln x_{t-1} \equiv \Delta \ln x_t$ (and $\ln 1 = 0$), whereby

$$\Delta \ln A_{it} = \Delta \ln q_{it} - \frac{\alpha}{1-\alpha} \Delta \ln \kappa_{it} - \Delta \ln h_{it} . \tag{4}$$

Equations (3) and (4) can be seen as prescriptions of how to calculate TFP both in levels and growth rates based on data regarding Y, K, L and h, thereby controlling for the role of pure factor accumulation for output and productivity growth. Bearing in mind that A is often found to be the most important driver of economic growth, one can then go ahead and subject the measures obtained for $\ln A$ and $\Delta \ln A$ to further examination.

Following Lindh and Malmberg (1999) as well as Feyrer (2007), I specifically assume that q is influenced – mainly through the TFP parameter A – by the age composition of the labour force, implying that the latter may have an impact on productivity *levels*, while changes in the age composition of the active population may then affect productivity *growth*. I therefore construct an index representing the age composition of the labour force, Λ, with

$$\Lambda_{it} = \mathrm{e}^{\sum_s \beta_s L_{sit}} , \tag{5}$$

where L_s is the share of age group s in the total labour force. Inserting (5) in (3) and (4) via the assumption that $A = \gamma \Lambda$ yields a decomposition of the TFP residual,

$$\ln A_{it} = \ln \gamma_{it} + \ln \Lambda_{it} = \ln \gamma_{it} + \sum_s \beta_s L_{sit} , \tag{6}$$

or, in terms of first differences,

$$\Delta \ln A_{it} = \Delta \ln \gamma_{it} + \sum_s \beta_s \Delta L_{sit} , \tag{7}$$

which easily lend themselves as testable hypotheses. To obtain regression equations, one simply has to split $\ln \gamma_{it}$ into a constant γ (that disappears when differencing), a time-invariant country fixed effect λ_i, and a pure time trend μ_t, and add an error term ε_{it}. Before turning to estimating the model, however, a few more reflections regarding the theoretical background and some more technical aspects of its estimation may be useful.

Note, first of all, that the assumption that the TFP residual A is a function of (the structure of) L, makes the theoretical model converge to a model of endogenous growth in the tradition of Lucas (1988) and Uzawa (1965), with human capital as an engine of TFP growth. (I will further look into this feature in Section 4.2.) Up to a point, this is at odds with the application of the basic growth-accounting framework, which is necessary to measure A in the first place, as it implies that there are super-linearities linked to one of the production factors entering the $F(\cdot)$-functional. One way out of this dilemma is to interpret the above model as a model of transitional growth (Barro and Sala-i-Martin 1995), such that the TFPs measured for each country would not reflect genuine technological *progress* ("inventions"), but the current state of technology *adoption* ("innovation"). In a process of universal convergence, the uniform production possibilities frontier itself would then not depend on the age composition of the labour force. Alternatively, one may simply accept the internal inconsistency of the theoretical model, as there is no other way to isolate A, and take it to yield an imperfect test on whether there is genuine endogenous growth linked to L and its age composition.

Second, from a technical point of view, the model suggested here for empirical testing has a number of nice features. The age-structure variables which are considered the main determinants of TFP and TFP growth are not likely to be endogenously linked to the dependent variables, as they are essentially determined by decisions taken some 20 to 60 years ago.[11] This avoids problems regarding the direction of causality that are notorious with respect to many other potential determinants of output or output growth, such as trade, investment, education, political institutions, *etc*. Also, unlike other variables that are plausibly exogenous, such as geographical characteristics, demographic variables not only exhibit variation across countries but also considerable time-series variation, at least in the industrialized world. Serial correlation, another potential problem that typically plagues time-series analyses of the determinants of output, is naturally being dealt with in this set-up when switching to first differences, not as a technical response but as a variant of the model which has a material interpretation. Provided it exists in the level-estimates based on equation (6), the problem of serial correlation is also mitigated by the fact that I effectively use data collected at 5-year intervals.

Finally, I am mainly interested in the role of the age composition of the labour force for TFP and TFP growth. The work by Brandner and Dowrick (1994) or Ahituv (2001) suggests that changes in demographic variables may also affect saving and investment,

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[11] This is certainly true with respect to (past) fertility rates and their impact on the current age composition of the labour force, probably less so with respect to migration. But one may take the role of migration which has taken place *very* recently to be of small significance for the observable age composition of the active population. This is shown in Feyrer (2007) using lagged workforce and population data.

To some extent, participation rates could be influenced by the current economic situation of a country, hence by the level and growth rate of its TFP. It is however not clear that this also distorts the age structure of the labour force which actually enters the following estimates. In any case, it has been ruled out in Feyrer (2007) who uses pure population shares as potentially unbiased instruments.

hence the entire time path of the physical capital stock (see Section 2.2). Similar things may apply to the stock of human capital. Estimates regarding the role of demographic change for economic development could therefore be biased if these alternative channels were not taken into account. To check whether this potential bias exists, and also to determine the relative importance of the impact of the age composition on TFP, running additional regressions regarding the impact on the broader productivity measure q and Δq and on any of the components of equations (3) and (4) may thus be useful.

4 Data and estimates

4.1 Demographics, TFP and TFP growth

The data base which has been set up for this study spans a time frame from 1960 to 2000 at 5-year intervals and covers a maximum of 106 countries, among them 27 OECD countries which are taken to represent the developed world.[12] As both growth experience and current demographic trends in most developed countries differ from those in the rest of the world, I exploit the larger "all countries" panel including as many observations as possible to avoid a selection bias, but run separate regressions for the OECD countries to see whether they show any peculiarities.

The estimates rely to a great deal on measures and procedures that have been developed in recent empirical growth research. Throughout, I amend data used in earlier work and re-construct transformations, intermediate estimations *etc*. from scratch. Specifically, the productivity measure q_{it} that serves as a starting point for calculating the TFP residual is output per worker as constructed in the Penn World Tables ("PWT 6.2", Heston *et al*. 2006). Capital per worker k_{it} is calculated applying a "perpetual-inventory" method to PWT 6.2 data following Easterly and Levine (2000),[13] and κ_{it} is simply defined as k_{it}/q_{it}. Human capital per worker is measured as $h_{it} = e^{\phi(s_{it})}$, following Hall and Jones (1999) and using data regarding educational attainments provided by Barro and Lee (2001) and returns to schooling provided by Psacharopoulos (1994).[14] Based on evidence from a host of international studies, capital's share of output, α, is simply assumed to be 1/3 (see, *e.g*., Gollin 2002).

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[12] For a list of the countries covered, see Appendix A.2.

[13] The value of the initial capital stock per worker is estimated to be $i/(g+\delta)\,q_0$; the investment share i is calculated as a 10-year average from 1960 onward (later if data become available only later); "steady-state" growth g is calculated as a weighted 10-year average of the economy's aggregate growth rate and the world growth rate of aggregate output; the depreciation rate δ is assumed to be 7 %; and initial output per worker q_0 is a 3-year average (for further details, see Easterly and Levine 2000, footnote 3).

[14] Here, s_{it} are average years of schooling in the active population; the function $\phi(s)$ is piecewise linear over years of schooling at different levels; it exhibits decreasing returns to higher education and is thus similar to the education-related components of a Mincerian wage regression (see Section 2.3).

Like in Feyrer (2007), the age composition of the labour force is measured by the relative size of 10-year age groups (*L10–19, L20–29*, *etc.*, representing the share of those aged 10–19, 20–29, *etc.* in the active population). Data are taken from the ILO's (2007) LABORSTA database, where they are available at 10-year intervals. To run estimates based on 5-year intervals, missing values are imputed using data on the age structure of total population that are provided by the UN Population Division (2006).

The results of a series of estimates that are based on equation (6), relating to the TFP residual in levels, are summarized in Table 1.[15] Specifications that differ from Model 1 ("M 1") to Model 6 ("M 6") are meant to explore, first, how much additional structure is needed for a simple regression of the TFP term on the *L*-variables to yield meaningful results and, second, how robust these results are with respect to alternative estimation procedures. M 1 is a simple OLS regression, with all the available data simply pooled together, while M 2 adds country dummies and M 3, in addition, time dummies.[16] Allowing for country-specific effects contributes substantially to improving the overall fit and shapes the results regarding age-structure variables *L*10–19 through *L*60+ much more clearly. (*L*40–49 is omitted from the regression and serves as a reference group, the coefficients for the other *L*-variables measuring effects relative to those of this prime-aged group of workers.) Introducing time dummies does not do much to increase the explanatory power of the model. It further modifies the pattern of the *L*-coefficients, but does not change their structure altogether.

To understand the progress from M 1 to M 3 more fully, it is important to keep in mind what the inclusion of time and country-specific effects implies in the present framework. Note, first of all, that all cross-country differences in output and productivity that are due to differences in investment in physical and human capital have already been taken into account when calculating the TFP residual. The estimates therefore focus on differences in productivity, both over time and across countries, that are not explained by factor accumulation alone. Including time dummies in the estimation then allows for TFP levels to vary over time with trend growth rates that are common to all the countries considered. Including country-level dummies means that individual countries may be away, some more and some less, from the current technology frontier defined at a global level. Against this background, additional effects of the age-structure variables indicate that the composition of the labour force may matter for closing, or widening, the gap to the world productivity frontier, for instance, by playing a role for the adoption and use of new technologies. Later on, I will check whether the age com-

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[15] See Appendix A.3 for descriptive statistics related to the variables used in the analysis.

[16] To control for heterogeneity across countries in a rough fashion, M 1 includes dummies for OECD countries and a subset of "least" developed countries as additional regressors. With the introduction of country dummies, these broader controls can be dropped.

Table 1: The age composition of the labour force and TFP

	M 1	M 2	M 3	(a) M 4	(b)
Sample	All Countries	All Countries	All Countries	All Countries	OECD
Estimation method	Pooled OLS	OLS	OLS	Robust OLS $^{a)}$	Robust OLS $^{a)}$
Dep. variable:	ln *A*	ln *A*	ln *A*	ln *A*	ln *A*
*L*10–19	–1.989	–2.341***	–6.247***	–6.247***	–4.133***
	(*1.425*)	(*0.907*)	(*1.068*)	(*1.779*)	(*1.197*)
*L*20–29	1.369	–2.905***	–3.379***	–3.379***	–1.917*
	(*1.311*)	(*0.718*)	(*0.739*)	(*1.063*)	(*1.120*)
*L*30–39	1.019	–2.464**	–2.782**	–2.782**	–2.940***
	(*2.147*)	(*1.159*)	(*1.185*)	(*1.390*)	(*1.023*)
*L*40–49 (ref. group)					
*L*50–59	2.548	–1.601	–1.888	–1.888	–1.827
	(*2.625*)	(*1.598*)	(*1.590*)	(*1.652*)	(*1.193*)
*L*60+	–4.379***	–2.368*	–4.145***	–4.145**	–2.974*
	(*1.664*)	(*1.229*)	(*1.242*)	(*1.924*)	(*1.499*)
Year dummies	No	No	Yes	Yes	Yes
Country dummies	No	Yes	Yes	Yes	Yes
OECD	0.135*				
	(*0.075*)				
Least	–0.729***				
	(*0.067*)				
Constant	8.384***	11.106***	12.238***	12.238***	9.742***
	(*1.323*)	(*0.727*)	(*0.771*)	(*0.876*)	(*0.701*)
Observations	858	858	858	858	233
Countries	106	106	106	106	27
(Adj.) R^2	38.8%	84.7%	86.4%	88.2%	87.7%

a) Residuals clustered by countries to avoid distortions of standard errors through serial correlation.

***, ** and * denote significance at a 1-percent, 5-percent or 10-percent level, respectively. (Standard errors are in parentheses.)

position of the labour force of a given country also matters for persistent differences in trend growth rates, which could point to a potential role of demographics for technological inventions and the position of the technological frontier itself.

Model M 4 is very similar to M 3. Now, however, residuals are clustered by countries as a means to avoid potential distortions of the standard errors through serial correlation. Estimated coefficients are unchanged against M 3, showing a pronounced age-related pattern of the impact of the *L*-variables on the log-TFP measure. What is more interesting for the moment is that the significance of these effects is next to unaffected. Four of the five age-structure variables are significant in the regression relating to all

Table 1 (cont'd.): The age composition of the labour force and TFP

	(a) M 5	(b)	(a) M 6	(b)
Sample	All Countries	OECD	All Countries	OECD
Estimation method	OLS (fixed effects)	OLS (fixed effects)	GLS (random eff.)	GLS (random eff.)
Dep. variable:	ln *A*	ln *A*	ln *A*	ln *A*
*L*10–19	–6.247***	–4.133***	–7.367***	–3.407***
	(*1.068*)	(*1.017*)	(*0.964*)	(*0.966*)
*L*20–29	–3.379***	–1.917***	–2.931***	–1.596***
	(*0.739*)	(*0.609*)	(*0.750*)	(*0.619*)
*L*30–39	–2.782**	–2.940***	–3.098***	–2.606***
	(*1.185*)	(*0.817*)	(*1.189*)	(*0.842*)
*L*40–49 (ref. group)				
*L*50–59	–1.888	–1.827*	–2.158	–1.328
	(*1.590*)	(*0.994*)	(*1.592*)	(*1.026*)
*L*60+	–4.145***	–2.974***	–5.008***	–2.761***
	(*1.242*)	(*0.993*)	(*1.230*)	(*0.967*)
Year dummies	Yes	Yes	Yes	Yes
Constant	-11.625***	-10.915***	11.879***	10.571***
	(*0.748*)	(*0.544*)	(*0.754*)	(*0.554*)
Observations	858	233	858	233
Countries	106	27	106	27
R² overall	32.7%	5.7%	35.2%	6.4%
Within	14.5%	40.6%	14.1%	40.4%
Between	35.3%	0.1%	39.5%	0.2%

***, ** and * denote significance at a 1-percent, 5-percent or 10-percent level, respectively. (Standard errors are in parentheses.)

countries in the sample. The same is true for an otherwise identical regression based on OECD countries only. Additional tests reveal that, in models M 4a and M 4b, all coefficients of the five *L*-variables are jointly significant at a 1-percent level for all countries, at a 5-percent level in the case of OECD countries.[17]

The search for an appropriate specification is continued in M 5, a genuine fixed-effects model. Apart from the constant, the coefficients are identical to those of M 3 and M 4, and their significance turns out to be as high as in M 3, that is, without the adjustment in standard errors through clustered residuals. At the same time, the assumption of country-level fixed effects[18] takes away some of the explanatory power of the other re-

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[17] The *F*-test on joint significance of all the *L*-variables rejects the Null hypothesis that they are all equal to zero with *prob* > *F* = 0.0015 for model M 4a. With M 4b, the test statistic is *prob* > *F* = 0.0412.

[18] These effects are jointly significant at a 1-percent level in both versions of model M 5.

gressors. In the regression covering all countries, this can be seen from the moderate results regarding "R^2 within" (measuring the model's fit over time for a given country) and the new, combined measure of the "overall R^2" (over time and across countries). In the OECD regression, the "within" fit is still rather high. All these observations are not uncommon in a context like the present one. M 6 is a random-effects specification using the generalized least squares (GLS) method for analysing the otherwise unchanged model. The results are qualitatively unchanged against M 3 through M 5. More importantly, additional tests do not support the random-effects specification.[19] In the light of these results, I am thus inclined to consider M 4 – which yields quantitatively the same results regarding the L-coefficients as M3 and M5 – as the final specification of the present TFP-in-levels estimation and use it as a baseline for further analyses.

A major result of the estimates thus far is that the coefficients for L10–19 through L60+ exhibit a highly remarkable pattern. Age-related TFP contributions clearly peak for workers in their 40s, as the coefficients for all other age groups turn out to be negative. In the all-countries regression, the overall pattern is in fact of a perfect, inverse *U*-shape, resembling that of a standard Mincer-type wage regression. This is illustrated in Figure 1.[20] In the OECD-variant of M 4, the pattern is less pronounced in general, and there appears to be a deviation from the inverse *U*-shape related to those aged 20–29. (Note, however, that the point estimate is only borderline-significant in this case.) Thus, if one were to take age-related wage profiles as indicating age-specific productivity differentials that are observable at an individual level and can be internalized through wages, the structure of contributions of each age group to TFP would exhibit a similar structure. Yet, the differential impact on TFP appears to be much stronger, pointing to quantitatively important "growth externalities" by which the age composition of the entire labour force of a given country matters a lot for technology adoption and, hence, for levels and movements of total factor productivity.

Moving from level accounting to growth accounting in its genuine form, I now look at equation (7), investigating whether changes in the age composition of the labour force have an impact on TFP growth which is in line with the results derived from the level-equation (6). The new results are summarized in Table 2. Note that, in this case, none of the estimations allows for a constant. M 7 also does not include country dummies and is thus equivalent to the baseline model M 4: the common assumption is that the trend

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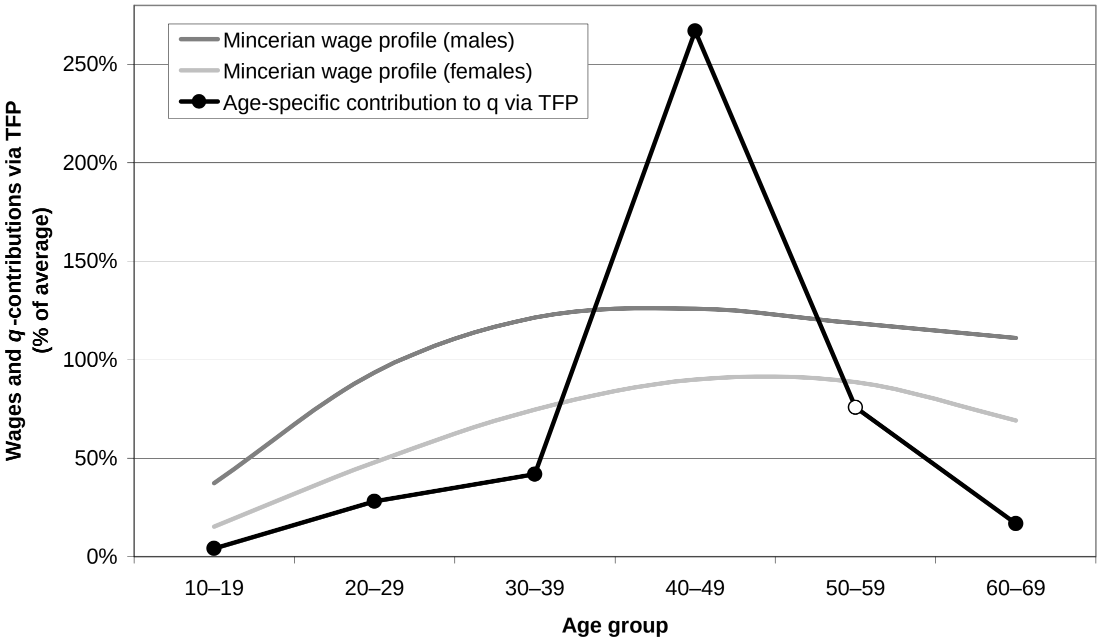
[19] The Hausman test clearly rejects that country-specific effects are uncorrelated with the other explanatory variables. The Breusch-Pagan test confirms that there is no autocorrelation in the country-specific effects. Both these results imply that the country-level effects are not randomly distributed.

[20] For a typical Mincerian wage regression, Figure 1 draws on results reported in Fenge *et al.* (2006), based on German micro-data. For illustrative purposes, the age-related relative contributions of each age group to the level of TFP are assessed based on the estimates derived from model M 4a above, using the year-2000 age structure of the German labour force.

Figure 1: *Age-related wage profiles and age-specific contributions to TFP*



Sources: Fenge *et al*. (2006) for wage profiles; own calculations based on Model M 4a.

On the black curve, points representing the results of model M 4a are filled if the underlying estimate is significant. The estimate for the 50–59 group is not significant.

growth rate is determined by the global technology frontier and is thus the same across countries, while the demographic structure of the labour force may speed up, or slow down, convergence. The alternative model with country dummies, M 8, allows for trend growth rates that would permanently differ across countries, potentially giving demographics an additional role as a true driving force of technological progress, not merely a role for technology adoption.

Table 2 shows that the results of M 7 are basically in line with those of M 4. In the all-countries version of the estimation, three of the five *L*-variables are significant by themselves for explaining TFP growth, and they are jointly significant at a close-to-1-percent level.[21] Results for the OECD sub-sample are weaker in both respects, suggesting that demographics alone are less important for TFP growth in industrialized countries than they are in the rest of the world. Most importantly, however, the age-related pattern of the impact of the age composition of the labour force on a given country's growth rate of TFP remains largely unchanged for both samples. Things are different with respect to M 8, the variant with country dummies. Here, the significance of estimates for the *L*-variables largely vanishes, and only in the OECD-variant the *L*-coeffi-

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[21] The F-test on joint significance of all the L-variables yields $prob > F = 0.0153$ for model M 7a and $prob > F = 0.1054$ for model M 7b.

Table 2: Changes in the age composition of the labour force and TFP growth

	(a) M 7	(b)	(a) M 8	(b)
Sample Estimation method	All Countries Robust OLS [a]	OECD Robust OLS [a]	All Countries Robust OLS [a]	OECD Robust OLS [a]
Dep. variable:	$\Delta \ln A$	$\Delta \ln A$	$\Delta \ln A$	$\Delta \ln A$
ΔL10–19	–2.635**	–1.832*	–2.012*	–1.721
	(*1.096*)	(*0.967*)	(*1.082*)	(*1.016*)
ΔL20–29	–2.475***	–1.369*	–2.081*	–1.499**
	(*0.863*)	(*0.733*)	(*1.241*)	(*0.730*)
ΔL30–39	–0.794	–1.384	–0.660	–1.337
	(*0.967*)	(*1.038*)	(*1.002*)	(*1.093*)
ΔL40–49 (ref. group)				
ΔL50–59	–1.491	–1.114	–1.253	–1.010
	(*1.588*)	(*0.958*)	(*1.800*)	(*1.105*)
ΔL60+	–1.629*	–2.029**	–0.459	–1.895*
	(*0.948*)	(*0.781*)	(*1.177*)	(*1.013*)
Year dummies	Yes	Yes	Yes	Yes
Country dummies	No	No	Yes	Yes
Observations	752	206	752	206
Countries	102	27	102	27
R²	8.4%	33.9%	23.3%	42.2%

a) Residuals clustered by countries to avoid distortions of standard errors through serial correlation.

***, ** and * denote significance at a 1-percent, 5-percent or 10-percent level, respectively. (Standard errors are in parentheses.)

cients still exhibit a clear-cut, age-related pattern. What is probably more interesting is that most of the country dummies turn out to be significant, but the overwhelming majority of the coefficients are in a very narrow band ranging from 0.1 to 0.2 in M 8a, from 0.0 to 0.05 in M 8b. It appears that, once the impact of demographics on growth performance is controlled for, strong cross-country differences in trend growth rates are not supported by the data.

To put the results in a broader perspective and test for alternative channels of the impact of labour-force demographics on productivity and productivity growth, I finally use equations (3) and (4) and regress all of their components on the vector of L-variables. The results of these estimations are summarized in Tables 3 and 4.[22] All of the findings reported there point to a first-order importance of the TFP channel for the

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[22] The columns representing results for $\ln A$ and $\Delta \ln A$ in Tables 3 and 4 are identical with those of models M 4a, M 4b, M 7a and M 7b, respectively.

Table 3: The composition of the impact of demographics on productivity

	(a)	(b)	(c)	(d)
	M 9			
Sample	All Countries			
Estimation method	Robust OLS [a)]			
Dep. variable:	ln q	ln A	$\alpha/(1-\alpha)\ln\kappa$	ln h
L10–19	–6.554***	–6.247***	0.674	–0.980**
	(*1.408*)	(*1.779*)	(*0.876*)	(*0.397*)
L20–29	–2.649***	–3.379***	0.551	0.179
	(*0.920*)	(*1.063*)	(*0.339*)	(*0.235*)
L30–39	–2.999***	–2.782**	0.040	–0.257
	(*0.971*)	(*1.390*)	(*0.680*)	(*0.277*)
L40–49 (ref. group)				
L50–59	–0.720	–1.888	0.932	0.236
	(*1.321*)	(*1.652*)	(*0.693*)	(*0.427*)
L60+	–2.689	–4.145**	1.342	0.114
	(*1.662*)	(*1.924*)	(*1.003*)	(*0.587*)
Year dummies	Yes	Yes	Yes	Yes
Country dummies	Yes	Yes	Yes	Yes
Constant	11.070***	12.238***	–1.367***	0.199
	(*0.686*)	(*0.876*)	(*0.409*)	(*0.215*)
Observations	858	858	858	858
Countries	106	106	106	106
R²	96.4%	88.2%	86.6%	96.9%

	(e)	(f)	(g)	(h)
	M 9			
Sample	OECD			
Estimation method	Robust OLS [a)]			
Dep. variable:	ln q	ln A	$\alpha/(1-\alpha)\ln\kappa$	ln h
L10–19	–6.716***	–4.133***	–1.618**	–0.965
	(*1.706*)	(*1.197*)	(*0.787*)	(*1.010*)
L20–29	–1.869*	–1.917*	–0.315	0.363
	(*0.943*)	(*1.120*)	(*0.311*)	(*0.400*)
L30–39	–3.637***	–2.940***	–0.752	0.055
	(*0.615*)	(*1.023*)	(*0.445*)	(*0.472*)
L40–49 (ref. group)				
L50–59	–0.838	–1.827	0.580	0.409
	(*1.032*)	(*1.193*)	(*0.594*)	(*0.527*)
L60+	–1.442	–2.974*	0.733	0.799
	(*1.991*)	(*1.499*)	(*1.087*)	(*0.897*)
Year dummies	Yes	Yes	Yes	Yes
Country dummies	Yes	Yes	Yes	Yes
Constant	10.856***	9.742***	0.326	0.788**
	(*0.487*)	(*0.701*)	(*0.275*)	(*0.316*)
Observations	233	233	233	233
Countries	27	27	27	27
R²	94.6%	87.7%	89.3%	93.8%

a) Residuals clustered by countries to avoid distortions of standard errors through serial correlation.

***, ** and * denote significance at a 1-percent, 5-percent or 10-percent level, respectively. (Standard errors are in parentheses.)

Table 4: The composition of the impact of demographics on productivity growth

	M 10			
	(a)	(b)	(c)	(d)
Sample Estimation method	All Countries Robust OLS $^{a)}$			
Dep. variable:	$\Delta \ln q$	$\Delta \ln A$	$\alpha/(1-\alpha)\,\Delta \ln \kappa$	$\Delta \ln h$
ΔL10–19	–2.455***	–2.635**	0.452	–0.271
	(*0.770*)	(*1.096*)	(*0.398*)	(*0.216*)
ΔL20–29	–1.886***	–2.475***	0.530	0.059
	(*0.485*)	(*0.863*)	(*0.559*)	(*0.133*)
ΔL30–39	–1.071*	–0.794	–0.195	–0.082
	(*0.631*)	(*0.967*)	(*0.425*)	(*0.202*)
ΔL40–49 (ref. group)				
ΔL50–59	–1.105	–1.491	0.291	0.095
	(*1.010*)	(*1.588*)	(*0.632*)	(*0.261*)
ΔL60+	–0.933	–1.629*	0.634	0.071
	(*0.785*)	(*0.948*)	(*0.459*)	(*0.297*)
Year dummies	Yes	Yes	Yes	Yes
Country dummies	No	No	No	No
Observations	752	752	752	752
Countries	102	102	102	102
R^2	27.7%	8.4%	23.6%	42.4%

	M 10			
	(e)	(f)	(g)	(h)
Sample Estimation method	OECD Robust OLS $^{a)}$			
Dep. variable:	$\Delta \ln q$	$\Delta \ln A$	$\alpha/(1-\alpha)\,\Delta \ln \kappa$	$\Delta \ln h$
ΔL10–19	–2.530***	–1.832*	–0.337	–0.360
	(*0.527*)	(*0.967*)	(*0.262*)	(*0.516*)
ΔL20–29	–1.456**	–1.369*	–0.266	0.180
	(*0.576*)	(*0.733*)	(*0.233*)	(*0.270*)
ΔL30–39	–1.588**	–1.384	–0.215	0.011
	(*0.649*)	(*1.038*)	(*0.265*)	(*0.344*)
ΔL40–49 (ref. group)				
ΔL50–59	–0.816	–1.114	0.177	0.122
	(*0.579*)	(*0.958*)	(*0.455*)	(*0.311*)
ΔL60+	–1.268*	–2.029**	0.245	0.516
	(*0.729*)	(*0.781*)	(*0.463*)	(*0.472*)
Year dummies	Yes	Yes	Yes	Yes
Country dummies	No	No	No	No
Observations	206	206	206	206
Countries	27	27	27	27
R^2	73.6%	33.9%	52.3%	45.0%

a) Residuals clustered by countries to avoid distortions of standard errors through serial correlation.

***, ** and * denote significance at a 1-percent, 5-percent or 10-percent level, respectively. (Standard errors are in parentheses.)

observed impact of the age composition of the labour force on output per worker and its development over time. Note that, by construction, coefficients for $\ln q$ and $\Delta \ln q$ equal the sum of the coefficients related to $\ln A$ or $\Delta \ln A$, $\alpha/(1-\alpha) \ln \kappa$, *etc*.

It is easy to see that the L-coefficients related to the TFP-measure are always substantially larger than coefficients related to the capital coefficient and human capital. Also, in the estimations for κ and h, almost none of the L-coefficients are significant. In fact, they are all insignificant in model M10, *i.e.*, for the variables in first differences, $\alpha/(1-\alpha) \Delta \ln \kappa$ and $\Delta \ln h$. Only in the level-estimate for all countries, the age-structure variable relating to the youngest group of workers, L10–19, yields a significant estimate with respect to the human-capital stock measure, $\ln h$. In the OECD-version, the same is true with respect to the capital coefficient, $\alpha/(1-\alpha) \ln \kappa$. In both cases, the coefficients are negative. The first of these results is easily understood. Outside the OECD world, labour-force participation of young adults is sometimes substantial, but this reduces the level of final educational attainments of the entire labour force. The second result points to a negative relationship between the relative size of the cohort of workers who are just entering the labour force and the current capital coefficient which, in turn, contributes to a lower level of output per worker. Up to a point, this may reflect the "capital-dilution" effect of a growing labour force, probably the "baby boomers", for productivity that was discussed in Section 2. There may thus be a limited influence of demographics on factor accumulation, as was also found by Brandner and Dowrick (1994) or Ahituv (2001), but it appears to be next to negligible *vis-à-vis* the strong impact on total factor productivity.

All in all, the findings thus far basically confirm the results obtained by Feyrer (2007) based on an up-dated sample with a longer time series, pointing to a significant role of the age composition of a given country's labour force for both the level and the growth rate of output per worker. Furthermore, the observation that this effect mainly works via TFP, not via factor accumulation, can be taken to indicate that labour-force demographics are effectively a major determinant of (transitory) endogenous growth.

4.2 Extensions: Is there also a role of human capital?

Due to the nature of the macro-level data that are used, the foregoing analysis is certainly rough in many respects. It is prone to a number of measurement errors, and it provides little detail that could be helpful in identifying the mechanisms at work behind the results. I have argued before (in Section 2.3) that macroeconomic data are nevertheless the appropriate level for investigating age-related productivity differentials. The results so far clearly support this view as they highlight a strong role of labour-force demographics for TFP and its growth. I will now discuss some of the potential limitations of this finding and then try to shed a little more light on how it may actually be driven.

As the TFP-measure is determined residually, everything that is not accounted for when calculating it, *i.e.*, everything not included in the κ and h-terms in equation (3), is – probably wrongly – attributed to $\ln A$. Here, two aspects of this well-known problem may deserve a little more attention. First, for countries where not only the accumulation of physical and human capital, but also the exploitation of natural resources plays a major role for economic development, the TFP-measure may be distorted. As a prominent example, one may therefore use various definitions to identify oil-exporting countries and exclude them from the sample while re-doing the level-estimates based on model M 4. The results are basically unchanged against those reported in Table 1.[23] Second, productivity is defined on per-worker terms throughout the above calculations. Therefore, if the average number of hours worked has declined over time this may create another distortion, mainly affecting calculated changes in TFP. Unfortunately, longer time series of data regarding this issue which also cover a sufficiently large number of countries are lacking. Essentially, such data exist only for OECD countries where, at the same time, changes of this kind may have been most prominent over the last few decades. In this case, it has already been demonstrated by Feyrer (2007) that controlling for these changes leaves the structure of coefficients, hence the estimated impact of labour-force demographics on TFP growth, essentially unaffected.

If, therefore, one takes the results presented in Section 4.1 as what they are – a clear indication that demographic ageing may matter for productivity and TFP growth – the question as to why this is so moves to the fore. By themselves, the estimates say nothing on how to answer this question. There may be a number of plausible stories that could be told to motivate the observed pattern of age-specific contributions to TFP and its growth (see Section 6 fur further discussion). But, either because macro-level data are lacking which could be used to illustrate their potential significance or because one would really have to investigate them at the micro level, none of these stories can be subjected to closer scrutiny through relevant extensions of the present analysis. Yet, there is one natural extension of the framework I have utilized so far which appears to be feasible. In accordance with the Lucas–Uzawa model of endogenous growth, not only the structure of the labour force (measured through the L-variables) but also their human capital (that is, age-specific values of h10–19, h20–29, *etc*.) might affect the TFP residual. Since individuals well into their 20s are still in the process of accumulating

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[23] See Appendix A.4. If anything, the age-related pattern of TFP contributions becomes even more pronounced when more and more oil-exporting countries are dropped. Note that results for the L-variables are jointly significant at the 1-percent level in all cases but the last one, where they are only close to being so. In this case, the definition of "oil-exporters" is extreme in that it encompasses all countries where, more than once in the 1960–2000 period, the share of fuel exports in total merchandise exports was in the top third of the annual global distribution of these shares. Since countries where foreign-trade data are lacking are also omitted, more than half of the observations are lost.

human capital, while older workers often have lower final educational attainments than their successors, the entire age-related pattern of TFP contributions could therefore, at least partly, be driven by cohort effects located in this specific area.

To investigate this idea more closely, data on educational attainments by age groups are needed that have a similar coverage as the data panel I have been using. Once more, data of this kind are nowhere provided directly. It is difficult, though possible, however, to re-cover such information from the Barro–Lee (2001) dataset I already used to account for human-capital accumulation in the TFP calculations. The data that result from a series of transformations[24] have a number of limitations. Most importantly, they cannot reflect the full age-related variation of educational attainments for the entire sample period, as more and more entries for older age groups have to be set to uniform averages when moving backward in time. Also, the resulting data may effectively convey some noise, especially in the case of non-OECD countries where educational attainments are often low and formal education processes do not follow a strongly standardized timing.

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[24] The data set on educational attainments constructed by Barro and Lee (2001) offers two series of results, one for the population aged 15 and above – which I have used in calculating $\ln h$ – and one for the population aged 25 and above. Educational attainments of those aged 15–24 should therefore be given by $h_{15\text{–}24} = (h_{15+}\,Pop_{15+} - h_{25+}\,Pop_{25+})\,/\,(Pop_{15\text{–}24})$; detailed population data are taken from the UN Population Division's (2006) data base which shows only minimal deviations from the figures for Pop_{15+} and Pop_{25+} provided by Barro and Lee (2001). In line with the timing of human-capital accumulation assumed by Barro and Lee (2001, eq. (6)–(9), *viz*. that 15–19 year olds are beyond primary education, half way through secondary education and have no tertiary education; that 20–24-year olds are beyond secondary education and half way through tertiary education), one can then infer final, or full, educational attainments of those currently aged 15–24 and consider these constant from age 25 onward. Thus, $c\,h_{15\text{–}24,\,\mathrm{t}} = h_{25\text{–}34,\,t+10} = h_{35\text{–}44,\,t+20}$, *etc*., where c is a conversion factor which is based on the assumptions just mentioned and on the proportions of the relevant age groups. This yields a series of educational attainments by age groups which runs from 1960 to 2000 for those aged 15–24 but, unfortunately, covers those aged 55–64 only in the year 2000. In other words, relying on data resulting from these transformations only I would largely lose the time-series dimension.

To overcome this serious limitation without doing violence to the data that are in place, I therefore take a second step. Based on $h_{X+} = (h_{15+}\,Pop_{15+} - h_{<X}\,Pop_{<X})\,/\,(Pop_{X+})$ I impute adjusted figures for average educational attainments to all groups aged X and above for which these data are missing. This certainly implies a loss in potential variation across age groups, but does not rely on any additional conjectures that might not be supported by the original data. Only, with the population measured in 1,000s and educational attainments measured as average years of schooling (differentiated by levels) with just one decimal digit, this procedure is susceptible to relatively large rounding errors, especially where average educational attainments are close to zero. I thus drop a limited number of results that are either implausibly low (< –0.2) or exceed the highest figures observed for 2000. Remaining negative figures are set to zero. Note that, in general, rounding errors should produce noise, but generate no systematic biases. In any case, I will also use only non-imputed figures for robustness checks.

As the last step to take I switch from results for "odd" age groups (15–24 *etc*.) to "even" ones (10–19 *etc*.) in a straightforward way. Without making any further assumptions regarding cohort effects at the level of 5-year age groups, but taking into account the Barro–Lee assumptions regarding the standardized timing of human-capital accumulation, I use population-weighted averages of $h_{15\text{–}24}$ and $h_{25\text{–}34}$ *etc*. for adjacent age groups and determine the end points $h_{15\text{–}19}$ and $h_{60\text{–}64}$ residually. Finally, I take the latter two results to apply to workers aged 10–19 and 60+, respectively, as labour-force participation among those aged less than 15 or 65 and above is usually low.

As a further limitation for any in-depth analysis, the number of observations I am using is limited from the out-set, definitely in the OECD sample, and therefore does not easily allow for introducing a multitude of additional regressors. To deal with this problem, I therefore run two series of regressions, one where I add a full set of age-specific human-capital variables (h10–19 through h60+) to the baseline models defined in Section 4.1 and one where I use each of these variables in turn, but only one at a time.

The h-variables are defined as age-specific educational attainments derived from the Barro and Lee (2001) data, converted into a comprehensive human-capital measure following Hall and Jones (1999).[25] They are then divided by the average stock of human capital per worker in each country and year in order to remove correlations between them and to avoid that, when used in isolation, they are simply a proxy for average human capital.[26] As a complement of the shares of each age group in the labour force captured by the regressors L10–19 *etc*., the h10–19s *etc*. thus reflect the relative level of qualifications of individuals in any of these groups. Tables 5 and 6 report on the results of estimations which augment models M 4 and M 7 in the way just described.[27]

Models M 11 and M 12 which use age-specific measures of human capital as additional regressors essentially show two things. First, cohort effects in educational attainments appear to play some role in determining both TFP levels and TFP growth. But second, they never make the strong age-related pattern of the L-coefficients disappear. When the h-variables are thrown in, the age profile for the L-variables becomes a bit less pronounced but, at the same time, gets sharper in terms of significance.[28] By them selves, the -coefficients show no clear, age-related pattern. But taken in isolation, they are jointly significant in the growth-estimates in models M 11h and M 12h and there are also a number of significant estimates for human capital of single age groups.

The regressions bundled in Tables 5 and 6 should be read as follows. The columns where all the h-variables are present are what I really want to look at. Due to the relatively large number of regressors, however, significance and (insignificant) signs of the

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[25] See footnote 24 on the way the Barro–Lee data are being used and footnote 14 for further details regarding the human-capital measure suggested by Hall and Jones (1999).

[26] Regressions on human-capital data without this normalization do not look very different.

[27] For comparison, Appendix A.5 lists the results for Models M 4 and M 7 when, in each case, the sample is restricted to observations which also enter the human-capital augmented regressions. Also, as one may doubt the validity of the imputations of missing human-capital data explained in footnote 24, Appendix A.6 reports on parallel regressions using only non-imputed data. To the extent that these results can be compared at all to those provided in Tables 5 and 6, they are much in line with them.

[28] This can be seen by comparing M 11 and M 12 to their counterparts in Appendix A.5. The L-coefficients are jointly significant in all of the models M 11a, M 11h, M 12a and M 12h (with $prob > F = 0.0214$, $prob > F = 0.0838$, $prob > F = 0.0360$ and $prob > F = 0.0353$, respectively). They are also jointly significant in models M 4g, M 7c and M 7d (with $prob > F = 0.0238$, $prob > F = 0.0480$ and $prob > F = 0.0666$, respectively), but not in M 4h.

Table 5: The age distribution of human capital and TFP

	(a)	(b)	(c)	M 11 (d)	(e)	(f)	(g)
Sample	All countries						
Estim. Method	Robust OLS a)						
Dep. variable:	ln *A*	ln *A*	ln *A*	ln *A*	ln *A*	ln *A*	ln *A*
*L*10–19	–5.717***	–6.184***	–6.260***	–6.470***	–6.329***	–6.208***	–6.075***
	(*1.923*)	(*1.849*)	(*1.914*)	(*1.805*)	(*1.821*)	(*1.884*)	(*1.933*)
*L*20–29	–2.659**	–3.219***	–3.358***	–3.537***	–3.480***	–3.253***	–3.332***
	(*1.247*)	(*1.089*)	(*1.129*)	(*1.028*)	(*1.096*)	(*1.189*)	(*1.212*)
*L*30–39	–1.803	–2.838**	–2.836*	–2.941**	–2.812**	–2.484	–2.229
	(*1.746*)	(*1.430*)	(*1.488*)	(*1.422*)	(*1.391*)	(*1.705*)	(*1.654*)
*L*40–49 (ref. gr.)							
*L*50–59	–1.536	–2.157	–2.111	–2.224	–1.797	–1.968	–1.874
	(*1.952*)	(*1.787*)	(*1.761*)	(*1.788*)	(*1.751*)	(*1.714*)	(*1.820*)
*L*60+	–2.945	–3.396	–3.591	–3.830*	–4.226**	–3.735*	–3.550*
	(*2.157*)	(*2.122*)	(*2.235*)	(*2.042*)	(*2.000*)	(*2.122*)	(*2.065*)
*h*10–19	–0.456	0.086					
	(*0.282*)	(*0.096*)					
*h*20–29	1.425**		0.157				
	(*0.618*)		(*0.156*)				
*h*30–39	–1.464**			–0.003			
	(*0.735*)			(*0.158*)			
*h*40–49	1.330**				0.070		
	(*0.588*)				(*0.108*)		
*h*50–59	–0.731					–0.006	
	(*0.446*)					(*0.097*)	
*h*60+	0.187						–0.045
	(*0.145*)						(*0.066*)
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ctry. dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	11.067***	12.026***	11.951***	12.379***	12.223***	12.118***	12.042***
	(*1.183*)	(*0.874*)	(*1.099*)	(*1.014*)	(*0.926*)	(*1.003*)	(*1.069*)
Observations	815	823	823	835	841	834	831
Countries	103	103	103	103	103	103	103
R²	88.1%	87.6%	87.6%	87.6%	87.7%	87.8%	87.9%

a) Residuals clustered by countries to avoid distortions of standard errors through serial correlation.

***, ** and * denote significance at a 1-percent, 5-percent or 10-percent level, respectively. (Standard errors are in parentheses.)

Table 5 (cont'd.): The age distribution of human capital and TFP

	(h)	(i)	(j)	M 11 (k)	(l)	(m)	(n)
Sample Estim. Method	OECD Robust OLS [a)]						
Dep. variable:	ln A	ln A	ln A	ln A	ln A	ln A	ln A
L10–19	–4.455***	–4.299***	–4.429***	–4.014***	–4.107***	–4.230***	–3.990***
	(*1.308*)	(*1.237*)	(*1.389*)	(*1.210*)	(*1.250*)	(*1.341*)	(*1.163*)
L20–29	–2.185*	–2.066*	–2.083*	–1.901	–1.894	–1.942	–1.888
	(*1.162*)	(*1.154*)	(*1.185*)	(*1.118*)	(*1.113*)	(*1.158*)	(*1.112*)
L30–39	–3.336***	–3.110***	–3.205***	–2.892**	–2.850**	–2.993***	–2.823***
	(*0.999*)	(*1.072*)	(*1.128*)	(*1.055*)	(*1.049*)	(*1.078*)	(*1.000*)
L40–49 (ref. gr.)							
L50–59	–2.565**	–2.273*	–2.935	–1.976	–1.756	–2.125*	–1.927
	(*1.133*)	(*1.241*)	(*1.780*)	(*1.272*)	(*1.176*)	(*1.209*)	(*1.200*)
L60+	–3.095	–2.869	–2.935	–2.731	–3.063*	–2.968*	–2.746
	(*1.842*)	(*1.739*)	(*1.800*)	(*1.737*)	(*1.653*)	(*1.690*)	(*1.671*)
h10–19	0.202	–0.089					
	(*0.230*)	(*0.064*)					
h20–29	–0.525		–0.074				
	(*0.546*)		(*0.180*)				
h30–39	0.796			0.128			
	(*0.635*)			(*0.118*)			
h40–49	–0.718				0.157		
	(*0.563*)				(*0.125*)		
h50–59	0.697					0.096	
	(*0.449*)					(*0.112*)	
h60+	–0.220						–0.030
	(*0.176*)						(*0.061*)
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ctry. Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	11.016***	11.217***	10.947***	10.109***	9.570***	10.939***	10.923***
	(*0.849*)	(*0.732*)	(*0.874*)	(*0.725*)	(*0.677*)	(*0.737*)	(*0.706*)
Observations	217	219	219	225	231	228	228
Countries	27	27	27	27	27	27	27
R^2	88.0%	88.0%	87.8%	87.8%	88.1%	87.7%	87.7%

a) Residuals clustered by countries to avoid distortions of standard errors through serial correlation.

***, ** and * denote significance at a 1-percent, 5-percent or 10-percent level, respectively. (Standard errors are in parentheses.)

Table 6: Changes in the age distribution of human capital and TFP growth

	(a)	(b)	(c)	M 12 (d)	(e)	(f)	(g)
Sample	All countries						
Estimation method	Robust OLS [a)]						
Dep. variable:	$\Delta \ln A$	$\Delta \ln A$	$\Delta \ln A$	$\Delta \ln A$	$\Delta \ln A$	$\Delta \ln A$	$\Delta \ln A$
ΔL10–19	–2.683***	–2.701**	–2.711**	–2.800**	–2.771**	–2.618**	–2.607**
	(*0,966*)	(*1.099*)	(*1.115*)	(*1.095*)	(*1.107*)	(*1.046*)	(*1.017*)
ΔL20–29	–1.277	–2.578***	–2.571***	–2.600***	–2.561***	–1.482**	–1.455*
	(*0.788*)	(*0.925*)	(*0.881*)	(*0.872*)	(*0.872*)	(*0.665*)	(*0.751*)
ΔL30–39	–0.939	–0.908	–0.840	–0.893	–0.922	0.944	–0.947
	(*1.309*)	(*1.056*)	(*1.067*)	(*1.001*)	(*0.956*)	(*1.017*)	(*1.180*)
ΔL40–49 (ref. gr.)							
ΔL50–59	–1.904	–1.664	–1.649	–1.590	–1.508	–1.864	–1.654
	(*1.624*)	(*1.705*)	(*1.674*)	(*1.690*)	(*1.619*)	(*1.544*)	(*1.567*)
ΔL60+	–0.795	–1.494	–1.184	–1.485	–1.470	–1.009	–1.130
	(*1.006*)	(*0.987*)	(*0.991*)	(*0.984*)	(*0.964*)	(*0.942*)	(*0.954*)
Δh10–19	–0.305**	0.045					
	(*0.153*)	(*0.057*)					
Δh20–29	0.749**		0.208***				
	(*0.369*)		(*0.080*)				
Δh30–39	–0.920**			0.061			
	(*0.445*)			(*0.084*)			
Δh40–49	0.709*				–0.060		
	(*0.371*)				(*0.065*)		
Δh50–59	–0.623**					–0.145**	
	(*0.277*)					(*0.069*)	
Δh60+	0.107						–0.062
	(*0.093*)						(*0.046*)
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country dummies	No	No	No	No	No	No	No
Observations	701	714	714	731	738	726	721
Countries	100	100	100	100	100	100	100
R²	10.3%	8.2%	9.0%	8.3%	8.3%	8.9%	8.4%

a) Residuals clustered by countries to avoid distortions of standard errors through serial correlation.

***, ** and * denote significance at a 1-percent, 5-percent or 10-percent level, respectively. (Standard errors are in parentheses.)

Table 6 (cont'd.): Changes in the age distribution of human capital and TFP growth

	(h)	(i)	(j)	M 12 (k)	(l)	(m)	(n)
Sample	OECD						
Estimation method	Robust OLS $^{a)}$						
Dep. variable:	$\Delta \ln A$	$\Delta \ln A$	$\Delta \ln A$	$\Delta \ln A$	$\Delta \ln A$	$\Delta \ln A$	$\Delta \ln A$
ΔL10–19	–1.586	–2.063**	–1.553	–1.673*	–1.752*	–1.452	–1.524
	(*0.940*)	(*0.994*)	(*1.096*)	(*0.946*)	(*1.024*)	(*0.955*)	(*0.916*)
ΔL20–29	–1.498**	–1.546*	–1.314*	–1.235	–1.280	–1.238	–1.309*
	(*0.714*)	(*0.764*)	(*0.763*)	(*0.747*)	(*0.769*)	(*0.752*)	(*0.730*)
ΔL30–39	–1.474*	–1.786	–1.568	–1.374	–1.333	–1.153	–1.111
	(*0.889*)	(*1.097*)	(*1.141*)	(*1.080*)	(*1.056*)	(*0.965*)	(*0.933*)
ΔL40–49 (ref. gr.)							
ΔL50–59	–1.346	–1.688	–1.437	–1.258	–1.101	–0.918	–0.900
	(*0.908*)	(*1.006*)	(*1.033*)	(*0.997*)	(*0.973*)	(*0.900*)	(*0.896*)
ΔL60+	–1.308	–1.632**	–1.303	–1.403*	–1.760**	–1.539**	–1.636**
	(*0.781*)	(*0.763*)	(*0.866*)	(*0.767*)	(*0.800*)	(*1.924*)	(*0.704*)
Δh10–19	–0.043	–0.090					
	(*0.168*)	(*0.064*)					
Δh20–29	0.022		0.241**				
	(*0.414*)		(*0.093*)				
Δh30–39	0.141			0.174*			
	(*0.444*)			(*0.092*)			
Δh40–49	–0.240				–0.006		
	(*0.487*)				(*0.077*)		
Δh50–59	0.137					–0.128**	
	(*0.341*)					(*0.058*)	
Δh60+	–0.097						–0.051
	(*0.138*)						(*0.038*)
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country dummies	No	No	No	No	No	No	No
Observations	185	188	188	197	204	199	199
Countries	26	26	26	26	26	26	26
R²	38.9%	34.8%	35.7%	33.7%	32.0%	34.5%	34.3%

a) Residuals clustered by countries to avoid distortions of standard errors through serial correlation.

***, ** and * denote significance at a 1-percent, 5-percent or 10-percent level, respectively. (Standard errors are in parentheses.)

estimates may be obscured. The additional regressions, each with just one *h*-variable, may therefore serve as robustness checks. Only if results for the *h*s of single age groups are basically the same in both cases, they may be fully trustworthy. Also, because of the smaller number of observations, the models generally perform weaker for OECD countries than they do for the all-countries sample. Besides the finding that the age structure of human capital may generally matter for TFP and TFP growth, this leaves us with a potentially positive effect relating to human capital of workers in their 20s and a potentially negative effect for workers in their 50s. By the definition of h10–19 *etc*., these results are difficult to interpret, certainly with respect to TFP-levels. Yet, they may reflect that relatively high qualifications of younger workers, with those aged 25 usually reaching their final level of educational attainments, point to a current improvement in human capital; that relatively high qualifications of older workers result from a (temporary) decline in educational attainments of new labour-market entrants which has been observed in a number of developing countries, especially among former colonies.

Up to a point, these extensions beyond purely demographic effects are therefore instructive in themselves. In the final analysis, however, they mainly reinforce that there is a strong impact, with a particular age-related shape, of labour-force demographics on TFP, labour productivity and, hence, on economic growth in general, as was already shown in Section 4.1.

5 Illustrative simulations

It has already been stated that, for a given country and a given time period, the current age composition of the labour force is largely pre-determined by fertility decisions that were taken up to six decades ago. Also, demographics exhibit a substantial amount of variation, both over time and across countries, even if one limits attention to the small group of highly developed countries. To illustrate the relevance of the findings in this paper, I will therefore round off the foregoing econometric analyses with a number of simulations that are meant to show how economic development could be influenced by future demographic change in the US, Japan, Germany, the UK, and France. These are the five largest OECD economies in terms of GDP, and expected changes in the structure of the labour force as well as the entire population are rather diverse.

The estimates based on models M 4 and M 7 imply that the age composition of the labour force affects levels of TFP and that changes in this composition lead to deviations from TFP trend growth at a national level, while trend growth as such is basically the same across all countries. Using the results obtained for model M 7b (referring to the OECD sample),[29] I can therefore start the exercise by simulating predicted deviations from trend productivity growth implied in current demographic projections (combined with current age-specific participation rates which are simply held constant) over

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[29] Simulations derived from the all-countries regression would not be altogether different. Only, due to stronger variation in the L-coefficients, the profiles obtained would be even more pronounced than in the OECD variant which is used for Figure 2 and for all subsequent simulation results shown here.

the next four decades.[30] I can then combine the results with aggregate figures for employment and total population implied in the same projections to translate them into predicted deviations from aggregate trend growth and trend growth per capita. The simulations are illustrated in Figure 2, effectively spanning the time period from 1990 to 2050 to see how the predictions derived from the above estimations relate to actual developments over the last fifteen years.

According to these simulations, the five countries considered here are likely to be affected by changes in the age composition of their labour force in a different way. As to predictions for past and current developments, *i.e.*, in the 1990–2005 sub-period, the estimates are able to explain, up to a point, the strong growth in productivity and aggregate output that the US has seen in the 1990s and also the underperformance that Japan was faced with in the same period. In the UK, above-trend growth in the 1990s and a current return to more moderate growth rates could also be derived from the estimates. The model works less good for France and Germany, where it predicts above-trend growth for the periods from 1990–95 and from 1995 onward to the present, respectively. In the case of France, some of this can probably be seen in relatively high growth rates of productivity and aggregate output in the late 1980s, while the German growth performance has been relatively weak during the entire period from 1995 to 2005. A possible interpretation of these observations is that, due to a number of structural problems, *e.g.*, persistent labour-market rigidities, Germany has effectively been forgoing the opportunity of some demographically induced extra-growth which could have taken place over the last decade, when the German baby boomers entered their 40s. Now, that some of these rigidities have been removed, this effect may finally become apparent for a few more years. By contrast, the US may have been able to exploit a similar opportunity during the 1990s, among other things because of their flexible labour markets.[31]

As to projected developments from 2005 onward, any of the growth rates I am looking at in Figure 2 is likely to exhibit much stronger fluctuations in Germany and Japan than it will in France, the UK and the US. Given lower past and current birth rates observed in the two former countries and their consequences for the projected age composition of their labour force, this result is probably not too surprising. Note that, in these simulations, the econometric estimates presented in Section 4 directly lead to the predicted patterns of productivity growth, while results regarding aggregate and per-capita

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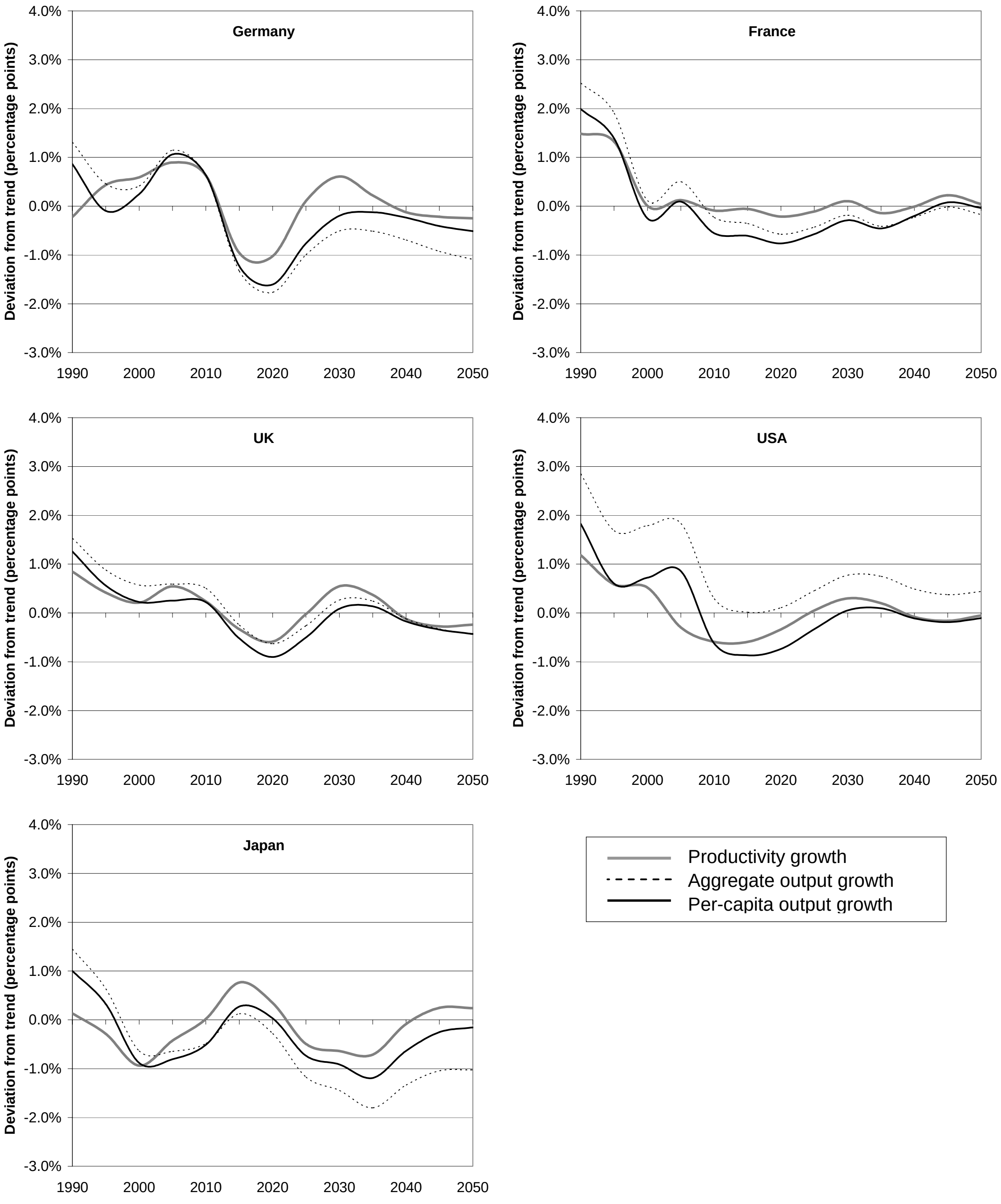
[30] Population data and projections are taken from the 2006 release of the “World Population Prospects” prepared by the UN Population Division (2007, “constant-fertility” variant). Information regarding current activity rates is taken from the ILO (2007) LABORSTA database.

[31] Of course, this reasoning by no means implies that inflexible labour market institutions could also isolate a country against the downward risks for growth performance resulting from changes in the demographic structure which are projected to take place in the future.

Figure 2: The impact of projected demographic change on economic growth (1990–2050) – OECD regression



Sources: UN Population Division (2006; 2007), ILO (2007), author's estimates.

growth are obtained through additional calculations which, in themselves, involve little economics. The core result is that, due to projected changes in the age composition of their labour force, Germany as well as Japan will be faced with continued swings, both up and down, in productivity growth. Developments differ between these two countries because Japan had an early, and rather strong, post-war baby boom and a two-stage decline in birth rates afterwards,[32] while the German baby boom was late and rather weak, followed by a very fast reduction in birth rates. In both cases, the resulting shifts in the demographic structure of the working-age population are becoming smaller over time, but last until around 2040. France, the UK and also the US will have a labour force with a relatively stable age structure, once the cohorts of their baby boomers have retired. The US, with a much stronger and more long-lasting baby boom than elsewhere, will have to deal with substantial swings in the age composition of their labour force over the next ten to fifteen years; thereafter, the effect will fade out. In the UK the baby boom again was smaller and took place later, giving rise to limited swings until around 2030. In France, where after an early and rather strong baby room birth rates never fell very low, there will be virtually no deviations from trend productivity growth caused by demographic shifts from 2005 onwards.

Simulated changes in productivity growth translate into lower rates of aggregate growth wherever the labour force must be expected to decline in the future, *viz.*, in Germany and Japan and, much less so, in France and the UK (see, again, Figure 2). In the US, the predicted demographic impact on aggregate growth rates is positive almost throughout, as there will be a projected increase in the labour force which is large enough to off-set any small, adverse effects for productivity. From an economist’s perspective, changes in aggregate growth that are due to demographic change are clearly less important than changes in the growth rate of per-capita output (see Section 2). It is therefore interesting to note that, in Germany and Japan, future simulated changes in per-capita growth are less pronounced than those in aggregate growth because, in these two countries, even total population is expected to decline in the future, although at a smaller rate than their labour force. Things are different with respect to France, the UK and the US. Mainly due to increasing longevity, total population will roughly stay constant in the former two countries and will even increase at a higher rate than the labour force in the latter. In all three cases, per-capita output must therefore be expected to grow more slowly than aggregate output.

The simulations thus far demonstrate that changes in the age composition of the labour force can have sizable effects for annual growth rates of productivity, aggregate output and output per capita and that these effects may also show some diversity across

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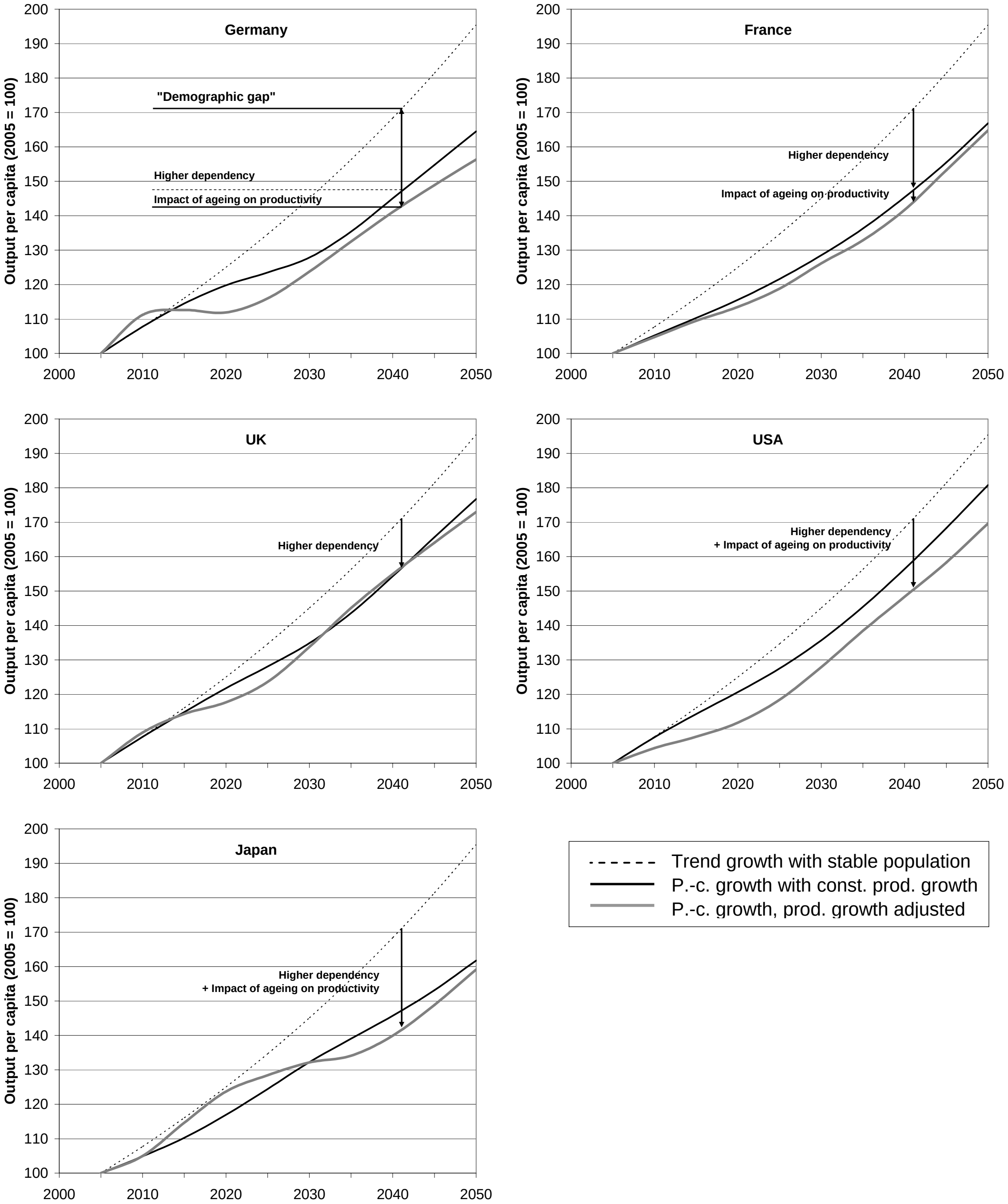
[32] In a sense, Japan has gone through the “first stage” of demographic transition, with a reduction in birth rates to a “replacement level” only in the short period between 1945 and 1955, while the same had happened around the beginning of the 20th century in most other developed countries. As elsewhere, the Japanese birth rate started falling again in the mid-1970s – slower, but eventually to a lower level, than in Germany and, *a fortiori*, in the most other developed countries.

countries. Given that, I can go ahead and also simulate the accumulated effects of projected demographic change on future levels of output per capita in any of the countries considered here. I will do so under the assumption that, abstracting from the impact of demographics, economic growth in all developed countries would be driven by a constant, uniform rate of trend productivity growth. This common rate of global technological progress is set at 1.5 per cent *p.a.* on real terms, which is about the average rate of annual real productivity growth in industrialized countries since 1990 (see OECD 2007). It is then modified for each country using predicted deviations from trend productivity growth as derived from the OECD regression (see Figure 2). Results are shown in Figure 3, illustrating the predicted time paths of output per capita for the period from 2005 to 2050.

If, for each of the countries considered, the year-2005 level of per-capita output is set to 100, the fundamental rate of productivity growth assumed here implies that GDP per capita would largely double until 2050 in the case of a stable population (hence, constant productivity growth). In reality, populations are not expected to be stable in the sense that (*a*) the activity rate, *i.e.*, the share of the labour force in total population, will vary over time, mainly through changes in old-age dependency, and (*b*) the age composition of the labour force will also change, affecting productivity in line with the estimates presented above. Taken together, these two effects potentially create a “demographic gap” in terms of smaller output per capita which is highlighted in Figure 3 for the case of Germany, where this gap is effectively the largest among all countries considered here, closely followed by Japan.

As dependency ratios are projected to increase almost everywhere, per-capita output must be expected to grow at a lower rate than with a stable population structure in all the five countries considered here. This can be seen from the graphs representing future levels of per-capita output based on current population projections, but assuming that productivity growth would remain constant. This effect is weaker in the US than elsewhere, while it is strong in France and, even more so, in Germany and Japan. However, what really makes a difference for the future development of output per capita in all these countries is the direction and size of the productivity effect of projected shifts in the age composition of the labour force. Its impact is again almost negligible in France and the UK, while it is clearly negative in the US until around 2025 – implying a reduction in accumulated per-capita growth that is never made up for during the rest of the time horizon of the simulations. The effect is even more negative, especially between 2010 and 2025, in Germany, followed by a (transitional) recovery of accumulated per-capita growth. In Japan, it turns out to be positive, at least for quite a while, with subsequent changes that move down and up again towards 2050.

Figure 3: The impact of projected demographic change on the level of output per capita (2005–50) – OECD regression



Sources: UN Population Division (2006; 2007), ILO (2007), author's estimates.

In Germany, the total demographic gap could cost more than half of accumulated growth related to a stable population structure until 2020, almost two thirds of this effect being due to the impact of labour-force demographics on productivity. Between

2010 and 2020, the negative impact of shifts in the age composition of the labour force could in fact imply that aggregate output remains largely constant on real terms if one is inclined to take the econometric findings seriously. Over the remaining simulation period, the gap could then become relatively smaller, reducing per-capita output by “only” about 40 percent until 2050, of which 10 percentage points could be attributed to shifts in the age composition of the labour force. In the UK, France, and the US, the total demographic gap amounts to about 20, 25 and 30 percent, respectively, over the entire time horizon.[33] While in the former two countries, changes in the age structure basically play no role for this result, in the US, about 10 percentage points, or two fifths of the total effect, are related to the impact of the age composition of the labour force on productivity. Until about 2020, this latter effect could be rather strong in the US, explaining about two thirds of the reduction in per-capita output as an implication of a very large cohort of baby boomers approaching and entering retirement.

In Japan, the demographic gap could amount to about 35 percent of accumulated growth in output per-capita until 2050. In this case, however, particular trends in the age composition of the labour force, which is relatively old already today, may first have a positive effect on accumulated productivity growth. In terms of per-capita growth, this may over-compensate the unfavourable trend in old-age dependency until around 2030. (Remember that the opposite may have been true for some time in the recent past; see Figure 2.) Only afterwards, the reduction in accumulated productivity growth through demographic shifts may bite, but the divergence between a scenario with constant productivity growth and the one where productivity growth is adjusted in line with the above empirical estimates will again start to reduce the total demographic gap after 2040. Toward the end of the simulation period, the productivity effect may become almost negligible.

6 Conclusions

In this paper, I have taken a closer look at the potential impact of changes in the age composition of the labour force, hence changes in past fertility rates, on the prospects for future economic growth in countries that are affected by demographic ageing. Building on the limited amount of existing literature that attempts to address this issue in an empirical framework, I found an effect that appears to be surprisingly strong, affecting productivity and productivity growth, and therefore goes beyond the simple arithmetic

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[33] Note that in the US, the labour force is projected to grow substantially until 2050, implying that aggregate growth may be higher than with a stable population. In the UK, the number of active individuals is projected to stay roughly constant in the long run, whereas in France it is expected to shrink, although on a much smaller scale than in Germany.

of changes in population size and dependency ratios. More specifically, the age composition of a given country's labour force appears to affect total factor productivity (TFP) and its growth, which are generally observed to be the most important sources of variation in economic performance in the empirical growth literature. The effect thus assumes the features of a phenomenon of (transitory) endogenous growth.

Because of the nature of the multi-country, macro-level evidence brought forth here, one can of course only speculate about the precise nature of the economic mechanisms which drive these results. An interesting aspect is that the age-related profile of contributions to TFP implies that workers in the age group 40–49 are most important for attaining high levels and faster growth of productivity, while the contributions of younger and older workers are considerably smaller. In other words, the particular age profile reflected in Mincerian wage regressions, which is usually taken to reflect productivity differentials related to age or experience, could feed through to TFP through externalities in the invention or, probably even more so, in the adoption and utilization of new technologies. This effect is indeed much stronger than anything that can be observed at the micro level. Closer scrutiny reveals that cohort effects in educational attainments may contribute, to some extent, to shaping this particular age-related pattern. But basically, it does not appear to be driven by the age structure of human capital.

There are a number of other plausible stories which could help explaining this pattern and, hence, might deserve further examination in order to fully understand the results derived here. Essentially, though, they would have to be investigated in a different framework and, more importantly, at another level. For example, the aggregate-level findings in this study could reflect effects of the age composition of work teams which originate at the firm level. The specific education–experience mix, or simply the way in which members of different age groups interact with each other in such teams, could easily matter for their total productivity. There could be other factors, such as entrepreneurship, creativity or simply pragmatism, which give prime-aged individuals a particular weight in determining TFP and TFP growth through the creation of new inventions or their successful exploitation. Starting from intriguing measurement problems, it would certainly not be easy to conceptualize and really investigate these issues. Still, the results derived in this paper may effectively define a research agenda that ought to be tackled when further exploring the economic implications of demographic ageing.

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Appendix

A.1 "Capital dilution" and endogenous saving

As the original Ramsey (1928) model is based on infinitely-lived agents, it is not particularly suited for addressing questions of changes in the size of the labour force or the entire population. (An alternative interpretation by which the model reflects the behaviour of infinitely-lived "family dynasties" with perfect, descending altruism is also based on extreme, rather than standard, assumptions regarding the nature of intergenerational linkages.) Here, I will thus argue against the background of a simple two-period overlapping-generations (OLG) model with three generations (children, working-age population, retirees), in which the saving rate is determined endogenously through individuals who optimize their life-time consumption profile. To keep things as simple as possible, labour supply and fertility of working-age individuals are taken to be exogenous (and child costs are included in the parents' current consumption). The model is thus close to Barro and Sala-i-Martin (1995, Ch. 3, Appendix).

a) Households

In period t, total population N_t is assumed to consist of members of three generations, numbered by the period in which they become economically active:

$$N_t = L_{t-1} + L_t + L_{t+1} \tag{A.1}$$

The number of those who are currently of working age is L_t, with $L_t = (1+n_t)\, L_{t-1}$, *etc*. At the beginning of period t, working-age individuals choose their optimal life-time consumption plan by maximizing a utility function with a constant intertemporal elasticity of substitution. (Also, children are born at the beginning of t, so that parents can take into account changes in $1+n_{t+1}$ against $1+n_t$ when making their decisions.) Their problem is given by

$$\max\ u_t = \frac{c_t^{1-\theta}-1}{1-\theta} + \frac{1}{1+\rho}\,\frac{z_{t+1}^{1-\theta}-1}{1-\theta} \tag{A.2}$$

$$\begin{aligned} \text{s.t.}\quad &(i) \quad c_t = (1-s_t)w_t \\ &(ii) \quad z_{t+1} = (1+r_{t+1})s_t w_t . \end{aligned}$$

In equation (A.2), c_t denotes current consumption and z_{t+1} consumption at old age. To nourish t+1-consumption, individuals save a fraction s_t of their current wage earnings w_t, from which they derive an interest income of $(1+r_{t+1})s_t w_t$ in t+1; they leave no bequests. The elasticity of substitution between c and z is $\sigma = 1/\theta$, governed by the parameter $\theta > 0$; $\rho \geq 0$ is a pure time-preference rate (and may be zero).

Substituting the budget constraints (i) and (ii) into (A.2), differentiating with respect to s_t and solving for the optimal saving rate yields

$$s_t = \frac{1}{1+(1+\rho)^{\frac{1}{\theta}}(1+r_{t+1})^{-\frac{1-\theta}{\theta}}} . \tag{A.3}$$

Here, s_t is a fraction of wages w_t, not an aggregate-level saving rate. Yet, if total wage earnings, $w_t L_t$, are a constant share of aggregate output, a constant s_t translates into a constant aggregate saving rate. (With the Cobb–Douglas production function I am about to introduce, the aggregate saving rate is $(1-\alpha)s_t$.)

b) *Firms*

Firms maximize profits and utilize a standard Cobb–Douglas technology,

$$q_t = f(k_t) = k_t^{\alpha} , \tag{A.4}$$

q_t being output per worker and k_t the capital–labour ratio in period t.

With competitive behaviour on all markets, factor prices are given by

$$w_t = f(k_t) - f'(k_t)k_t = (1-\alpha)k_t^{\alpha}\,, \tag{A.5}$$

$$r_t = f'(k_t) - \delta = \alpha k_t^{\alpha-1} - \delta\,, \tag{A.6}$$

δ being the rate of depreciation.

c) Equilibrium

For simplicity, I assume that $\delta = 1$ over the length of t (as a non-critical assumption with respect to any of the results). The resource constraint of the economy then implies that

$$k_{t+1} = \frac{s_t w_t}{1+n_{t+1}} = \frac{s_t(1-\alpha)}{1+n_{t+1}} k_t^{\alpha}\,. \tag{A.7}$$

Since s_t depends on $1+r_{t+1}$ (see equation A.3), hence on k_{t+1}, the saving rate and the future capital–labour ratio are interdependent. Without any further assumptions, for example, regarding the shape of u_t, it is therefore difficult to characterize the steady state and the transitional dynamics in this economy. (Note, for instance, that if $\theta = 1$, so that the utility function behaves asymptotically as if it were logarithmic, the interdependence vanishes, and s_t is constant as in the Solow model.) Still, existence and uniqueness of the steady state can safely be taken as given for any variant captured by the current degree of specification.

d) Behaviour of the saving rate

Using (A.6) for t+1 and (A.7), equation (A.3) can be re-written as

$$s_t = \frac{1}{1+(1+\rho)^{\frac{1}{\theta}}\left[\alpha\left(\frac{s_t(1-\alpha)k_t^{\alpha}}{1+n_{t+1}}\right)^{\alpha-1}\right]^{-\frac{1-\theta}{\theta}}} = \frac{1}{1+\psi(s_t, 1+n_{t+1})}\,. \tag{A.8}$$

Equation (A.3) is an optimality condition which must hold under whatever circumstances. I can therefore differentiate both sides with respect to $1+n_{t+1}$, defining $s_n = \partial s_t / \partial(1+n_{t+1})$, and solve for s_n. After a number of tedious computations and re-arrangements, I obtain

$$s_n = \frac{1-\theta}{\theta}\frac{(1-\alpha)(1-s_t)}{(1+n_{t+1})\left(1+\frac{1-\theta}{\theta}(1-\alpha)(1-s_t)\right)}, \quad \text{with} \quad s_n \left\{\begin{matrix} > \\ = \\ < \end{matrix}\right\} 0 \ \text{ for } \ \theta \left\{\begin{matrix} < \\ = \\ > \end{matrix}\right\} 1\,. \tag{A.9}$$

It is easy to show that the denominator of the second term on the right-hand side of (A.9) is always positive because $(1-\theta)/\theta$ is strictly larger than –1. Therefore, the sign of s_n depends on the first term on the right-hand side, again $(1-\theta)/\theta$. This term is zero if $\theta = 1$, implying that s_t is a constant and does not respond to changes in $1+n_{t+1}$, as already noted earlier. It now becomes clear that this case separates two widely differing scenarios.

If $\theta > 1$ (*i.e.*, if the intertemporal elasticity of substitution is relatively low and the timing of consumption really matters), individuals will save more in terms of a higher s_t if labour force growth is expected to decelerate in t+1. In other words, through higher savings they will reinforce the inverse capital dilution effect which, in its pure form, results from a constant saving rate. Conversely, if $\theta < 1$ (*i.e.*, if the elasticity of substitution is high and consumption smoothing is less important), individuals will save less, thereby weakening the capital dilution effect. All in all, the intertemporal elasticity of substitution turns out to be crucial for which effect of an increasing capital–labour ratio and the resulting downward pressure on the rate of return will dominate the final outcome: consumption smoothing in the face of a foreseeable reduction in consumption possibilities at old age, or a substitution effect in favour of current consumption because the latter is becoming less “expensive” in terms of future consumption forgone.

A.2 List of countries included in the sample

OECD countries (27):	*Non-OECD countries* (79):		
Australia	Afghanistan	Guatemala	Papua New Guinea
Austria	Algeria	Guinea-Bissau	Paraguay
Belgium	Argentina	Haiti	Peru
Canada	Bahrain	Honduras	Philippines
Denmark	Bangladesh	Hong Kong	Rwanda
Finland	Barbados	India	Senegal
France	Benin	Indonesia	Sierra Leone
Germany	Bolivia	Iran	Singapore
Greece	Botswana	Iraq	South Africa
Hungary	Brazil	Israel	Sri Lanka
Iceland	Burundi	Jamaica	Sudan
Ireland	Chile	Jordan	Swaziland
Italy	China	Kenya	Syria
Japan	Cameroon	Kuwait	Tanzania
Korea, Rep. of	Central African Rep.	Liberia	Thailand
Mexico	Colombia	Lesotho	Togo
Netherlands	Congo, Dem. Rep.	Malawi	Trinidad & Tobago
New Zealand	Congo, Rep. of	Malaysia	Tunisia
Norway	Costa Rica	Mali	Uganda
Poland	Cyprus	Mauritania	United Arab Emirates
Portugal	Dominican Rep.	Mauritius	Uruguay
Spain	Ecuador	Mozambique	Venezuela
Sweden	Egypt	Nicaragua	Yemen
Switzerland	El Salvador	Niger	Zambia
Turkey	Fiji	Nepal	Zimbabwe
United Kingdom	Gambia	Pakistan	
United States	Ghana	Panama	

With data spanning the period from 1960 to 2000 at 5-year intervals, the maximum number of observations for each country is 9. The average number of observations which enter the level-estimates reported in Section 4.1 is 8.1 for the “all countries” sample, 8.6 for the OECD sample. In the growth-estimates that follow, differencing implies a reduction by one observation per country (while countries with just one observation drop out). Here the average number of observations is 7.4 and 7.6, respectively. For several reasons, sample size is further reduced in terms of countries and/or observations in the estimates reported in Section 4.2 and in the appendix.

A.3 Descriptive Statistics

Variables	Mean	Std. dev.	Min.	Max.
Growth accounting:				
q (real GDP per worker, US-$)	17,214	16,786	487	196,173
κ (capital coefficient)	1.3623	0.8195	0.0892	6.2989
$\ln h$ (log measure of hum. cap.)	0.6056	0.3351	0.0141	1.3962
$\ln A$ (log TFP measure)	8.5801	0.7995	5.0615	12.4691
Labour force by age groups:				
L10–19 (share in total L)	0.1535	0.0699	0.0031	0.3063
L20–29 (share in total L)	0.2806	0.0370	0.1780	0.4380
L30–39 (share in total L)	0.2247	0.0343	0.1213	0.4046
L40–49 (share in total L)	0.1674	0.0350	0.1041	0.3010
L50–59 (share in total L)	0.1105	0.0296	0.0596	0.2243
L60plus (share in total L)	0.0633	0.0209	0.0039	0.1583
Human capital by age groups:				
h10–19 (relative to $\ln h$)	1.2691	0.3692	0.1972	3.4578
h20–29 (relative to $\ln h$)	1.2311	0.1870	0.6966	2.2302
h30–39 (relative to $\ln h$)	0.9895	0.1969	0.3649	2.1448
h40–49 (relative to $\ln h$)	0.8237	0.2256	0.0000	1.7753
h50–59 (relative to $\ln h$)	0.7515	0.2646	0.0000	1.8850
h60plus (relative to $\ln h$)	0.7416	0.3923	0.0000	2.7021

Correlation Matrices						
	$\ln A$	$\ln q$	$\ln \kappa$	$\ln h$		
$\ln A$	1.0000					
$\ln q$	0.8376	1.0000				
$\ln \kappa$	0.0336	0.5339	1.0000			
$\ln h$	0.3804	0.7727	0.6296	1.0000		
	$\ln A$	L1019	L2029	L3039	L4049	L5059
$\ln A$	1.0000					
L1019	–0.5381	1.0000				
L2029	0.0644	0.0246	1.0000			
L3039	0.4073	–0.7427	0.1118	1.0000		
L4049	0.4193	–0.8091	–0.4695	0.5744	1.0000	
L5059	0.3228	–0.6403	–0.5953	0.1408	0.7332	1.0000
L60plus	–0.1405	0.0950	–0.3970	–0.5220	–0.1243	0.3195
	$\ln h$	h1019	h2029	h3039	h4049	h5059
$\ln h$	1.0000					
h1019	–0.5920	1.0000				
h2029	–0.3288	0.5438	1.0000			
h3030	0.3359	–0.5816	0.1993	1.0000		
h4049	0.5076	–0.6442	–0.6200	0.4562	1.0000	
5059	0.4363	–0.4899	–0.8128	–0.1815	0.6679	1.0000
h60plus	0.2625	–0.2857	–0.6246	–0.3363	0.2016	0.7360

A.4 The age composition of the labour force and TFP: estimates for "non-oil" samples

	(c)	(d) M 4	(e)	(f)
Sample Estimation method	Non-oil 90% [a)] Robust OLS [b)]	Non-oil 80% [a)] Robust OLS [b)]	Non-oil 75% [a)] Robust OLS [b)]	Non-oil 66,7% [a)] Robust OLS [b)]
Dep. variable:	ln *A*	ln *A*	ln *A*	ln *A*
*L*10–19	–7.688***	–8.062***	–8.465***	–6.987***
	(*1.539*)	(*1.872*)	(*2.086*)	(*1.954*)
*L*20–29	–4.139***	–4.545***	–4.874***	–4.246***
	(*0.977*)	(*1.195*)	(*01.375*)	(*1.586*)
*L*30–39	–2.543**	–2.643**	–2.633*	–2.016
	(*1.163*)	(*1.289*)	(*1.441*)	(*1.766*)
*L*40–49 (ref. group)				
*L*50–59	–3.018*	–2.647	–3.211*	–2.366
	(*1.697*)	(*1.715*)	(*1.787*)	(*2.157*)
*L*60+	–3.242*	–3.770*	–3.744	–3.788
	(*1.911*)	(*2.114*)	(*2.275*)	(*2.416*)
Year dummies	Yes	Yes	Yes	Yes
Country dummies	Yes	Yes	Yes	Yes
Constant	-12.765***	-12.435***	11.776***	10.694***
	(*0.793*)	(*1.046*)	(*1.1147*)	(*1.068*)
Observations	745	602	505	405
Countries	90	73	62	49
R²	88.9%	89.0%	87.8%	88.2%

a) "Non-oil *X*%" means that countries are excluded if, in the 1960–2000 period, the share of fuel exports in total merchandise exports was more than once at or above the X^{th} percentile of the annual global distribution of these shares. Countries for which data on foreign trade are lacking are also omitted.

b) Residuals clustered by countries to avoid distortions of standard errors through serial correlation.

***, ** and * denote significance at a 1-percent, 5-percent or 10-percent level, respectively. (Standard errors are in parentheses.)

A.5 The age composition of the labour force, TFP and TFP growth: estimates for the samples with detailed human-capital data

	(g) M 4	(h)	(c) M 7	(d)
Sample Estimation method	All countries [a] Robust OLS [b]	OECD [a] Robust OLS [b]	All countries [a] Robust OLS [b]	OECD [a] Robust OLS [b]
Dep. variable:	ln *A*	ln *A*	Δ ln *A*	Δ ln *A*
(Δ) *L*10–19	–6.090***	–4.315***	–2.547**	–1.855*
	(*1.971*)	(*1.256*)	(*1.019*)	(*1.045*)
(Δ) *L*20–29	–3.249**	–2.094*	–1.456*	–1.606**
	(*1.276*)	(*1.154*)	(*0.814*)	(*0.750*)
(Δ) *L*30–39	–2.364	–3.205***	–0.984	–1.688
	(*1.696*)	(*1.066*)	(*1.352*)	(*1.028*)
(Δ) *L*40–49 (ref. group)				
(Δ) *L*50–59	–2.223	–2.415*	–2.065	–1.510
	(*1.818*)	(*1.262*)	(*1.557*)	(*1.020*)
(Δ) *L*60+	–3.435	–2.940	–1.134	–1.924***
	(*2.192*)	(*1.767*)	(*1.001*)	(*0.671*)
Year dummies	Yes	Yes	Yes	Yes
Country dummies	Yes	Yes	No	No
Constant	-12.072***	-11.112***		
	(*1.087*)	(*0.749*)		
Observations	815	217	701	185
Countries	103	27	100	26
R^2	87.8%	87.6%	7.4%	34.9%

a) Samples restricted to observations for which data on the age composition of human capital as used in models M 11 and M 12 are available.

b) Residuals clustered by countries to avoid distortions of standard errors through serial correlation.

***, ** and * denote significance at a 1-percent, 5-percent or 10-percent level, respectively. (Standard errors are in parentheses.)

A.6 The age distribution of human capital, TFP and TFP growth: estimates without imputed figures for age-specific human capital

	(a)	(b)	(c)	M 13 (d)	(e)	(f)	(g)
Sample	All countries a)						
Estim. method	Pool. OLS	Robust OLS b)				Pooled OLS	
Dep. variable:	ln A	ln A	ln A	ln A	ln A	ln A	ln A
L10–19	–7.867**	–4.460*	–4.767*	–4.994*	–6.373	–8.482***	–8.452***
	(*3.063*)	(*2.411*)	(*2.671*)	(*2.722*)	(*6.654*)	(*2.849*)	(*2.842*)
L20–29	–2.350	–2.558**	–2.892**	–3.903***	–2.905	–3.589	–3.593
	(*2.861*)	(*1.236*)	(*1.300*)	(*1.334*)	(*1.822*)	(*2.719*)	(*2.709*)
L30–39	–0.831	–1.606	–1.641	–1.893	–1.189	–1.684	–1.608
	(*5.190*)	(*1.568*)	(*1.694*)	(*1.219*)	(*1.687*)	(*4.990*)	(*4.994*)
L40–49 (ref. gr.)							
L50–59	–0.333	–1.201	–1.162	–1.821	1.220	–3.253	–2.993
	(*5.443*)	(*1.861*)	(*1.908*)	(*2.326*)	(*1.990*)	(*4.900*)	(*4.978*)
L60+	–8.428**	–3.459*	–3.520	–1.329	–8.781	–9.605**	–9.598**
	(*4.075*)	(*1.968*)	(*2.184*)	(*2.833*)	(*8.682*)	(*3.951*)	(*3.948*)
h10–19	–0.222	0.167					
	(*0.772*)	(*0.113*)					
h20–29	0.709		0.156				
	(*1.815*)		(*0.153*)				
h30–39	–0.671			–0.132			
	(*2.385*)			(*0.167*)			
h40–49	–1.389				–0.153		
	(*2.040*)				(*0.171*)		
h50–59	1.688					–0.020	
	(*1.335*)					(*0.258*)	
h60+	–0.715						–0.055
	(*0.464*)						(*0.184*)
Year dummies	No	Yes	Yes	Yes	Yes	No	No
Ctry. dummies	No	Yes	Yes	Yes	Yes	No	No
Constant	11.436***	11.149***	11.292***	11.993***	11.387***	11.893***	11.859***
	(*2.918*)	(*1.054*)	(*1.401*)	(*1.424*)	(*2.253*)	(*2.737*)	(*2.727*)
Observations	86	661	660	469	276	91	91
Countries	86	100	100	99	96	91	91
R^2	63.8%	88.9%	88.8%	92.8%	96.3%	60.1%	60.1%

a) Samples restricted to observations for which data on the age composition of human capital are available that have not been imputed based on Step 2 of the procedures explained in footnote 24.

b) Residuals clustered by countries to avoid distortions of standard errors through serial correlation.

***, ** and * denote significance at a 1-percent, 5-percent or 10-percent level, respectively. (Standard errors are in parentheses.)

A.6 (cont'd.) The age distribution of human capital, TFP and TFP growth: estimates without imputed figures for age-specific human capital

	(a)	(b)	(c) M 14	(d)	(e)	(f)
Sample Estimation method	All countries a) Robust OLS b)					
Dep. variable:	$\Delta \ln A$	$\Delta \ln A$	$\Delta \ln A$	$\Delta \ln A$	$\Delta \ln A$	$\Delta \ln A$
ΔL10–19	–3.297	–10.405	–2.972*	–2.882	–3.928*	–10.784
	(*2.037*)	(*6.494*)	(*1.764*)	(*1.871*)	(*2.041*)	(*6.835*)
ΔL20–29	–2.643	–4.373**	–2.382**	–2.410**	–2.961*	–4.688**
	(*1.834*)	(*2.154*)	(*1.037*)	(*0.954*)	(*1.693*)	(*1.988*)
ΔL30–39	0.395	0.595	–0.597	–0.414	–0.098	–0.197
	(*1.130*)	(*1.640*)	(*1.028*)	(*1.020*)	(*1.046*)	(*1.459*)
ΔL40–49 (ref. gr.)						
ΔL50–59	–1.701	0.468	–1.142	–1.387	–1.804	–0.093
	(*2.295*)	(*2.169*)	(*2.053*)	(*2.077*)	(*2.242*)	(*1.931*)
ΔL60+	–0.197	–10.425	–1.203	–0.590	–1.030	–11.598
	(*1.921*)	(*9.200*)	(*1.329*)	(*1.360*)	(*2.039*)	(*7.990*)
Δh10–19	–0.025	0.060	0.051			
	(*0.094*)	(*0.164*)	(*0.072*)			
Δh20–29	0.0389*	0.591		0.338***		
	(*0.198*)	(*0.375*)		(*0.108*)		
Δh30–39	–0.133	–0.188			0.053	
	(*0.186*)	(*0.341*)			(*0.134*)	
Δh40–49		0.036				–0.124
		(*0.209*)				(*0.119*)
Δh50–59						
Δh60+						
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Country dummies	No	No	No	No	No	No
Observations	360	172	556	555	368	180
Countries	96	87	100	99	98	92
R²	14.6%	30.2%	8.5%	10.4%	13.5%	28.0%

a) Samples restricted to observations for which data on the age composition of human capital are available that have not been imputed based on Step 2 of the procedures explained in footnote 24.

b) Residuals clustered by countries to avoid distortions of standard errors through serial correlation.

***, ** and * denote significance at a 1-percent, 5-percent or 10-percent level, respectively. (Standard errors are in parentheses.)