The Relationship Between Demographic Change and Economic Growth in the EU

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EXECUTIVE SUMMARY

Population ageing is expected to put certain strains on social security expenditures such as pension, health and old-age care expenditures. Future economic growth rates in the EU-25 will determine the feasibility of projected age-related expenditures in all Member States. The recent budgetary forecasts of the EU (EPC report 2005) postulate that GDP per capita growth rates decline from a growth rate of 1.9% during the intervals 2004-10 and 2011-20 to a growth rate of 1.4% in 2021-30 and 1.3% in 2031-40. Afterwards, they increase again towards a growth rate of 1.6% in 2041-50.

Economic growth itself will be correlated to the age structure of the population. In this report we present an in-depth analysis on demographic change and economic growth and contrast our findings with the results in the EPC report 2005.

We provide a review of the recent literature that links changes in the demographic structure to economic growth and introduce three new empirical growth regressions for the EU-15 countries over the last decades (1950-2005). We choose one of our empirical estimations to conduct a prospective analysis of the future implications of demographic change on economic growth for the EU-25 countries up to 2050.

While population growth turned out to have no effect on economic growth in growth equations with the growth rate of the total population as the only demographic variable, during the last decades several authors have indicated that demography indeed matters once one considers the age structure of the population, i.e., once one abandons the assumption of a stable and hence constant age distribution. Changes in the age distribution of the population have been marked in the EU countries during the last five decades. The baby boom in the post-WWII period created a demographic dividend (starting in the 1970s) when the baby boom generation entered the labour market with the result that the growth rate of population became slower than the growth rate of the working age population. Indeed, this demographic dividend has recently been denoted as the first demographic dividend since there might exist a second demographic dividend when the population ages. The first demographic dividend can be decomposed into an accounting and a behavioural effect. While the former denotes the difference in the growth rates of the working and total population, the latter focuses on the role of demographic change for the output per worker ratio (often termed the productivity component). Demography may affect the productivity component through its impact on savings, investments, human capital formation, technological change, etc. As fertility will continue to decline, a demographic burden can be foreseen when the growth rate of the working-age population will fall short of that of the total population. However, as argued by Mason (2005) this demographic burden may result in a second demographic dividend. The second demographic dividend denotes the increase in the wealth-to-output ratio that may result as a consequence of increased savings as a response to the prospective of higher life expectancy and lack of labour income in retirement.

An important distinction in recent economic growth regressions that test for demographic effects is the distinction between the productivity component (output per worker) and the accounting effect (the difference in the growth rate of workers and the total population). For the EU-25 we have found the following patterns for the accounting effect: Among western European countries we find the peak of the positive accounting effect during the 1980s, while the accounting effect will turn negative during the 2030s. A similar but more volatile pattern can be found for the Nordic countries where the baby boom took place during different time spans. For southern European countries we find a similar but much less pronounced pattern than recorded for the western European countries. The ten new EU Member States in central and eastern Europe have not experienced the baby boom and hence did not profit from any positive accounting effect as the EU-15 countries did. Up through 2010 the accounting effect is rather erratic and for some countries negative most of the time. Starting in 2010 most of the new EU-10 countries will experience a positive accounting effect.

To test whether demographic structure also plays a role for output per worker (in addition to the accounting effect) economic growth regressions that include demographic variables as important explanatory factors have been tested. Most of the literature applies the framework of the convergence model where the growth rate of output per worker is modelled to be proportional to the gap between the logarithm of the current and the long-run level of output per worker. The growth rate is assumed to be constant, while the steady-state equilibrium of output per worker is modelled to be country- and time-specific and to depend on country-specific characteristics. A review of recent studies on the empirics of demography and economic growth implies that although the setup of the models (with respect to the choice of explanatory variables and time periods) and the methods of estimation (cross-country vs. panel regressions) differ, the results of the various studies are generally compatible. An important finding is the fact that the growth rate of the working-age population has a positive effect on the growth rate of output per worker, i.e., the growth rate of the working-age population not only determines the accounting effect but also influences the behavioural component (the productivity term). Among the various demographic variables introduced, the youth dependency ratio turned out to be significantly negative in most of the studies reviewed. Evaluating the role of demography, Kelley and Schmidt (2005) find that for Europe the accounting effect was exhausted in the 1970s while the decline in the youth dependency ratio had a strong positive effect for the growth rate of output per worker during the 1970s and 1980s. Among the other explanatory variables included, Kelley and Schmidt found that human capital (as measured by life expectancy and education) was strongly growth-inducing over periods and regions while financial and political components had more ambiguous impacts. Similar findings as in Kelley and Schmidt have been obtained by other authors as well. E.g., Bloom and Williamson (1998) found that population dynamics explain almost 20 per cent of the growth observed in Europe over the time period 1965-1990. Kelley and Schmidt arrive at similar estimates since they note that core demographic variables account for 24% of the variability in the growth rate of output per capita for Europe over the time span 1960-1995. Bloom and Williamson (1998) propose two distinct channels through which demography may influence growth: through the labour force and through savings and investment. In Bloom and Canning (2001a) a third channel through which demography may affect economic growth is added: educational enrolment and human capital. Moreover they find a significant interaction between demographic variables and policies. Good policies lead to higher growth and the impact of demographic change is greater when institutions are of higher quality. Similarly, Bloom, Canning and Sevilla (2003b) stress that open economies, a flexible labour force and modern institutions assure that a country can actually reap the demographic dividend.

While most of the studies either use the growth rate of the dependent or working-age population or dependency ratios as core demographic variables influencing economic growth rates, recent papers (e.g., Feyrer 2004) take the internal demographic composition of the workforce into account. The findings of these studies indicate that the share of workers aged 40 to 49 is associated with higher output. As a review of the various empirical studies indicates, the growth rate of the working-age population is in general one of the most robust demographic variables that is positively and significantly linked to output-per-worker growth in most of the studies. Combined with the fact that the growth rate of the working-age population also positively affects the accounting effect, the overall demographic role of the working-age population for economic growth is even higher. A similar consistent finding can be verified for the youth dependency ratio. If added as an additional demographic regressor, it turned out to be significant and negatively related to economic growth in most of the studies. The overall conclusion from this review is that independent of the method applied and of the set of additional control variables considered, the important role of the growth rate of the working-age population and the youth dependency ratio is robust. Many authors have noted the importance of the policy and social environment aspect and its interaction with demographic changes as an important determinant of long-run economic growth.

The focus of this report is on three new empirical studies that model economic growth in the EU and its relation to changes in the demographic structure for the past six decades. These three empirical exercises are intended to provide us with a deeper understanding of the effects of demographic factors on growth, as well as the nature of the interaction between demography and development. With this purpose, we carried out different empirical studies to highlight selected channels for the effect of demography on growth.

We started out to replicate a previous study of economic growth (GDP/working age population) and demographic structure (that was based on OECD data and limited to the period 1950-1990, Lindh and Malmberg 1999) for the EU-15 and a longer available time series: 1950-2005. The empirical approach is based on a human capital augmented Solow model. Other than in the framework of Mankiw, Romer and Weil (1992) we assume that technology is different across countries and we postulate a convergence of technology to an exogenous world technology. In sum, our results are similar to the previous findings for the OECD and the shorter time period. By applying a more detailed age structure we find that it is again the 50-64 age group that positively contributes to economic growth while both a large old-age population and a large young population affect economic growth negatively. As we argue in the report, these results imply that changing proportions of different age groups in the workforce require changes in labour market institutions and policies in order to take advantage of different types of growth opportunities. But not only the composition of the labour supply will change. The change in the composition of demand and supply of capital as the age structure changes will have an impact on economic growth as well. Most importantly it needs to be kept in mind that the exact nature of the various mechanisms proposed behind these correlations needs to be studied with micro data.

We next tested whether demographic variables such as proportions in different age groups and their change in time are robust determinants of long-run economic growth in the EU-15 by taking into account the variation in parameter estimates depending on the set of variables which is controlled for in the regressions. Through the robustness analysis we identified the key demographic variables that were related to economic growth during the period 1960-1990. Our results based on the empirical distribution of estimates indicate a robust positive partial correlation between the initial proportion of the workforce in the 30-49 age group and economic growth in the 30-year period thereafter and a robust negative partial correlation for the case of the proportion of the workforce in the 15-29 age group. These results are coupled with robust partial correlations with opposite signs of their respective changes in the period. Compared to our first study, it is now the middle 30-49 age group and not the 50-64 age group that is significantly positively linked to economic growth. This, however, implies that in the middle of the period (15 years later) the 45-64 age group represents the initial 30-49 age group. The results for the young age group are similar. Thus the results are actually completely compatible with the first study. However, as previously shown by Lindh and Malmberg (2004) and several other authors, the hump-shaped pattern of the age structure effects does shift to the right as life expectancy increases. Since increases in life expectancy are to be expected with certainty in the future, we opted to take our results from the first study as the baseline for the forecasts we present in Section 4 of this report.

While our first two studies indicate differential effects of various age groups on economic growth, in our third empirical rendering of economic growth and demography we investigated the nature of such effects by empirically analysing the influence of age structure on technology adoption (and, subsequently, on GDP per capita growth) in the EU for a panel setting from 1950 to 2005. Our estimates are based on the convergence model and we additionally assume that the distance to the technological frontier determines the speed of technology adoption. We then test whether the age structure of the economy can have an effect on the adoption parameter. We find that economies with a relatively low proportion of the workforce in the youngest age group (15-29) present insignificant absorption rates, as opposed to economies above the threshold, which tend to catch up with the technological frontier. For the other age groups (that are of course closely correlated with the youngest age group) we find that countries in the lower regime of the 30-49 and the 50-64 age groups have positive and significant absorption parameters. As we argue in this report, these age effects may support our hypothesis that for convergence it is highly educated youngsters who drive the absorption process while mature adults drive the mature productivity process. Though we cannot identify the validity of our hypothesis, the age-growth relations we uncover at least do not refute this young-old complementarity that also may be present in the labour market due to their different skill profiles.

Inclusion of further demographic variables did not appear significant as linear regressors. This can be interpreted as an indication that the effect of age structure on growth takes place through its interaction with the relative level of development of the country, and thus could be understood as an effect whose channel to growth is technology absorption.

In the final part of this report we apply our first econometric setup to forecast economic growth rates for EU-25 assuming population forecasts as provided by EUROSTAT. For all countries we find that the long-term trend in the growth rates is downward, caused by the negative effect of an increasing share of the old age population. However, the time pattern of this decline differs between regions. Applying the baseline scenario of the population projections by EUROSTAT, the general trend is that most countries in the EU-15 can expect to end up with a growth rate around or below 1% per year, whereas the new Member States can expect a somewhat faster growth, between 1.5% and 2.0% per year. Applying alternative population projections yields almost no effect on projected income growth rates for the high-fertility scenario since it is only after 2050 that the bigger birth cohorts will enter into the 50-64 age group and have a strong positive effect on per worker GDP growth. An increase in the life expectancy by increasing the share of the 65+ age group will have a negative effect on income growth rates. However, all these results are to be understood as ceteris paribus results where it is assumed that increased life expectancy has no effect on the economic behaviour of individuals. A comparison of the baseline and the no-migration scenario indicates that the zero migration scenario has a relatively strong negative effect on per-capita income growth for countries that today have a positive net migration. While economic forecasts are not very sensitive to different demographic assumptions when we consider per capita GDP growth rates, differences between the population scenarios become more substantial when we consider total GDP growth rates.

A comparison of our projections with the EUROSTAT productivity forecasts (EPC 2005) indicates that our results exhibit more heterogeneity among countries and more fluctuations during the projection period. Moreover, our projections with respect to the annual growth rates are in general slightly more optimistic—in particular with respect to the next two decades—than the EU projections and exhibit more pronounced fluctuations.

Summing up, our report supports the argument that demographic factors matter for economic growth just as much or sometimes even more than the factors commonly stressed in the growth literature, such as technological change, innovation and political/institutional explanations. At the very least this indicates that any economic growth study which does not control for heterogeneity in population structure is very likely to suffer from omitted variables bias. Most importantly, through a series of sensitivity tests we found that demographic effects turned out to be extremely robust, independent of the economic variables included and the specific method (cross-country vs. panel data regressions) applied. We found a significant hump shaped pattern for the workforce age structure on economic growth. Demographic variables are better measured and defined and suffering from less endogeneity problems (except possibly the younger age groups) than most other variables commonly included in growth regressions. Combining our econometric estimates with the recent EUROSTAT population projections, we may conclude that it will be hard to avoid a decline in GDP growth rates in the EU and that this decline will be more severe in demographic scenarios that imply slow or even negative rates of workforce growth. It needs to be said that our forecasts only offer a possible alternative scenario to be compared with the recent EPC (2005) productivity forecasts. However, it seems to be rather promising that even within such a simple stylised econometric model that mainly relies on the projections of the future age structure, we arrive at a rather convincing productivity forecast not fundamentally different from the EPC (2005) productivity estimates. One could argue that the assumption of convergence in productivity forecasts inherent in the EPC (2005) forecasts might be too strong, at least for the next two to three decades since it ignores the demographic diversity across the EU-25 that may be important for the demographic dividend still to be reaped by many of these countries. Our results also imply that many of the economic processes over the next five decades might be closely correlated to the demographic structure and hence can be captured by forecasts of the age structure. One should note that the demographic projections themselves are rather shaky over such long horizons though. It also needs to be kept in mind that macro-level econometric studies as presented in this report are not adequate to identify the mechanisms and causality that operates between the link of economic and demographic factors (although our results in the third empirical study partly offer such an explanation where we have shown that the absorptive capacity is related to the age structure). The next steps in the research agenda are clearly in-depth micro studies on economic-demographic interactions.

1 INTRODUCTION

During recent years there has been an increasing awareness of a direct influence of population age structure on the macro economy. The theoretical foundations of the reduced form models applied in econometric studies are: (1) the life cycle model of savings and investment and (2) age-specific variations in labour productivity. Because people's economic behaviour and needs vary at different stages of life, changes in a country's age structure can have significant effects on its economic performance. While young people require investment in health and education, prime-age adults supply labour and savings, and the elderly require health care and retirement income.

Recently, several authors argue that a falling youth dependency ratio (the population below working age divided by the population of working age) contributed to the economic growth miracle in East Asia. More general, recent evidence suggests that falling youth dependency ratios in developing countries can create an opportunity for economic growth assuming that policies to take advantage of the "demographic dividend" (openness to trade, labour-market flexibility, etc.) are in place. As argued by David Bloom and his colleagues "… the combined effect of this large working-age population and health, family, labour, financial, and human capital policies can effect virtuous cycles of wealth creation". On the other hand, if a large share of the population is constituted by elderly persons (as projected for Europe during the next decades), the effects may be similar to those of a very young population. In this case a large share of the population depends on the output produced by a shrinking productive working-age population and might constitute a "demographic burden".

Significant age structure effects have been found for economic growth, inflation and savings in OECD countries for the second half of the 20th century as well. The implications of this evidence have not yet been discussed widely. A few studies present evidence that statistical models of inflation and GDP growth explained mainly by the share of five-year age groups perform well in out-of-sample forecasting on a horizon of 3-5 years ahead during the 1990s. A different methodology applied in the literature is to use the estimated coefficients on demographic variables—as estimated by pooled time series and cross-county regression of economic growth—to assess the future contribution of demographic change on economic growth. Various authors have found that "population dynamics can explain between 1.37 and 1.87 percentage points of growth in GDP per capita in East Asia". On the other hand they also found that "in East Asia, the growth in GDP per capita attributable to demographic influences is projected to be negative between 1990 and 2025, … a loss of 0.14 to 0.44 percentage point up to 2025". On the other hand, countries in South Asia are projected to gain from their demographic changes in the future. A similar study at EU level has not yet been performed.

It needs to be said that age structure is only one of a set of relevant factors that determine economic growth and this is equally relevant for the EU where the role of R&D and human capital formation are particularly relevant. As recently argued in a series of papers, the planned increase of R&D spending to 3% of GDP by 2010 will most likely not be sufficient to reach the US productivity level by 2010. R&D expenditures need to go hand in hand with other measures such as human capital development to increase the absorptive capacity of a country, i.e., the ability to absorb and take advantage of technologies initially developed abroad and to facilitate international technological spillover. Demographic changes will intervene with these other forces of growth and in particular the foreseen ageing of the European population requires intensified and longer utilisation of existing human capital.

The challenge to estimate the role of demographic structure and dynamics on economic growth in the second half of the 20th century is the divergence of demographic patterns across Europe (e.g., patterns of fertility in eastern Europe have historically been very different from the West). On the other hand, the baby boom and its subsequent baby bust constitute a unique variance in the age structure over the last five decades that will help to identify the role of demography for economic growth. The prospective analysis will be more difficult since the foreseeable ageing of the European population is unique in history and one may not directly apply the effects of demographic variables found for the 1950-2000 period to forecast economic growth over the first half of the 21st century.

In this study we offer a comprehensive review of empirical evidence that relates demographic structure to economic growth (Section 2). We first discuss key developments of the demographic structure and introduce the concepts of the demographic dividend and demographic burden (Section 2.2). After a brief review of the correlation between savings, economic growth and demographic change (Section 2.3) we introduce an organising and modelling framework of linking demographic structure to economic growth (Sections 2.4 and 2.5). In the section on empirical rendering of demography and growth (2.6) we review several of the recent studies that have estimated the link between demographic change and economic growth. We conclude Section 2 by briefly summarising the various specifications of age structure used in the literature.

The focus of the current report is Section 3 where we introduce three new empirical studies that model economic growth in the EU and its relation to changes in the demographic structure for the past six decades. The three empirical exercises in Section 3 are meant to provide a deeper understanding of the effects of demographic factors on growth, as well as the nature of the interaction between demography and development. In this sense, we will carry out different empirical studies which highlight selected channels of the effect of demography on growth.

Our empirical approach in section 3.1 is based on a human capital augmented Solow model. We derive an expression of transitional growth rates conditioned on the demographic structure, initial income and a set of independent variables that will control for social infrastructure including quality of institutions, trade, investment, R&D, human capital, etc. Because of feedback effects from the level of output per working person, many of the independent variables we consider might be endogenous. We will therefore propose various instrumental variables to avoid biases in our regression estimates.

In Section 3.2 we test whether the results on the demographic structure are sensitive to the inclusion of various explanatory variables used in other recent studies on cross-country growth. Several approaches can be used to test the robustness of the various explanatory variables to changes in the set of controls used in the growth regression. The literature on measuring the robustness of growth determinants tends to rely on extreme bound analysis, or other techniques based on this methodology. The rationale to this approach is to obtain the estimates of the parameter attached to a given explanatory variable for all possible combinations of other potential controls available. A level of robustness for the variable under study can then be obtained by evaluating the full distribution of all these estimates. Several refinements of this methodology, including the use of Bayesian techniques (Bayesian averaging of classical estimates, BACE) and nonlinear regression models with threshold effects have recently been developed . We will implement a robustness exercise in our piece of research in order to evaluate the robustness of demographic variables growth determinants in Europe for the period under study. Through the robustness analysis we will identify the key demographic variables related to economic growth during the second half of the 20th century.

In Section 3.3 we analyse empirically the influence of age structure on technology adoption (and, subsequently, on GDP per capita growth). We hypothesise that the age structure of the economy can have an effect on the technology adoption parameter. This hypothesis will be empirically tested making use of recent developments in the econometric literature of threshold estimation.

We select the model of Section 3.1. to estimate the implications of demographic change on the future development of economic growth for the next five decades (Section 4.1). While the growth regressions for the past are based on the EU-15 countries, the prospective analysis is conducted for the EU-25. In particular we investigate the sensitivity of the results with respect to alternative population forecasts as given by EUROSTAT. In Section 4.2 of the report we compare our forecasts of economic growth to the assumptions underlying the recent projections of age-related expenditures by the European Commission.

We conclude our report by reviewing and discussing the key findings of our study.

2 DEMOGRAPHIC STRUCTURE AND ECONOMIC GROWTH: THEORY AND EVIDENCE

The current section of the report will focus on reviewing existing research that has investigated the relation between age structure and economic growth. Sections 2.1, 2.4 and 2.5 are based on Kelley and Schmidt (2005).

2.1 Introduction

According to the neoclassical growth model (Solow 1956) population growth reduces economic growth due to capital dilution. However, various studies using cross-country data found an insignificant effect of population growth on economic growth for the 1960s and 1970s. In the 1990s Barro (1991, 1997) introduced a set of demographic variables into "convergence" models of economic growth (cf. Section 2.5 below). In general, fertility, population growth and mortality turned out to be negatively, and population size and density to be positively, related to per capita output growth. In the late 1990s several authors confirmed that population growth has no effect on economic growth in growth equations with the growth rate of the total population as the only demographic variable. However, they show that demography matters for economic growth, once one considers changes in age structure, that is, once one drops the implicit assumption of a constant age composition of the population. The theoretical foundation of these models can be found in the (a) life cycle model of savings and investment and (b) age-specific variations in labour productivity. More specifically, these authors regress the growth rate of GDP per capita on the growth rate of the working age population and the growth rate of the total population (and various other control variables). The results show a positive and significant effect on the growth of GDP per capita due to the growth of the working age population, and an opposite, negative and significant effect from the growth rate of the total population. As argued in Kelley and Schmidt (2005, p. 277) "What has changed with the evolution of modeling in the 1990s is a clearer interpretation of the channels and sizes of demographic changes on the economy."

Before we continue to introduce the modelling framework (Sections 2.3 through 2.7) we briefly review the empirical evidence of the change in demographic structure and its possible link to economic growth. As discussed in Feyrer (2004), demographic variables offer a great opportunity for empirical growth estimation since they are (a) strongly predetermined (the current age structure of the active population was determined roughly twenty years ago and should be predetermined w.r.t. current output movements) and (b) they display an important time series variation (e.g., the baby boom that had a strong repercussion on the age structure of the active population). The time series variation allows to exploit the panel nature of the data. In the empirical growth literature many of the time-varying variables like investment, schooling, etc. are endogenous while exogenous variables, such as geographic ones, lack the time series variation.

2.2 Demographic Transition and the First and Second Demographic Gift/Dividend

Ever since World War II, developing countries have been undergoing a demographic transition at varying rates and times (Lee 2003). During the standard demographic transition scenario, infant mortality declines and fertility falls with a lag only after the mortality decline has begun. As a consequence, a demographic transition leads first to a demographic ”burden” because population growth is faster than the growth of the working age population. Later, as fertility declines, the demographic transition leads to a demographic “dividend” because the growth of the working age population is faster than the growth of the total population (cf. Bloom et al. 2003b). In addition, as argued in Mason (2005) the working age population increases also due to lower mortality. However, once the mortality further declines at higher ages and fertility stays at low levels, the demographic dividend turns into a demographic burden again as the retired population increases.

Similar to developing countries, the demographic dividend could be observed in the time since World War II in industrialised countries as well when they underwent first a baby boom which was followed by a baby bust and continued low fertility (with the latter phenomena often referred to as the second demographic transition) at varying rates and time points. As a consequence, the demographic change first led to a demographic ”dividend” when the baby boom generation entered the labour market because population growth was slower than the growth of the working age population. In the coming decades, the fertility decline that set in will lead to a demographic “burden” because the growth of the working age population will fall short of that of the total population.

The demographic “dividend” leads to opportunities for growth of output per capita for two reasons. First, there is an *accounting effect* because a rising ratio of the working age population to the total population increases the ratio of “producers” to “consumers”. Obviously this contributes positively to the growth of output per capita. Second, there might also exist “behavioural effects” on the growth of output per capita. As Bloom and Williamson (1998) stress, a rising growth rate of the working age population leads, on the one hand, to capital dilution, that is, a reduction of the ratio of capital to the working age population. On the other hand, a rising ratio of the working age population to the total population implies a decrease in the dependency ratio. Bloom et al. (2003a), using aggregate data of developing and developed countries, show that a falling dependency ratio increases aggregate savings (see, among others. Kelley and Schmidt 1996). As argued in Mason (2005) further mortality decline at retirement age reduces the first demographic dividend.

By comparing cross-sectional age profiles of production and consumption in the USA in 2000, Mason (2005) identifies the population aged 24 to 57 to contribute positively to the first demographic dividend. To estimate the magnitude of the first dividend, Mason (2005) computes time series of the support ratio (which gives the ratio of effective workers per effective consumers[1]). The growth of this ratio for the five-year period [t,t+5) is interpreted as the dividend. While the support ratio exceeded 1.1 in the USA in 1950 it was below 0.9 in Mexico. Therefore, the USA had a clear advantage which is expected to remain until 2015. In both countries this ratio declined during the 1950s and 1960s as a result of relatively high fertility. Fertility decline caused an increase of the support ratio beginning in the USA in 1970 and in Mexico in 1975. In the USA this increase lasted until 2000 and in Mexico it is expected to persist until 2025. Comparing the total increase of 12.7 per cent over a 30-year period in the USA with an increase of 46.4 per cent during a 50-year period in Mexico reveals that Mexico gained much more from the first demographic dividend—albeit starting from a significantly lower level with respect to the support ratio.

Comparing world regions, Mason (2005) finds that the dividend period started in the industrial countries in 1970 followed by Latin America, the Pacific Islands (around 1975), the Middle East and North Africa, East and Southeast Asia, the transitional economies (around 1980), South Asia (around 1985), and sub-Saharan Africa (just before 2000). The duration of the dividend period ranges from 30 years in the industrial countries to 60 years in South Asia. Comparing individual countries with respect to duration and magnitude of the dividend reveals a positive correlation between duration and magnitude for countries with a dividend period lasting less than 40 years. Despite the comprehensive comparison of dividends, i.e., increases of support ratios, among countries and regions Mason (2005) conceals throughout most of the paper that it is not only the increase but also the absolute level of the support ratio that matters. Although the first demographic dividend may last for several decades, it is temporary in its nature since the increase of the working age population due to demographic transition cannot be sustained.

When the first demographic dividend turns negative due to an increase in the retired population, the second demographic dividend comes into play. Its magnitude depends on the foresight of consumers and policymakers, therefore it is highly policy-dependent. Ageing populations face a substantially reduced labour income. Since individuals are aware of increases in life expectancy they adapt their savings behaviour and accumulate wealth to compensate for the lack of labour income during their retirement—in particular but not only in countries which do not provide a pay-as-you-go pension system. Investing these savings in the domestic economy results in

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[1] Effective means that the definition of the support ratio allows for weighting the number of workers and consumers by their age-specific labour force participation rates, earning capacities, and consumption needs, respectively.

capital deepening and accelerated growth in output per worker. Foreign investments, on the other hand, increase the current account and national income. Both types of investment result in more rapid growth of income per capita.

Calculating the magnitude of the second demographic dividend is more difficult than for the first dividend partially because it is a forward-looking factor. Capital accumulation typically takes place during the late working age when peak earnings coincide with completed childrearing responsibilities. Thus, Mason takes the ratio of the wealth of the age group 50 and older to total labour income as an input to estimate the second dividend. Comparing world regions reveals that the wealth to output ratios varied between 0.4 for the Pacific Islands and 2.2 for the industrial countries. The wealth ratios exhibit a pronounced increase from 1950 to 2000 for all regions except sub-Saharan Africa. While between 1950 and 1975 the most rapid annual growth occurred in the industrial countries (1.1 per cent), from 1975 to 2000 East and Southeast Asia (2.8 per cent), the Pacific Islands (2.6 per cent), Latin America (2.1 per cent), the Middle East and North Africa as well as East and Southeast Asia (both 1.7 per cent) and even the transitional countries (1.4 per cent) clearly surpassed the industrial countries which also exhibited an increased growth of 1.3 per cent.

Mason considers a Cobb-Douglas production function with capital and effective labour being the only production factors. Moreover, the elasticity of output with respect to capital is assumed to be one third. Consequently, an increase in the growth rate of wealth to labour income of one per cent results in an increase in growth of income per effective consumer of 0.5 per cent. Thus, the elasticity of labour income with respect to capital is 0.5. With this elasticity and the ratio of the wealth of the age group 50 and older to total labour income (see previous paragraph), Mason estimates the second demographic dividend. Comparing the first and second demographic dividend with the actual growth in gross domestic product per effective consumer for the period from 1970 to 2000 reveals that only in three regions of the world—the industrial countries, East and Southeast Asia, and South Asia—the countries succeeded in achieving a rate of economic growth exceeding the sum of the first and second demographic dividend. The other world regions failed to exploit the growth potential provided by demography and savings behaviour. The second dividend depends on how the accumulation of capital is related to population ageing. In contrast to the first demographic dividend the second demographic dividend can be sustained and it is usually about twice as high in magnitude.

2.3 Savings, Economic Growth and Demographic Change (Mason 1988)

In Section 2.6 we will review empirical studies and their theoretical foundation that link demographic change and economic growth. In this section we briefly analyse one of the most commonly applied arguments: the correlation between savings, economic growth and demographic change (Mason 1988).

While in most of the industrialised world nowadays the main concern with respect to population dynamics and economic growth is focused on the impact of a shrinking and ageing population, Mason (1988) discusses the economic consequences of the developing countries' growing population. A rapidly growing population requires increasing investment to maintain the labour to capital ratio and, thus, labour productivity. Besides this simple relationship between population growth, savings, and economic growth, the accumulation of human capital, institutional and restructuring problems also play an important role. Some researchers even put into question whether investment is determined by national savings. Mason (1988) investigates (1) How important is a high rate of savings to rapid economic growth? and (2) Does a rapid population growth impede efforts to raise the rate of savings?

There is empirical evidence supporting that domestic saving is the major source of investment (Mason 1988). A cross-country comparison reveals a correlation between the gross domestic saving ratio and the gross domestic investment ratio of 0.74 and the slope of the corresponding regression line is 0.63, i.e., a one per cent increase in saving results in an increase of investment by 0.63 percentage points.

However, the neoclassical growth model (Solow 1956) suggests that saving has no influence on the long-run growth of total and per capita output because capital deepening not only increases the capital to labour ratio but also requires an increased share of output to replace and maintain existing capital. Thus, depreciation of capital may eventually exceed net investments. A growing labour force may aggravate this process since more workers need to be equipped with capital. Within the neoclassical framework, an increase in investment temporarily enhances the rate of growth of output and persistently increases the level of output per worker. Mason (1988) calibrated a simple neoclassical growth model to capture the development in the United States from 1950 to 1975 and in Japan from 1885 to 1940. With that simulation he addressed the question of the impact of changes in the investment rates on output per worker. The model does not capture human capital, prices, structural change, and foreign trade. The simulation results reveal short-term deviations from the actually observed levels in output per worker but the simulation is consistent with the long-run trends. Despite the good fit of the model, Mason concludes that the model may not be appropriate for most developing countries which do not have mostly inward looking-economies like the US and Japan during the period under consideration.

Net investment, gross investment minus investment devoted for replacing depreciated assets, determines the actual increase in a country's real wealth. However, for most countries reliable data on net investment are not available. This holds especially for time series data. As a consequence, many empirical studies employ gross investment to indicate the resources available for enlarging a country's physical plant. For some countries, net national saving can be decomposed into government saving and private saving, and private saving can be further decomposed into corporate and household saving. This decomposition is relevant since the impact of demographic factors on these three components of savings differs.

Tobin (1967) and Leff (1969) investigate the impact of population growth on aggregate savings. Both studies are based on the life cycle savings model, which connects savings and demographic factors and incorporates effects on the household level and on the aggregate level as well. Within this framework there is no match between current income and desired expenditures since consumption and earnings are assumed to vary in different ways over the life cycle. Life cycle savings allow households to shift income between time periods to adapt to the path of desired expenditures. In periods when earnings exceed desired expenditures households will save and vice versa. Consequently, savings will be highest in the middle of a person's life when saving for retirement takes place. Aggregate savings, being among the major sources of investment, depends on savings of currently working households and the dissaving of currently retired households. According to life cycle savings, decreasing fertility influences savings for two reasons. A reduced burden of childrearing leads to less consumption and an increase of savings at the household level. This is called the dependency effect. On the other hand, reduced fertility causes population ageing and, in turn, the relative number of older households increases. Since older households on average have a lower rate of saving, this again reduces savings. A growing population, on the other hand, means that the young and saving households outnumber the old and dissaving households. Consequently, a growing population leads to an increase in aggregate savings. Therefore, this second effect is called the rate of growth effect. While the dependency effect implies a negative relation between rapid population growth and savings, the growth effect implies a positive relation.

Not all saving that takes place is actually due to life cycle saving. Households also conduct estate savings which is saving for the purpose of a permanent increase in wealth. Estate savings always result in increased aggregate saving which is not the case for life cycle savings. If a fertility decline stimulates households to allocate a higher share of their income to estate savings, then aggregate savings will increase. Within the life cycle savings framework a decline in the number of children will increase savings according to the growth rate of aggregate income. Moreover, a lower rate of population growth results in a lower number of households engaged in life cycle savings relative to the number of households engaged in life cycle dissavings.

The dependency effect and the rate of growth effect are both based upon the life cycle hypothesis which is fundamentally a microeconomic theory. On the macro level, changes in the age structure affect savings because an increase of younger age groups, for instance, increases consumption relative to production and vice versa. There are three competing hypotheses which try to explain the impact of additional children on aggregate savings:

Redistribution effect: Changes in the composition of a household result in a redistribution of consumption among household members, leaving both the total consumption and the rate of consumption unaffected.

Level effect: An increase of the number of household members causes an increase only in the level of household consumption.

Intertemporal substitution or Timing effect: An increase of the number of household members results in intertemporal substitution, i.e., a currently increased level of consumption is compensated by reduced consumption during other periods of time.

According to the redistribution hypothesis, there is no influence of childbearing on aggregate savings. The level hypothesis implies that a decline in childbearing results in an increase in aggregate savings. Finally, the timing effect states that lower fertility reduces current consumption and increases savings to pay for future consumption. The timing effect corresponds with the life cycle model.

2.4 An Organising Framework

The recent development accounting literature (Hall and Jones 1999) has stressed that only workers can contribute to production and therefore an understanding of differences in output per worker is more important than an understanding of differences in output per capita. Therefore, an understanding of the role of demographic structure on economic growth requires to concentrate on output per worker. This approach has been followed in recent papers. Starting from the identity Y/N = (Y/L)(L/N), where Y denotes output, N total population and L working age population, and applying growth rates yields:

$$\frac{Y}{N}_{gr} = \frac{Y}{L}_{gr} + L_{gr} - N_{gr} \qquad (1)$$

where the subscript gr indicates growth rates. The first part on the right-hand side of equation (1) constitutes the productivity component (i.e., the growth rate of output per worker) while the second part represents the translational component (Bloom and Williamson 1998) as defined by the difference of the growth rate of the working age population and the growth rate of the total population.

Kelley and Schmidt (2005, p. 278ff) discuss three forms of the translational component:

1. Translations I: $L_{gr} - N_{gr} = 0$

Under these conditions population growth only affects output per worker growth through the productivity term. As argued in Kelley and Schmidt, such an assumption is most applicable under stationary (long-run) population conditions where every age group grows at the same constant rate. During transitional periods of demographic change, this condition is likely to be violated.

2. Translations II: $L_{gr} - N_{gr} = (L/LF)_{gr} + (LF/WA)_{gr} + WA_{gr} - N_{gr}$

where L denotes total labour hours, LF denotes labourers available for work and WA working-aged population. Hence, the first term on the right-hand side constitutes a measure of labour utilisation and the second term constitutes a measure of labour force participation. Kelley and Schmidt discuss the potential endogeneity that such a representation constitutes, i.e., while the growth rate of the working age population is predetermined, the growth rate of the population will be determined by fertility which will interact with the labour force participation.

3. Translations III: $L_{gr} - N_{gr} = WA_{gr} - N_{gr}$

This formulation is referred to as the Harvard notation which assumes that the growth rate of the working age population is a rather close substitute to the growth rate of the labour force. In the empirical part of our document (Section 3) we follow this notation for three reasons: (i) similar to the suggestion by Kelley and Schmidt (2005) we also chose the same representation as in previous models to allow for direct comparability of the coefficient of important demographic variables (ii) we lack consistent cross-country time series of labour force participation and finally (iii) similar as in Kelley and Schmidt, by choosing the working age population instead of the population weighted by labour force participation we prevent the problem of endogeneity. It is very likely that labour force participation rates might reflect part of the economic growth prospects of countries.

Figure 1 depicts the observed and projected difference between the growth rate of the working age population and the growth rate of the total population in the EU-25 countries beginning in the 1950s until 2050. A positive difference indicates that the working age population grows faster and, as a consequence, the share of the working age population increases and vice versa.

The first picture describes the development in the six western European countries. A common pattern in these countries is a pronounced positive difference during the 1980s resulting from the post-World War II baby boom. Although the peak differs in magnitude its timing is synchronous among these countries. During the 2030s the difference is projected to become negative at the same time in all six countries which is an echo of the fertility decline which has already started and is expected to persist in western European countries.

In the second picture we illustrate the dynamics in the Nordic countries and the UK. This picture shows that the post-World War II baby boom exhibits a rather diverse pattern with respect to time. While Finland experienced the peak of the difference already during the 1960s, Denmark and the UK followed in the 1980s and Ireland in the 1990s. As a consequence, Finland arrives at the minimum around 2015, Denmark and the UK around 2030, and Ireland around 2040. The trajectory representing Sweden shows a perpetually oscillating pattern without a pronounced peak.

The third picture exhibits the situation in the southern European (Mediterranean) countries. The peak was reached during the mid-1980s followed by a steady but modest decrease persisting until the 2030s. The maximum is lower than in western European countries and also the fluctuations are less pronounced.

The last two pictures illustrating the development in the ten new EU Member States, i.e., the central and eastern European countries, differs strongly from the three pictures discussed so far. The time span from the 1950s until 2000 is characterised by erratic oscillations with negative differences dominating. Thus, in these countries the total population grew faster than the working age population during that time period. However, beginning around 2000 there is an upward trend with a transient peak between 2015 and 2020 followed by a temporary downward trend. However, beginning in the 2030s there is again a tendency to rise persisting until the end of the period under consideration.

Whether demographic variables have an additional effect on output per capita growth through the productivity component (i.e., output per worker growth) needs to be estimated with the help of proper econometric models. In the next section we briefly review the basic modelling framework that guides estimations of the productivity component.

2.5 The Modelling Framework

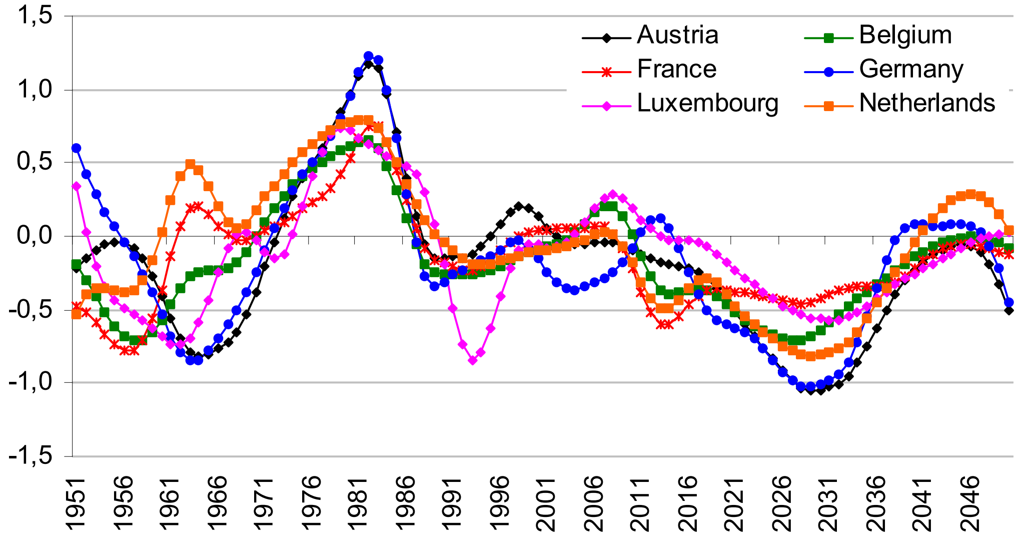
The underlying premise of these models is based on neoclassical growth theory assuming that countries converge to their long-run, steady-state equilibrium level of output (Y/L)*:

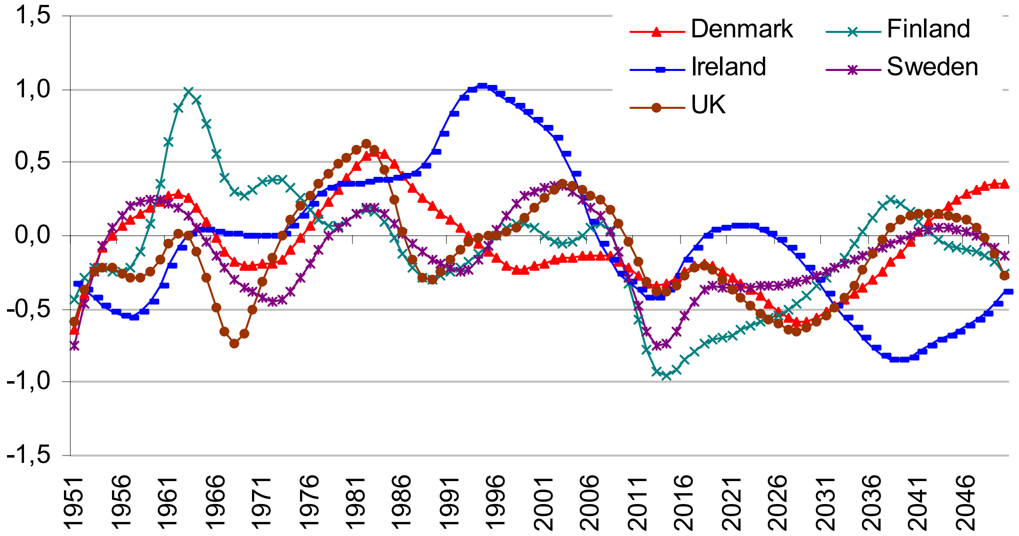
$$(Y/L)_{gr_{it}} = c\left[\ln(Y/L_{it})^{*} - \ln(Y/L_{it})\right]$$

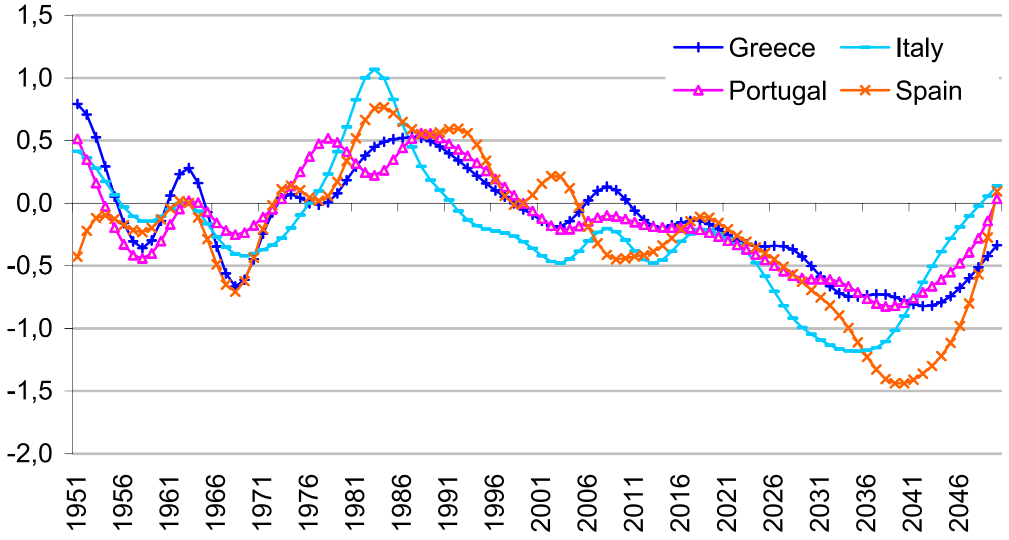
The growth rate of output per worker is modelled to be proportional to the gap between the logarithm of the current level of output per worker and the long-run level of output per worker. While the growth rate is constant, the steady-state equilibrium level of output per worker is country- (i) and time- (t) specific and is modelled as a linear function of time and country-specific characteristics:

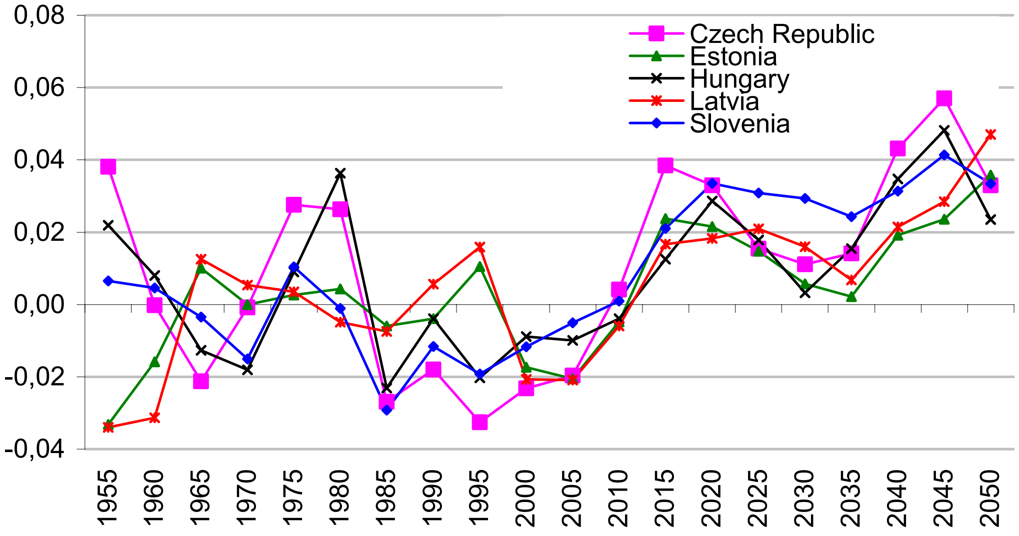
$$\ln(Y/L_{it})^{*} = a + bZ_{it}$$

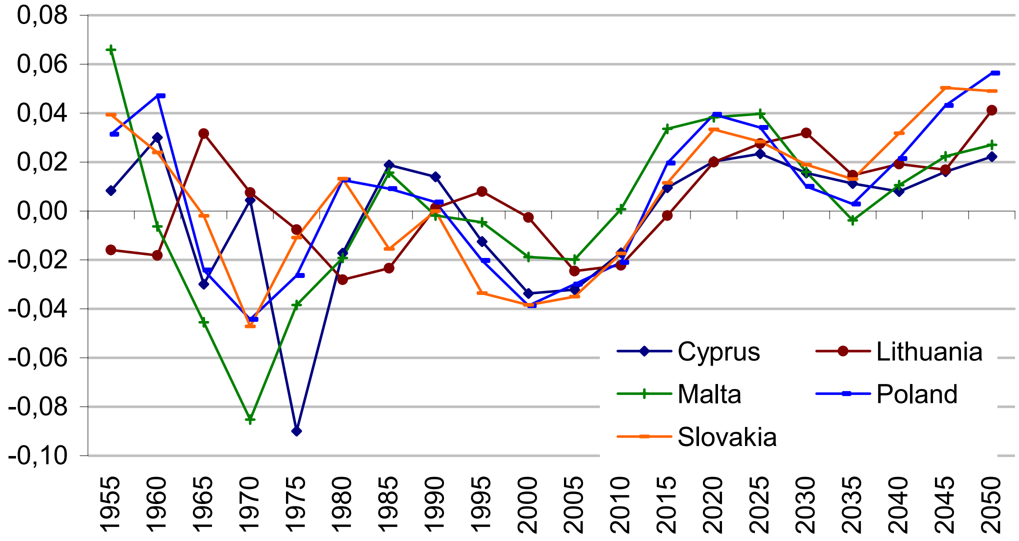
Figure 1:
Difference between growth rate of working age and total population, 1951-2050











Source: World Population Prospects

Recalling that the steady-state equilibrium level of output per worker derives from a production function, Z_{it} will encompass physical and human capital, resource stock, new technologies, government policies etc. The convergence parameter (c) is similar across all countries and thus requires further consideration of country-specific variables controlling for financial and political variables.

Whether or not the growth rates of the working-age and total population have an impact on the steady-state output per labour ratio has to be tested. Recalling the textbook growth model of Solow (1956) the steady-state output to labour ratio will depend on the savings rate, the population growth rate and the rate of technological progress. At least from a theoretical point of view, higher growth rates of the population will reduce the equilibrium output per worker level in such a model. Moreover, the current level of youth and age dependency will influence savings rates (see our discussion in Section 2.3) thereby indirectly (via s) influencing the steady-state output per worker level. Recent endogenous growth models of technical change that argue for positive scale effects attribute a positive contribution on growth from population size. Also population density has been argued to play a role for the development process, either positively through higher efficiency (e.g., in transportation, markets and communication) or negatively through increased congestion.

To sum up, demographic impacts on the productivity component will not be modelled through the indirect influences of N_{gr} and WA_{gr} which are constrained to their translational roles. They are rather measured directly through population's age structure which is modelled by dependency ratios (D1 for those under the age of 15 to working age (15-64) and D2 for those above 64 to working age), total population or density.

2.6 Empirical Rendering of Demography and Growth

In this section we review empirical studies that concentrate on the inclusion of demographic variables into economic growth regressions.

2.6.1 Kelley and Schmidt (2005)

The equation estimated in Kelley and Schmidt (2005) is as follows

$$(Y/N)_{gr_{it}} = ac + \boxed{bc(Ze+Zd))_{it} - c\ln(Y/L_{it})} + \boxed{L_{gr_{it}} - N_{gr_{it}}} + d\kappa_i + e\tau_t + \varepsilon_{it}$$

with κ_i as regional and τ_t as period-fixed effects allowing for exogenous shocks and ε_{it} a standard error term. Note that the term in the first square denotes the productivity model and the term in the second square denotes the translational model (cf. Kelley and Schmidt 2005, p. 284). The economic core variables (Ze's) are taken from Barro and contain economic, educational, political and health indicators. Among the demographic core variables (Zd's), the youth and old-age dependency ratio (D1, D2), population size (N) and density (D) are suggested.

The data cover 86 countries and 4 growth periods from 1960 to 1995, thus forming a panel with 344 observations. Regressions are oriented on Barro (1991, 1997) and employ two-stage least-squares estimation while introducing, among others, regional and period binaries.

After a simple demography model using mainly Barro's core, two translational demography models appending the Harvard translation component are estimated (cf. Kelley and Schmidt 2005, p. 287). In the first two models, the growth rate of output per capita constitutes the dependent variable. In the third model, the growth rate of output per worker is taken as the dependent variable. Thus the latter framework permits an explicit test for direct productivity impacts of Ngr and WAgr. In the first three estimated models, ln(Y/N) is used as convergence term and thus makes the introduction of the translational term ln(WA/N) necessary. However, this impedes the introduction of dependency ratios due to multicollinearity problems and therefore the coefficient of ln(WA/N) will include translational as well as dependency impacts. A fourth and fifth model enrich the demography specification in the long-run perspective by introducing the youth and old-age dependency ratio, population density and size.

The models fit the data satisfactorily and 9 out of 12 economic core variables Ze are always significant. Moreover, the economic core variables are not particularly sensitive to the demographic specifications.

Changing from the simple to the translational demography model, the negative impact of population growth Ngr becomes much stronger. Therefore it is reasonable to assume that the effects of Ngr in earlier studies were mixed since they absorbed the effect of the growth rate of the working age population Wgr as well.

While Ngr has no significant influence on the growth rate of output per worker, Wgr does have a positive effect indicating a role of Wgr beyond translations. According to the authors, however, the positive effect of Wgr is due to omitted variable bias which can be eliminated by the introduction of direct measures of the age structure. A similar problem occurs for the translation variable ln(WA/N) of the convergence term ln(Y/N) where omitted variable bias leads to a significant strong positive value. A solution is to use ln(Y/WA) as a convergence term which permits also to include youth and elderly dependency ratios in the estimation.

Among the demographic core variables Zd, only youth dependency is significant. The authors point out that the more demographic details are incorporated into the model, the more distinctly separable are the productivity and the translational model. Furthermore, they stress the importance of using dependency levels like the youth dependency rate rather than growth rates such as the working age population growth rate whose significance vanishes if the youth dependency is introduced.

How much does demography matter?

To study the role of demographic factors in explaining interdecade changes in output per capita growth rates, Kelley and Schmidt apply the estimated coefficients from their preferred model (Table 1, model 5, p. 287) to changes in mean values of the independent variables across decades.

At the average worldwide level they find positive economic impacts in the 1980s and 1990s and growth enhancing demographic trends throughout. However, translational effects have been exhausted after the 1970s. These average worldwide impacts, however, concealed a considerable variability across decades and regions.

While the impact of core economic variables (Ze) differ across region and time, core demographic variables (Zd) have a positive impact in 4 out of the 5 regions considered. Furthermore, the convergence term is negative between any two decades of economic growth in Europe and Asia. The most important role, however, is played by the largely unexplained exogenous factors.

A closer look at core economic variables indicates that human capital (as measured by life expectancy and education) had a strong growth-inducing effect over all periods and regions, while financial and political components had more ambiguous impacts. Although political components are the least influential worldwide, they are actually offsetting each other throughout the different regions. Among the demographic core variables, changes in youth dependency ratios had a strong positive impact, while elderly dependency ratios did not yet have an impact. Obviously, the variation in elderly dependency ratio is still rather limited for past decades. While life expectancy has been attributed to the economic core variables, possibly some of the impacts from life expectancy would also account for demographic changes. The translational components had positive impacts in 3 out of the 5 regions and the growth rate of the working age population could enhance the growth rate of output per capita only in the first two periods.

Translational components can well explain demographic transitions which took place differently across regions and time. Furthermore, they changed more rapidly than youth dependency ratios which exert their influences on a longer time period. In Table 1 we summarise the results for Europe as presented in Kelley and Schmidt (2005, p. 293).

A different presentation of the results is to consider relative contributions of the various influences to variability in the growth rate of output per capita. These relative contributions can be computed as component shares in total movement which is defined as the sum of the unsigned impacts of all variables. Globally, core demographic variables account for 8%, human capital for 16%, financial/economic factors for 15%, demographic translations for 13%, convergence adjustments for 9%, politics for 4% and exogenous factors for 36% (cf. Kelley and Schmidt 2005, Table 3, p. 296). For Europe the corresponding values are 24% (demographic core), 9%

(human capital), 16% (financial/economic factors), 10% (demographic translations), 13% (convergence adjustment), 9% (politics) and 33% (exogenous factors).

In summary, Kelley and Schmidt strongly argue that future research should be based on the distinction between demographic change affecting output growth per worker and variables which translate such growth into per-capita terms.

2.6.2 Bloom and Williamson (1998)

The aim of the paper is to show the role of demographic factors in explaining the boom in economic growth rates in East Asia during the 1965-90s. As the authors stress, the realisation of the demographic dividend in East Asia was possible since "social, economic, and political institutions and policies" were in place "that allowed them to realise the growth potential created by the transition".

Table 1:
Accounting for changes in Y/N_{gr} over time: impact of interdecade changes, Europe.

	1960s	1970s	1980s	Average
	to 70s	to 80s	to 90s	
Change in Y/N_{gr}	**-1.55**	**-0.48**	**-1.21**	**-1.08**
Convergence	**-0.53**	**-0.33**	**-0.24**	**-0.37**
Ze: Economic core	**-0.39**	**0.38**	**0.09**	**0.03**
Financial	-0.67	0.21	-0.13	-0.20
Human capital				
Ln e0	0.14	0.18	0.15	0.16
Male education	0.12	0.17	0.08	0.12
Political	0.01	-0.18	-0.01	-0.06
Zd: Demographic core	**0.06**	**0.43**	**0.23**	**0.24**
Ln D1	0.10	0.44	0.24	0.26
Ln D2	-0.05	-0.01	-0.02	-0.03
Density	0.00	0.00	0.00	0.00
Ln N	0.01	0.01	0.00	0.01
Demographic translations	**0.34**	**0.18**	**-0.26**	**0.08**
Ngr	0.19	0.21	-0.13	0.09
WAgr	0.14	-0.03	-0.13	-0.01
Period-fixed effects	**-0.91**	**-1.47**	**-0.46**	**-0.94**

Source: Kelley and Schmidt (2005), Table 2
Remark: Europe (17): Austria, Belgium, Denmark, Finland, France, Greece, Germany, Ireland, Italy, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, United Kingdom

The authors start from a neoclassical growth model and apply the conditional convergence model (cf. Section 2.5 of the report) to arrive at the the following equation to be estimated:

$$g_y = X\Pi_1 + y(T_1\ )\Pi_2 + g_{workers}\Pi_3 + g_{population}\Pi_4 + \varepsilon$$

with g_y being the growth rate of real GDP per capita in 1965-90 in purchasing power parity, $y(T_1)$ the logged initial output per capita, and $g_{workers}$ and $g_{population}$ the growth rates of the economically active and total population, respectively. X is a matrix containing the determinants of the steady state. The authors followed the Asian Development Bank (1997) in their selection of variables: average years of secondary schooling in the initial period (in natural logs), life expectancy in the initial period, a measure of natural resource abundance, a measure of openness, an index of institutional quality, average government savings, and geographic variables indicating the ratio of coastline to land area, whether there is access to major ports, and whether the country is located in the tropics (Bloom and Williamson 1998, Table 1, p. 432).

The World Bank database used for the econometric analysis contains 78 (Asian and non-Asian) countries covering the time period from 1965 to 1990. The dependent variable is the growth rate of real GDP per capita in 1965-90 in purchasing power parity. As no evidence is found for reverse causality while using IV estimators, estimations are done using OLS. In a basic specification where the economically active population is not modelled separately, the total population growth rate has only a significant positive effect if controlling for log life expectancy in 1960 and geography (a tropic dummy and a ratio of coastline to land area). By introducing growth rates of the economically active population (EAP, population aged 15 to 64, also called working age) between 1965 and 1990, the total population growth now has a strong negative impact while the EAP reveals a strong positive impact on GDP per capita growth rates. “An increase of 1 per cent in the growth rate of the working-age is associated with an increase of 1.46 per cent in the growth rate of GDP per capita. … an increase of 1 per cent in the growth rate of the overall population (effectively, the dependent population, since the empirical specification holds fixed the growth rate of the working-age population) is associated with a decrease of 1.03 per cent in the growth rate of GDP per capita.” (Bloom and Williamson 1998, p.435)

Interactions between the growth rate of the working age population and institutional quality and the growth rate of the working age population and openness turn out as insignificant. These results do not support the hypothesis that the policy environment is important for the linkage of population dynamics and economic growth.

In a further step, Bloom and Williamson replace the growth rate of the total population with the growth rate of the population under 15 and the growth rate of the population over 64. In this way the dependent population—as captured by the total population growth rates in the previous estimations—is separated into the young and elderly dependency effect. The results indicate a significant negative effect of the growth rate of the young population and a small (i.e., statistically insignificant) positive coefficient for the elderly population.

In summary, the model by Bloom and Williamson (1998) shows that economic growth is lower (higher) when the working age population falls short (exceeds that) of the total population.

Similar to Kelley and Schmidt (2005), the authors calculate the contribution of demographic change to past economic growth by world regions (Bloom and Williamson 1998, Table 7). In addition they also present the contribution of demographic change to future economic growth (Bloom and Williamson 1998, Table 8). In Table 2 we summarise the results for Asia and Europe. Population dynamics can explain 1.64 and 0.52 percentage points in GDP per capita growth rates for Asia and Europe, respectively. Expressed as a ratio of the observed GDP per capita growth rates yields: 1.64/3.33= 0.49 and 0.52/2.83= 0.18. Hence, population dynamics can explain almost half of the economic growth miracle in Asia and contributed about 20 per cent to the growth observed in Europe over the same time (1965-90). In the future population dynamics will contribute less to economic growth and in case of Europe even hold back economic growth prospects. As the authors underline, after having enjoyed the demographic gift phase, East Asia will get a negative demographic contribution to growth rates by entering the last stage of the demographic transition.

With respect to Asia, an interesting argument brought forward by the authors is also that demographic divergence in the second part of the 20th century between East, Southeast and South Asia might explain the economic divergence. The argument put forward for the future development is then that demographic convergence may lead to economic convergence among the three Asian regions.

Possible channels of impact

While the previous estimates indicated that population dynamics have and will be related to economic growth, the channels though which these effects work remain largely unspecified. To test for plausible theoretical models Bloom and Williamson consider three channels: demography influences the labour force, savings and investment.

Table 2:
Contribution of Demographic Change to Past and Future Economic Growth

		Contribution of demographic change to	
	average growth rate of real GDP per capita	past economic growth (1965-90)	future economic growth (1990-2025)
Asia	3.33	1.64	0.99
Europe	2.83	0.52	-0.16

Source: Bloom and Williamson (1998, Table 7 and Table 8)
Remark: We only present the results of model 1b (cf. Bloom and Williamson, Table 5), for future economic growth population projections from United Nations are applied.

In order to determine the impact of demography on labour force growth, the authors decompose labour input per person (working hours per capita H/P) as follows: H/P = (H/L) (L/EAP) (EAP/P) with (H/L) as hours worked per worker and (L/EAP) as labour participation rates among persons of working age. The share of the working age in the total population (EAP/P) represents the pure demographic effect. In East Asia the pure demographic effect accounts for 0.4 percentage points of Asia's transitional growth since 1975. Compared to the overall demographic contribution in Table 2, the pure demographic effect on labour force growth contributes about 37% of the overall demographic contribution (0.4/1.64).

The impact of demography on savings starts from the dependency hypothesis by Coale and Hoover (1958) (cf. Section 2.3 of our report). Using an approach of Higgins and Williamson (1996, 1997), the authors concentrate on effects of changes in population age distributions on changes in saving rates. In this vein the demographic transition could explain the entire rise in East Asian saving rates. If one constrains in addition capital accumulation to domestic saving, this would explain 1.5% of the East Asian economic growth. Allowing for international investment, the impact of demography on investment can be calculated as 1 percentage contribution to economic growth per capita. Adding the 0.6 percentage from the calculated labour market impact yields a result which fits the estimated 1.64 percentage of the total demographic impact very well.

The authors conclude with the hypothesis that it is age distribution rather than population growth which has an impact—albeit a purely transitional one—on economic growth.

2.6.3 Bloom and Canning (2001a)

Demographic change and its possible general economic impacts are described as in Bloom and Williamson (1998). This article further dwells upon reverse causality, i.e., in what way demography and economy are affecting each other and how this relationship may change over time.

The authors discuss three different mechanisms how demography may influence economic growth: (a) labour-market effect, (b) an effect on savings and capital accumulation, and (c) an effect on educational enrolment and human capital.

Labour market effects can be determined by looking at dependency ratios which reveal significant age structure effects. Several studies indicated that accounting effects are accompanied by strong behavioural elements, although it is not fully clear through what channels these behavioural effects operate.

Effects on saving and capital accumulation are based on the assumption of imperfect international capital markets, thus implying that national savings roughly equal national investment. However, life cycle theory cannot explain the strong rise in East Asian saving rates over the past decades, but rising life expectancy with the need for a retirement income seems to be a promising explanation.

Effects on educational enrolment and human capital work through life expectancy which is a robust predictor of school enrolment rates in a cross-country study according to Behrman et al. (1999). While this is due to increased rates of return for education, high youth dependency ratios may impede high school enrolment rates.

As the authors argue, reductions in the death rate can therefore increase labour force per capita, generate higher savings and increase returns to education. Later on, a higher proportion of old age dependents may increase productivity through a higher capital intensity; however, this is less probable in a pay-as-you-go pension system, as argued by the authors. Besides age structure, population density may affect economic growth. The empirical evidence on this is not clear though. Population density may impede economic growth through resource constraints or enhance it through economies of scale.

The size and speed of the demographic transition

The authors are refuting that fertility reductions in East Asia have been purely exogenous and try to determine whether and how causality may run both ways. The database spans the period 1870-1988 for a cross-section of countries where data on real GDP levels are from Maddison (1995) and data on population, vital statistics and age structure are from Mitchell (1992, 1993, 1995).

The model exploring the relationship between income and mortality and how this relationship changes over time is oriented on Jamison et al. (1996) and Jamison et al. (1997). The logarithm of infant mortality is the dependent variable whereas decade dummies and the logarithm of income per capita interacted with the decade dummies are the independent variables (ibid., p. 179, Table 7.1). A random-effects model seems to be the best specification and shows that a significant negative relationship between income levels and infant mortality only occurs after 1900 and that it becomes stronger over time. Regressions with the logarithm of fertility rates as dependent variable are run with dummy variables for 20-year periods (due to a smaller dataset) and those dummies interacted with log income per capita (ibid., p. 182, Table 7.2). A random-effects model is tested to be the most appropriate. From 1890 there is a negative significant relationship and together with the former estimations this reveals the necessity of considering reverse causality.

Models of the demographic transition and economic development

As endogenous growth theory lacks an explanation of wide income differences across countries, models exhibiting cumulative causality have to be considered. The authors propose a system approach where demography, output and capital accumulation are endogenous variables, influencing each other in both directions and where changes to exogenous factors such as politics will have repercussions for all endogenous variables. To elaborate the author's model, birth rates and death rates will be included and generally growth has to be understood as a process of cumulative causation rather than a mapping from causes to effects.

Standard growth regressions (2SLS) are estimated over the period 1965-1990 for a cross-section of countries with the average growth rate of GDP per capita 1965-

1990 as dependent variable (ibid., p. 188, Table 7.3). Only initial demographic factors are taken to be exogenous, whereas all population growth rates are assumed to be endogenous and are thus instrumented by the logarithm of the fertility rate of 1965, the youth dependency rate in 1965 and the lagged growth rates (1960-1965) of working age and total population. While population growth alone is not significant, this changes after introducing working-age growth. The differential growth rate (difference between population growth rate and working growth rate) matters as well. The initial ratio of workers per capita is growth-enhancing which implies that the steady-state level of income per capita is higher if the ratio of workers per capita is higher. Education tends to become statistically insignificant if demographic factors are included, which indicates that demographic change works partly through its effect on enrolment rates and education as such thus loses an independent explanatory role.

While policy variables were just included on their own in the first three growth regressions, they are also interacted with the differential growth rate in later regressions (ibid., p. 189, Table 7.4). Good policy leads to higher growth and the impact of demographic change is greater when institutions are of higher quality whereas policies have more importance in poor countries. Interaction of faster demographic transition and better economic policy in East Asia can account for 40% of the growth differential between East Asia and Latin America.

Potential policy implications

In summary, the results indicate that the economic impact of demographic changes is strongly influenced by politics. Moreover, if health policy increases life expectancy this may have a double dividend through increasing welfare directly and promoting long-run economic growth. The authors conclude that there may be two clubs, one with low income and high population growth rates and the other with high income and low population growth rates. Transition may be rare, but if it occurs, it occurs very fast due to cumulative causality.

2.6.4 Bloom, Canning and Sevilla (2003b)

The Rand publication by Bloom, Canning and Sevilla (2003b) constitutes a comprehensive survey of various studies of economic consequences of demographic change. We briefly review the main findings and arguments of the report and in particular we summarise the main findings of the studies for various world regions.

The debate over the effects of population change on economic growth

Summing up the development of research on how population matters for economic growth, the authors identify three main directions:

1. The “pessimistic” theory is presented by Bloom and Canning (2001a), for instance, and states that population growth can restrict economic development.
2. The “optimistic” theory sees the possibility of population growth fuelling economic growth through more ingenuity and economies of scale. Additionally, pressure on resources may boost innovations.
3. The “neutralistic” theory sees no significant effect of population change on economic growth. Three major research areas are responsible for the rise of population neutralism in the 1980s according to Kelley (2001):
    a. Exhaustion of natural resources was not strongly affected by population growth due to technology and efficient market allocation of resources.
    b. An impact of savings’ reductions on economic growth due to population growth could not be found.
    c. Population growth did not lead to any diversification of resources to less economically productive areas.

Additionally, former theories tend to ignore a population’s evolving age structure which could influence economic growth through life cycle behaviour.

Demographic transitions and the “demographic dividend”

Bloom and Williamson (1998) describe demographic transition by arguing that there exists a population momentum with fertility rates at the replacement rate when populations are growing until the bulge generations have passed through their prime reproductive years. The demographic dividend is presented in Bloom and Williamson (1998) and Bloom and Canning (2001a) who make a case of increasing labour supply that would be due to a larger share of the working-age population and more women entering the labour market because of smaller families and better education. The authors further underline that the current demographic transitions imply challenges to the developed world and opportunities for the developing world.

However, flexible labour markets, stable domestic financial markets and a good educational system are needed in order to profit from the demographic dividend.

Case studies of population change and economic growth

- East Asia profited from its fast transition (period of 50-75 years) because of good education and trade liberalisation.
- Japan is the most rapidly ageing country and is coming towards the end of its demographic transition. Having well profited from its demographic dividend due to high education levels and good institutions it may face problems sustaining its pay-as-you-go system because of an increasing dependency ratio from 47% in our days to 96% in 2050.

- North America and western Europe have reached an advanced stage of their demographic transition.
- South-central and Southeast Asia's demographic transition have lagged behind that of East Asia in the last decades. While Southeast Asia already benefited from the demographic dividend accounting for about 1% of per capita annual income growth, South-central Asia will be able to realise a growing potential if fertility declines, education is strengthened, the labour market is made more flexible and foreign investment increases.
- Although Latin America showed demographic changes that were similar to that of East Asia, it had a much smaller per capita annual growth rate (instead of 6.8 only 0.7 from 1975 to 1995). Approximately half of this gap can be accounted for by the interactive effect of policy and demography according to Bloom (1999). With its demographic transition being still under way, Latin America can still profit from the demographic dividend if appropriate policies are installed.
- Most Middle East and northern African countries are at early stages of their demographic transitions and have still high fertility rates. Economic growth could be substantially enhanced if the ratio of working-age to total population was changed and good policies such as more liberal labour markets and good educational systems were installed.
- Demographic transition has not yet started in sub-Saharan Africa. Declining infant and child mortality was not followed by a decline in fertility, which led to an enormous population growth with a slightly shrinking working-age share. While children are still seen as an insurance against old age and a source of labour, investments in human capital are not made because of their remaining low rentability. Additionally, dependency ratios tend to even worsen as a result of diseases such as HIV.
- Eastern Europe and the former Soviet Union have seen a constant fertility decline, which enhances population ageing while no baby boom generation brought any demographic dividend to economic growth. As there is also a decline in life expectancy, policies should target on health systems and good economic measures in order to cope with population ageing.

The importance of the policy environment

Open economies, flexible labour force and modern institutions assure that a country can reap the demographic dividend. In order to promote demographic transition (i.e., measures to speed up the fertility decline) through making human capital investment more profitable and helping women to achieve desired family sizes, improvements of public health and access to care are essential.

As population policy has a direct impact on speed, timing and completion of the demographic transition, it may also have an impact on the size of the growth potential. The impact of family planning programs on fertility rates has been highly significant, exceeding the impact of socioeconomic factors such as rising income. Higher education levels for parents mean rising opportunity costs of having children, which in turn reduces fertility.

On the other hand, changing family structures have led to higher proportions of single-parent families in developed countries. These are more likely to live in poverty than two-parent families. Developing countries undergoing the demographic transition have the possibility to leapfrog this problem by adapting measures to develop a "new" family.

As the authors argue, developing countries going through the demographic transition should therefore not simply copy from the developed countries, but try to learn from errors and realise big potentials like the high capacity of their youth bulge to adapt and use new technologies through providing good education.

Increased life expectancy and an ageing population are the final iterations of the demographic transition that will put pressure on pension systems originally designed to support only a small older population. The authors argue that pay-as-you-go pension systems are likely to become difficult to sustain and the demographic transition should push countries to introduce fully-funded pensions which in turn increase national levels of savings. Health expenditures, which for elderly persons are roughly three times higher than for younger ones, will increase as well and thus demand the need for limiting inequitable intergenerational transfers. Public-private partnership is maybe a solution for many areas of social policy. The demographic dividend is unlikely to recur and thus has to be used to push economic growth through supporting measures.

2.6.5 Beaudry and Collard (2003)

While the previous papers have focused on samples of all world regions, the contribution by Beaudry and Collard concentrates on industrialised countries. The authors investigate the impact of growth in the working-age population on economic performance across the richest industrialised countries. In the first part of their paper they run cross-country regressions covering the periods 1960 to 1974 and 1975 to 1997 and those countries where income per adult in 1985 exceeded US$10,000. Therefore, the sample of countries consists of Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Iceland, Italy, Japan, the Netherlands, New Zealand, Norway, Sweden, Switzerland, the United Kingdom, and the USA. The exclusive consideration of only rich industrialised countries allows for the assumption that all countries in the sample are affected by the same technological forces.

The dependent variables are the average annual growth rate in output per adult, output per worker, and employment per adult. The most important explanatory variable assigned to capture demographic influences is the annual average growth rate of the population aged 15 to 64. In the first approach the three dependent variables (see above) were regressed on the annual average growth rate of the population aged

15 to 64 and on the logarithm of the initial level of GDP per capita. In the second setting the average investment to GDP ratio and two country dummies were added to consider institutional differences. The first country dummy is one for Anglo-Saxon countries (Australia, Canada, New Zealand, United Kingdom, and USA) and the second dummy is one for the Scandinavian countries Denmark, Norway, and Sweden.

The results obtained for the 1960 to 1974 period differ significantly from those obtained for the 1975 to 1997 period (Beaudry and Collard 2003, Table 1, p. 444). While the coefficients capturing the influence of the working-age population were small and insignificant in the first period, Beaudry and Collard observed a significant correlation for the second period. Between 1975 and 1997, countries with higher growth of the adult population exhibited lower growth in output per worker but higher growth in employment per adult. Their estimates suggest that “a country with a yearly rate of adult population growth of 1% greater than the average experienced poorer growth in output-per-worker of approximately 1% per year” (Beaudry and Collard 2003, p. 446). As a result of these two counteracting effects the impact on output per adult was negative but insignificant. Thus, in the second period countries exhibiting slow growth in the adult population increase output per adult at the same rate as those countries with higher population growth rates but at a lower rate of exploitation of the potential labour force.

The impact of the initial level of GDP per capita on output per adult and output per worker was significant and negative between 1960 and 1974, providing strong evidence of convergence. In the 1975 to 1997 period, the respective coefficients were still negative but smaller in magnitude, indicating a decelerated convergence. The results appear to be robust with respect to the inclusion of the investment to GDP ratio and the two country dummies. Moreover, Beaudry and Collard mention that their results are also robust with respect to controlling for human capital measured in terms of the average number of years of education and school enrolment rates. However, these results are not reported in their paper. To find out whether it is indeed the growth rate of the adult population or purely the age structure of a given country, the authors provide a set of regressions controlling for the age structure by including the growth rates of the share of the population younger than 15 (children) and of the population older than 64 (elderly persons), and in a second set they include the growth rates of the child population and of the elderly population. Neither of the two variations affected the findings with respect to the impact of the growth rate of the adult population.

Beaudry and Collard conclude that their regression results are not driven by changes in the age structure but by differences in the growth rate of the adult population. However, they hold that differences in economic performance across industrialised countries—which are often claimed in the literature to be due to institutional factors—are actually caused by demographic factors.

It is then postulated that the difference observed between the periods of 1960 to 1974 and 1975 to 1997 can be explained by a major technological change. To motivate this explanation, they develop an analytical model in the second part of the paper which is based on the standard Solow (1956) growth model.

A model of the effects of population growth during a technological transition

They include the possibility of a drastic technological change and endow households with neoclassical preferences between consumption and leisure. In the model economy there is one final output Y_t produced by competing firms deploying a continuum of intermediate goods i ∈ [0,1]. Using a CES production function yields:

$$Y_t = \left(\int_0^1 Y_{i,t}^{\rho} di \right)^{1/\rho}, 0 \leq \rho \leq 1$$

Intermediate goods are produced using capital $K_{i,t}$, effective units of unskilled labour $\theta_t L_{i,t}$, and a traditional production technology,

$$Y_{i,t} = K_{i,t}^{\alpha} (\theta_t L_{i,t})^{1-\alpha}, 0 < \alpha < 1$$

Technological change is represented as growth in θ_t taking place at a constant and exogenous rate ν. A fraction of i_t* of sectors can alternatively produce intermediate goods according to a different production process,

$$\tilde{Y}_{i,t} = \Phi K_{i,t}^{\beta} (\theta_t L_{i,t})^{1-\beta}, 0 < \alpha < \beta < 1$$

The parameter Φ expresses the relative total factor productivity of the new technology. This alternative production process is characterised by less decreasing returns to capital than the former production process. The alternative production process is assumed to be a general purpose technology and technological change affects the economy in such a way that the share i_t* increases over time.

The way how countries adjust to technological change may differ because of differences in rates of population growth. Beaudry and Collard derive two propositions from the analytical model.

Proposition 1: An increase in i* will cause the relationship between the steady-state value of y/l (output per worker) and the rate of population growth to become more negative.

Therefore, the empirically observed increased importance of population growth on output per worker may be the effect of the introduction and diffusion of a new technology based on accumulation.

Proposition 2: An increase in i* (starting from i* =0) causes the emergence of a positive association between the steady-state rate of employment (l/n) and the economy’s rate of population growth.

The latter proposition provides an explanation for differences in the employment rate among industrialised countries which is not based on institutional factors. Countries exhibiting low population growth can adopt new capital-intensive technologies more quickly since they need fewer resources to endow workers with capital. Consequently, these countries have better access to advantages offered by capital deepening.

2.6.6 James Feyrer (2004)

While former papers on demographics and economic growth tended to concentrate on the dependency ratio, this paper takes the internal demographic composition of the workforce into account. Therefore the author focuses more on the age structure of the workforce rather than on the age structure of the entire population.

The regressions estimated are in the framework of the convergence models:

$$y_{i,t} = f_i + \mu_t + \beta x_{i,t} + u_{i,t}$$

with $y_{i,t}$ being output per worker in country i at time t, f_i being the country-fixed effect, μ_t a time trend common to all countries, x_{it} a set of explanatory variables and u_{it} the error term. As independent variables the following set of variables is chosen: the proportion of the workforce by 10-year age groups starting at age 10 and ending at age 60+ for the last category. The dependent variables are the logarithm of output (in first differences and level) and the components of the following decomposition which is based on a Cobb-Douglas production function of capital per worker ($k_{i,t}$), human capital per worker ($h_{i,t}$) and productivity ($A_{i,t}$):

$$\log(y_{i,t}) = \frac{\alpha}{1-\alpha}\log(\frac{K}{Y})_{i,t} + \log(A_{i,t}) + \log(h_{i,t})$$

Thus performing separate regressions for each of the right-hand side expressions produces a set of coefficients which sum to the coefficients of the regression performed on the logarithmic of output per worker. The relative magnitude of the coefficients indicates the importance of each channel in determining the demographic impact on output.

The International Labour Organisation (ILO) provides cross-country y on the number of workers by five-year age groups spanning ages 10 to 65 which are normalised by population and workforce size. The available ten-year intervals are imputed by the author to five-year intervals using UN population data because output and human capital data are available at five-year intervals. Therefore the data make up a panel at five-year intervals from 1960 to 1990 for two samples, one for 87 non-oil countries and one for 19 OECD countries.

Regression results

Regression of the difference in output per worker on differences in age shares of the working-age population with country and time dummies and the dependency ratio as additional control indicates that an increase of the share of workers aged 40 to 49 is associated with higher output (ibid. p.23, Table 1). The differences in age shares are large, e.g., a 5% point shift from the age group 30 to 39 to the age group 40 to 49 is associated with a 15% increase in output per worker. The dependency ratio has no significant influence. Furthermore, the decomposition of output yields that the productivity channel is the most important for the effects of demographics on output per worker. Demographic regressors are jointly insignificant in the regressions of capital output ratios and human capital.

The use of imputed values in the age structure of the workforce entails the risk that the imputation may be invalid. Another problem could be endogenous participation rates or that immigration may be moving the age structure in response to productivity shifts. Due to these problems, the author conducted IV regressions as well as regressions on original age structure. Cohorts aged 15 to 39 are associated with significantly lower productivity across estimation methods and larger in magnitude than suggested by microeconomic evidence. Using IVs and regressions with lagged population values shows neither participation rates nor immigration to impose the discussed problems. Results for older cohorts are less clear with coefficients being smaller and less precisely estimated than for the young cohorts.

In order to take a closer look on productivity, hours per worker data are used for constructing GDP per hour for 19 countries. Regressions show that a larger portion of 40 year old workers is associated with increased hours which could contribute to the base results (ibid., Table 3). However, the coefficients are not significant and the results thus cannot be explained by hours worked.

Using the predictability of demographic change, an out-of-sample prediction for 1990-1995 is made which allows for predicting almost 12% of economic growth in real GDP per worker by demographic change.

Applying the results to explain cross-country productivity differences the authors conclude that a lower proportion of forty year old workers in the poorer nations compared to the richer nations is associated with lower productivity. One-quarter to one-third of the observed logarithmic productivity gap between poorer and richer nations is associated with differences in workforce demographic structure. The authors then suggest that the acceleration in the increase of the gap after 1980 may be associated with divergence in the demographic structure.

2.7 Specification of Age Structure Effects

Many aspects of human behaviour such as labour supply, saving, criminal activity, and the like are inherently age-specific. When quantifying age structure effects a challenge arises as a consequence of the high dimension of a population's age structure. Moreover, co-linearity among the one or five-year age groups may result in badly determined age structure coefficients. Therefore, it is desirable to capture the age structure with a small set of variables without losing relevant information.

Most of the studies on demographic change and economic growth reviewed in the previous section relied on a linear specification of the age structure. The studies differ in the age-specific detail. Most commonly the youth and old-age dependency ratio are used to represent the different stages of the demographic transition. Alternatively some authors use age shares (Beaudry and Collard 2003, Feyrer 2004) or combine both (age shares and dependency ratios). In some studies additional population variables such as population density are considered (Kelley and Schmidt 2005).

One of the earliest study to model age structure effects on macroeconomic aggregates is the one by Fair and Dominguez (1991) who investigate the influence of the US age distribution on consumption, housing investment, money demand, and labour force participation. They use a specification including dummy variables for each age group and for each year. Therefore, they obtain age- and time-specific constant terms. The age group coefficients are restricted in such a way that they sum up to zero and they lie on a second-degree polynomial. The vector of coefficients for the other independent variables is the same for all individuals.

Fair and Dominguez apply two-stage least squares estimations to explain consumption and housing investment. The explanatory variables are real value of wealth, after-tax nominal wage, after-tax interest rate, real level of transfer payments, a labour constraint variable, and the lagged dependent variable. The labour constraint variable is zero in the case of full employment. The hypothesis that age variables matter is strongly supported and the obtained patterns are consistent with the life cycle hypothesis. Thus, people consume less relative to their income during their prime age, while young and old people consume more relative to their income. The results with respect to housing investment are similar: thus, prime-age people consume less housing relative to their income. However, older people consume even more housing relative to their income than younger people do.

Regarding money demand, they test the hypothesis whether the transaction costs of obtaining money have a positive impact on the money held by individuals. Baumol (1952) and Tobin (1956) anticipate that for people in their prime age the opportunity costs of bank visits, which constitute a part of their transaction costs, are higher and, as a consequence, they hold more money. The estimations of Fair and Dominguez with respect to money demand confirm this hypothesis.

Instead of using highly aggregate measures like dependency ratios, Bloom and Canning (2001b) suggest to impose restrictions on the coefficients. They start with the specification

$$y = c + \sum_{i=1}^{n} \beta_i x_i + \delta z + \varepsilon$$

to estimate the impact of the relative cohort sizes x_i on y, c is a constant, z is another variable in the relationship, and ε is the residual.

The first approach to reduce the dimension is to group the age shares x_i and impose that the coefficient $ß_i$ is constant within each group. A strategy for grouping may for instance take into consideration that each group should have about the same size or the boundaries may be defined so as to make it reasonable to assume that the particular behaviour under consideration does not vary too much within each group. Note that this is exactly the argument applied in most of the recent studies as reviewed in Section 2.6.

The second approach is to assume that the coefficients $ß_i$ lie on a polynomial of order m:

$$\beta_i = \alpha_0 + \alpha_1 i + \alpha_2 i^2 + \ldots + \alpha_m i^m$$

imposing n - m restrictions on the n coefficients.

The third approach is based on the principal components p_0 to p_m of x_0 to x_n, which can be written as orthogonal linear combinations

$$p_j = \sum_{i=1}^{n} \psi_{ij} x_i$$

Those principal components associated with the m largest eigenvalues are then used to estimate

$$y = c + \sum_{j=1}^{m} \sigma_j p_j + \delta z + \varepsilon$$

Bloom and Canning (2001a) illustrate their approach by an example, where national saving is the dependent variable and life expectancy, age structure, and country-fixed effects are the regressors.

Recently some authors have shown that theoretical models on the economic-demographic interrelationship may imply non-monotonic relations between demographic change and economic growth (Zhang et al. 2003).

To test for the possibility of non-monotonic relationships, An and Jeon (2006), suggest testing for three different functional forms: linear, quadratic and cubic. In particular, the authors advocate using a non-parametric kernel regression which does not depend on any functional form but estimates the functional form itself. The authors run 12 different models based on the conditional convergence model. As dependent variable they choose the log of GDP per capita. The set of explanatory variables they consider is: the logarithm of initial GDP per capita, total investment per GDP, average schooling years of the population aged 15 and over and variables representing the age structure (the share of old population 65+ (P65R), the square of P65R, the cubic of P65R, old-age dependency ratio (OAGDEP), the square of OAGDEP, the cubic of OAGDEP and similarlary six further regressors for the share of young population 0-14 (P014r), etc.). The authors find an inverted U-shape relationship between the share of old (share of young) and the old (young) age dependency ratio, respectively, and economic growth. By applying a non-parametric kernel estimator the authors confirm these non-monotonic results.

3 ECONOMIC GROWTH REGRESSIONS

3.1 EU-15 Economic Growth and the Age Structure of the Population

3.1.1 Introduction

The starting point for this part of the study is a paper by Lindh and Malmberg in Journal of Population Economics 1999. In this paper an empirical model of how different age groups affect economic growth in a panel of OECD countries is estimated controlling for technological convergence. The main result is that increases in the working population are associated with increased growth rates of GDP per worker. This result corroborates findings from many different studies on world data, a summary whereof is available in Section 2.6 above.

However, Lindh and Malmberg subdivide the population further and—somewhat more surprisingly—find that in the OECD sample the 50-64 age group has the most positive effect on the growth rate of GDP per worker. Similar results have been found in other studies, see below, but cannot yet be said to be generally accepted in the growth research community. For the economic future of the European Union with its ageing workforce, it is of course a crucial issue whether this result turns out to be a robust and stable feature of the EU growth experience or whether it somehow hinges on the period and sample of countries studied. Therefore, our aim here is to replicate the study in a EU context with a longer available time series to further probe the stability and robustness of the model.

In a later study on a global sample of countries, Lindh and Malmberg (2005) indeed find that the peak of positive age effects on GDP per capita shifts upwards with the increase in life expectancy. Thus, the pattern is not globally valid but its general features should still approximately hold for EU countries which all have life expectancies at the higher end of the scale. In a follow-up paper, De la Croix, Lindh and Malmberg (2006) find that the global pattern of age effects, shifting with life expectancy, has substantial validity for explaining the Swedish growth experience back in the late 19th century. There are indications, however, that the long-term rate of technological change may be partly unaccounted for in the global model, suggesting that forecasts need to take this into account.

The 1999 study controls for technological convergence so a further aim with the replication is to determine whether the controls used for technological convergence are still valid. Section 3.3 further studies how the process of technological absorption itself is affected by age structure in order to complete the picture of how we can expect the currently ageing (and eventually rejuvenating) European workforce to affect future European prosperity.

To sum up the argument and propose a hypothesis to be tested, a plausible story should go like this. For convergence highly educated youngsters drive the absorption process while mature adults drive the mature productivity process. As emphasised in the literature around General Purpose Technologies (Helpman 1998) the innovation phase of pervasive technological change is a phase of investment where productivity growth itself may be rather moderate and appears in full strength only after an extended period of experimentation, adaptation and infrastructural change. Thus, only after substantial experience with the new technologies for periods as long as 20-40 years can we reap the full benefits as the production system has adapted to new structural requirements. In a previous report by Prskawetz et al. (2006), a similar interpretation of Swedish plant level productivity processes could be made based on micro data studies at the plant level. That is, new and growing enterprises are associated with a young workforce while stagnant firms on the verge of exit tend to have an older workforce. Still, as we control for these plant characteristics an older workforce appears to be associated with faster productivity growth. Here we make essentially the same argument on the macro level.

We start by explaining a condensed version of the model and the results in the 1999 OECD study in the next subsection. Then we discuss data material and how we handled the choices of data sources for the replication. The following subsection reports empirical results from the replication. In the next subsection we discuss further how to interpret the results against the background of other results in this study as well as in relation to other results in the literature. In the conclusions we summarise and hint at how the results might be useful for a prospective analysis of the growth potential in EU-25 which is as later on conducted in Section 4.1 of the report.

3.1.2 Age Structure Effects and Growth in the OECD, 1950-1990 (Lindh and Malmberg, Journal of Population Economics 1999)

This section briefly explains the model and results in Lindh and Malmberg (1999). In that paper the age structure effects on economic growth in OECD 1950-1990 (21 countries with economic data from the Penn World Table 5.5 and demographic data from UN WPP 1990) are studied in a country panel with 5-year data. Distinct patterns of age share effects on the growth of GDP per worker are demonstrated with a robust positive effect from the 50-64 age group and negative effects from the 65+ group while younger age groups have more ambiguous effects.

Since we aim to replicate this study on EU data we need to go into some detail to explain the model. The basic model framework is the transitional Solow-type growth model as developed in the well-known paper by Mankiw et al. (1992) which posits that human capital is produced by educational investment. Mankiw, Romer, and Weil (1992)—henceforth MRW—put forward that human capital is produced by educational investment alone. Microeconomic evidence, however, indicates that experience plays a key role in human capital formation as well as variations in labour supply over age. A country with an experienced workforce will, ceteris paribus, have more human capital than a country with an inexperienced workforce. The model therefore allows for an experience effect on aggregate human capital by interacting the stock of educational capital with a Cobb-Douglas index, N, of the age structure,

$$N = \prod_i n_i^{a_i} \tag{2}$$

where n_i is the population share of age group i. No restriction is placed on the exponents a_i. The exponents can be negative and the sum is not restricted to unity. This on the one hand allows for the possibility of scale effects from population size through positive density effects from increasing specialisation or negative congestion effects. On the other hand it also allows for dependent age groups to offset positive effects from increases in the active population, e.g., by increasing the demand for household production not accounted for. This specification has the advantage of being tractable and easily incorporated with conventional specifications like MRW.

With this definition, a Cobb-Douglas production function in terms of output per worker, y, can be written

$$y = Ak^{\alpha}(hN)^{\beta} \quad 0<\alpha<1 \text{ ,} 0<\beta<1 \quad \text{and} \quad 0<\alpha+\beta<1 \tag{3}$$

where k is physical capital per worker, and h is educational capital per worker, and the restrictions on the exponents imply constant returns to scale in the three factors working population, capital and the measure for composite human capital.[2] A denotes the technology level.

Following MRW it is assumed that capital accumulation, both physical and educational, is governed by the standard dynamic equation, taking the saving rates s_k and s_h as exogenous

$$\dot{k} = s_k y - (\delta_k + w)k \quad \text{and} \quad \dot{h} = s_h y - (\delta_h + w)h \tag{4}$$

where δ_k and δ_h are constant depreciation factors and w is the exogenous growth rate of the workforce.

The assumption of an exogenous saving rate in this context needs some justification. In spite of the life cycle theory of saving, demographic variables in empirical studies of saving and consumption are generally viewed with considerable skepticism, see for example Bosworth et al. (1991) and Deaton (1992). There are other researchers who attribute quite a lot of explanatory power to variations in the age structure, for example Leff (1969), Fry and Mason (1982), Mason (1987), Attanasio and Browning (1995), and Kelley and Schmidt (1996) (see also Section 2.3. of our report). In the OECD data, age variables indeed have a significant impact on

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[2] The assumption of separability of educational capital and the available experience capital measured in the age group index implies that an increase in education has a proportional effect on the whole index. It would be preferable to let education have an age-specific impact but that would seriously complicate the specification of educational capital accumulation and also require much more detailed data. In this context the education channel will be reduced from the actual estimation model (see below) so it does not matter anyway.

savings but explain only a tiny four per cent of the variation as estimated in a simultaneous equation model, see Lindh (1997).

Moreover the closed economy assumption inherent in the formulation of equation (4) is clearly violated in an OECD context where investment capital may also be borrowed from other economies, or domestic savings invested abroad. The rate of accumulation should therefore not be taken literally as an actual saving rate but rather as a measure relating gross investment to GDP per capita.

MRW assume technology to be the same for all countries, but here the technology factor *A* converges to an exogenous world technology, A* only gradually

$$\dot{A} = \gamma\left(A^* - A\right). \tag{5}$$

The adjustment rate γ is assumed to depend on the productivity gap between best-practice technology and currently used technology. This may well be an unwarranted assumption in a worldwide context, where we easily can find examples contradicting such convergence. Within the convergence club of the OECD, and maybe even more so within the EU it is more appropriate, since these countries already are socially and politically committed to an industrial development process. They are also integrated to a large extent with respect to trade, as well as to their capital and labour markets.

As in MRW a common depreciation factor $\delta=\delta_k=\delta_h$ is assumed. Lindh and Malmberg test and find that a common rate of accumulation can be assumed, i.e., $s=s_k=s_h$. Although a drastic assumption, it has some support in attempts to measure human capital investments.[3] This leads to equal steady-state stocks of physical and human capital in real value terms:

$$h^* = \left(\frac{s}{\delta + w} A^* N^{\beta}\right)^{\frac{1}{1-\alpha-\beta}} = k^*. \tag{6}$$

The proportional growth rate for an economy in transition to the steady state can be approximated (for details see Appendix A) by

$$\frac{d\ln y}{dt} = \lambda\left(\ln y^* - \ln y\right) + u \tag{7}$$

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[3] Statistics Sweden (1991), e.g., estimates that investment in intangible capital by Swedish firms is of the same order of magnitude as physical capital investment. With the same rate of depreciation, stocks should therefore be of comparable size. Barro, Mankiw and Sala-i-Martin (1995, pp. 108-109) conclude that human capital accumulation predicted from their model is roughly comparable in size to physical capital accumulation in the US. Using schooling rates as a proxy for human capital accumulation, which is often done, works rather poorly in panel estimations but Lindh and Malmberg (1999, Table 2, p. 439) estimate such models as well, with negligible effects on other parameters. Even the implied elasticities α and β are of about equal order, the former being around 0.38 and the latter almost 0.3 and thus conforming to the generally assumed physical capital elasticity of about one-third. Trying to use human capital stock variables measured by average level of schooling fails conspicuously though.

with u denoting the error made and $\lambda = \tilde{\gamma}(\delta + w)(1 - \alpha - \beta)$, where $\tilde{\gamma}$ is proportional to γ the technological adjustment rate.

Inserting the expression for steady-state stocks in y^* specified as a production function the basic growth equation can be written

$$g = \lambda\left(\ln A^* + (\alpha+\beta)[\ln s - \ln(\delta + w)\ ] + \beta \ln N\right)/(1-\alpha-\beta) - \lambda \ln y + \lambda u. \quad (8)$$

and dividing through by $\Gamma = \tilde{\gamma}(\delta + w)$ using the definition of λ a weighted regression equation is obtained

$$\frac{g}{\Gamma} = \ln A^* + (\alpha+\beta)[\ln s - \ln(\delta + w)\ ] - (1-\alpha-\beta)\ln y + \beta \ln N + \frac{u}{\Gamma}. \quad (9)$$

The interpretation of (9) needs some comments. If there are no changes in age structure, saving rate, depreciation, workforce growth or potential technology level, the economy will eventually come so close to a stationary state that growth practically stops. However, changes in these variables shift the steady-state income to which the economy is converging and, consequently, the transitional growth rate. We can think of this as the economy aiming at an ever moving target.

One implication of (9) is that variations in age structure will also imply variations in the transitional short-run growth rate. In most growth models it is implicitly assumed that the age structure is constant and can therefore safely be ignored. In the real world, and in particular in the developed world, the age structure of the population is rapidly ageing and changing at a very fast rate.

While many growth papers seem to assume that current values are reasonable proxies for variables supposed to measure steady-state values, this is an untenable assumption when taking age structure into account. It will take a very long time before the population becomes balanced, probably several hundred years from now so we essentially have no inkling what the steady-state values of these accumulation rates may be then.

Note that the impact on the growth rate in the model laid out here is country- and time-specific because of the dependence on the rate of technological convergence proportional to Γ. Thus the model allows both for country heterogeneity as well as evolution over time in the parameters as the steady-state solution shifts, albeit in a fairly restrictive form. As found in Section 3.3 there may be non-linearities in the way age structure is connected to technological absorption or diffusion. The weighting with the gap variable gives us a more flexible control for this than inserting a simple trend variable. Indeed, the gap as we measure it does not decrease monotonically over time as a trend would imply.

This is an important point because we know that the life cycle events have changed their timing over the post-war period. In particular, increased education takes time so that very few young people today start working in their upper teens, which was still fairly common in the 1960s. Also labour force participation, especially for the elderly differs considerably across the OECD countries, as does the extent of female labour force participation. Since the estimated impacts differ with the convergence gap we allow for this heterogeneity over time, albeit perhaps only partly and imperfectly.

3.1.2.1 Empirical Specification

Is the theoretical model consistent with empirical data? To answer this question a regression model based on equation (9) was tested on five-year data for the OECD countries from 1950 to 1990:[4]

$$\frac{g_{tj}}{\Gamma_{tj}} = b_0 + b_1 \ln i_{tj} + b_2 \ln\left(\delta + w_{tj}\right) + b_3 \ln y_{tj} + b_4 \sum_m a_m \ln n_{mtj} + b_5 \frac{1}{\Gamma_{tj}} + \varepsilon_{tj}.$$

The growth rate of real GDP per worker over period *t* for country *j* is defined as $g_{tj} = \ln y_{t+1,j} - \ln y_{tj}$. This forward growth rate, divided by the country- and period-specific convergence term Γ_{tj}, is influenced by (*i*) by the average investment share i_{tj} over the period, (*ii*) the average growth rate of the work force (measured by the population 15-64), w_{tj}, over the period, and a fixed rate of depreciation δ (constant with a stylised value of 0.03), (*iii*) the initial level of GDP per worker, y_{tj}, in the period, (*iv*) the age group shares at the beginning of the period, n_{mtj}. The inverse of the convergence term, $1/\Gamma_{tj}$, is added to take care of a non-zero mean in the approximation error, u. Note that this means that b_5 will actually provide a proxy measure for the rate of exogenous technical change, i.e., the drift in world technology, see derivation in the Appendix A. The initial world technology level, $\ln A^*$, is estimated in the constant and cannot be separately identified.

The measures of age structure distinguish four important phases in the adult life cycle: young adulthood, prime age, middle age, and old age. Thus, population shares for the age groups 15-29, 30-49, 50-64, and 65+ years are included in the age index. Together these variables capture most of the age structure variation in the OECD countries in the post-war period and have sufficient individual variation to allow identification of distinct age effects. The youngest age group, children aged 0-14, had to be dropped in order to avoid high degrees of collinearity among the age variables. There are alternatives to the age share representation of the age structure[5] but here we just replicate a study and therefore do not consider alternatives.

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[4] Age group data were obtained from the United Nations' population division (United Nations 1990). These are end-of-the-year estimates and to some extent interpolated between-census estimates. Data on real GDP, investment, and workforce were taken from Penn World Table 5.5 (cf. Summers and Heston 1991).

[5] For example Fair and Dominguez (1991) use a polynomial restriction approach and more parsimonious approaches using dependency rates are common. But according to the only systematic comparison (Bloom and Canning 2001) that we know of, it essentially depends on the purpose of the study what to prefer. (cf. Section 2.7 of our report)

The rate of technological adjustment is proxied by the relative gap in GDP per capita to the world technological leader, taken to be the United States during the post-war period. GDP per capita instead of GDP per worker was chosen to minimise endogeneity issues. This implies that $\gamma_{tj} = \pi(\tilde{y}_{t,US} - \tilde{y}_{tj}) / \tilde{y}_{t,US}$, where π is a constant proportionality factor. This definition of γ_{tj} makes it necessary to exclude the United States.[6]

3.1.2.2 Estimation Results

Some of the estimation results from pooled regressions are presented in Table 3. If we look first at the non-age variables, we note that the investment share, workforce growth, and initial income all have parameters with the expected sign. High investment rates have a positive effect on growth, whereas workforce growth (presumably because of capital dilution) and initial income (because of convergence[7]) have a negative effect on growth rates. The estimated mean approximation error is significantly different from zero. The point estimate of 1.6 per cent is in line with the theory since the mean of the error should mainly catch US growth. See Appendix A for details. In Table 3 ordinary least-squares point estimates with heteroskedasticity- and autocorrelation-consistent errors—see Newey and West (1987)—are presented.

The model has one directly testable restriction. According to equation (6) the investment share and workforce growth parameters should be of the same size, but with different signs. This restriction is not rejected. The estimated total capital share, $\alpha + \beta$, is close to two-thirds, which is in accordance with the stylised value of one-third for the capital share of production. This is in line with the findings of MRW and other researchers. In addition, the estimate of the mean rate of convergence is in line with the findings of most other researchers, even if this may—as Caselli et al. (1996) claim—be due to a dynamic bias. When the approximation error is compensated for the implied rate of convergence $\tilde{\lambda}$ lies between 1 and 2 per cent in the pooled base regressions.

The age share variables are jointly significant according to the Wald test. The age parameter estimates also show the general hump-shape pattern that micro-studies of human capital accumulation lead us to expect. Surprisingly, the two younger age groups do not have significant positive effects on growth. However, we need to keep in mind that only the relative effect can be interpreted here and the country- and time-specific intercepts together with the gap variables and initial income control for any

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[6] This leaves 21 countries in the sample: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Greece, Iceland, Ireland, Italy, Japan, Luxembourg, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, the United Kingdom, and West Germany, i.e., including EU-15.

[7] Quah (1993), among others, has questioned that interpretation. We stick to the conventional interpretation, since our focus is not on convergence but on the age effects.

convergence effects. These convergence effects will be dependent on the absorptive capacity of the economy which is further studied in Section 3.3. If other variables are kept constant, the typical effect of a one percentage point increase in the middle-age share would be around a quarter to a half percentage point increase in growth per worker. The oldest age group, on the other hand, has a significant negative effect on growth.

A negative effect on growth of a large old-age population fits well with conventional ideas. The positive middle-age effect is more surprising. There are, however, many mechanisms by which a large middle-aged population may generate a high steady-state level of income and, hence, high levels of transitional growth. In Halvarsson et al. (2005) it is demonstrated that such patterns are in line with productivity estimates at the plant level in Swedish manufacturing, which indicates that the replacement of middle-aged people at the plant level with young adults will have negative productivity effects. Nordström Skans (2006) shows that this holds also in local labour market areas in Sweden. However, such estimates are riddled by difficulties associated to endogeneity, selection and cohort effects (concerning different educational levels).

It is very likely that the positive middle-age effect also has to do with increased national savings (whether through life cycle effects or government budgets is more uncertain) that have positive effects for which the investment rate is an insufficient control. High levels of self-employment among people over 50 years of age point in the same direction. On theoretical grounds, a positive middle-age effect on growth is therefore not at all implausible. Moreover, earlier empirical studies of age effects support the hypothesis that the middle-age effect on growth is positive, for example McMillan and Baesel (1990), or Malmberg (1994), see Gomez and de Cos (2006) and Feyrer (2004) for more recent examples.

Since Γ is a time- and country-specific variable, the actual parameters estimated will be period- and country-specific (only averages are reported in Table 3). In the shaded columns of Table 3 we report the original OECD regressions side by side with the shaded estimates we get using the original data and program but with the sample restricted to the EU-14 countries (excluding Luxembourg from EU-15[8]). The patterns then change a bit but the relative hump shape of the age coefficients is essentially preserved (it gets pushed upwards a bit in the EU sample but that is mainly due to a shift in the intercept). The main difference to the OECD sample is that the implied rate of convergence is essentially lower, mainly due to the near vanishing of the coefficient on the inverted gap variable. The theoretical restriction on the investment and workforce change is accepted but with less probability than in the OECD sample. Furthermore the implied capital elasticity $\alpha + \beta$ is substantially higher.

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[8] In our new data sources the GDP per capita of Luxembourg is higher than the US counterpart, which causes problems for our specification.

Table 3:
Sample of results from Table 1 (p. 436) in Lindh and Malmberg (1999). Shaded figures are a direct replication on the EU-14 subsample.

Full sample: 168 obs **(EU-14 112 obs)**	**Base regression**					
Dep. variable: g/Γ	**Unrestricted**		**Restriction** $b_1+b_2=0$		**Period**	
	OECD	**EU**	**OECD**	**EU**	**OECD**	**EU**
Constant	**2.98**	**2.13**	**6.61**	**9.74**	**8.00**	**8.63**
	(0.42)	**(0.31)**	**(1.96)**	**(1.98)**	**(2.50)**	**(1.94)**
$1/\Gamma$	**0.015**	**.77E-4**	**0.016**	**9.27E-4**	**0.016**	**0.003**
	(5.80)	**(0.02)**	**(6.03)**	**(0.20)**	**(6.96)**	**(0.83)**
$\ln n_{15-29}$	**-0.82**	**-0.16**	**-0.83**	**-0.39**	**-0.56**	**-0.81**
	(0.90)	**(0.15)**	**(0.93)**	**(0.36)**	**(0.69)**	**(0.83)**
$\ln n_{30-49}$	**0.25**	**0.97**	**0.38**	**1.27**	**0.65**	**1.53**
	(0.22)	**(0.92)**	**(0.34)**	**(1.15)**	**(0.61)**	**(1.49)**
$\ln n_{50-64}$	**3.56**	**4.28**	**3.49**	**4.01**	**2.59**	**2.52**
	(3.65)	**(4.10)**	**(3.61)**	**(3.85)**	**(2.65)**	**(2.62)**
$\ln n_{65+}$	**-2.34**	**-1.49**	**-2.03**	**-0.88**	**-1.52**	**-0.56**
	(3.24)	**(1.92)**	**(3.77)**	**(1.09)**	**(2.80)**	**(0.73)**
$\ln i$	**1.34**	**1.62**				
Restr: $\ln i - \ln(\delta + w)$	**(3.55)**	**(3.93)**	**1.60**	**2.20**	**1.54**	**1.99**
$\ln(\delta + w)$	**-1.92**	**-2.93**	**(5.05)**	**(6.19)**	**(5.55)**	**(6.06)**
	(2.97)	**(4.09)**				
$\ln y_0$	**-0.64**	**-0.21**	**-0.80**	**-0.58**	**-0.95**	**-0.71**
	(1.93)	**(0.66)**	**(4.02)**	**(2.42)**	**(5.02)**	**(3.10)**
60-70, 85-90					**0.78**	**0.77**
(dummy)					**(4.74)**	**(4.84)**
adj R^2	**0.566**	**0.411**	**0.567**	**0.399**	**0.622**	**0.485**
χ^2 **age shares**	**0.000**	**0.000**	**0.000**	**0.000**	**0.007**	**0.001**
χ^2 $\ln i = -\ln w$	**0.478**	**0.131**			**0.492**	**0.159**
F-test. country eff	**0.403**	**0.611**	**0.331**	**0.606**	**0.374**	**0.502**
F-test. time eff	**0.001**	**0.001**	**0.001**	**0.000**	**0.850**	**0.084**
$\alpha + \beta$ **implied**	**0.677**	**0.887**	**0.666**	**0.792**	**0.620**	**0.737**
$\tilde{\lambda}$ **implied**	**0.015**	**0.003**	**0.017**	**0.009**	**0.020**	**0.012**

Notes: Pooled OLS estimates with Newey-West error estimates corrected for heteroskedasticity and autocorrelation. Absolute t-values in parentheses. Significance at the 5%-level indicated by * and at the 1%-level by **. Wald test p-values for joint significance of the four age shares and the restriction $b_1 = -b_2$. F-test p-values for common country and time intercepts in the residuals. $\tilde{\lambda}$ is the mean convergence parameter with $(1-\alpha-\beta)b_5$ added to compensate for the approximation error.

As a first guess the cause of the differences here may be due to less cross-section variation that does not allow identification of the convergence effects with the same precision. Of course, EU countries are also more homogeneous already from the start and thus convergence may actually be less apparent. Since we have only one-third of the degrees of freedom in the smaller sample we would have expected less precise estimates but that does not seem to be the general case. Except for the gap variable and the initial income it rather seems to be the other way around although the explained variance decreases somewhat.

The indication is rather that the convergence process is less well-defined within the EU context than between all of the OECD countries. However, note that the test for time effects in the residual is much less decisive in accepting the null hypothesis of no time effects in the residuals for the EU sample. Thus, the dummy for the 60-70 and 85-90 period is less successful in catching the common time effects in the EU case.

To continue the investigation, using the longer time series now available may shed further light on whether the convergence process is peculiar in the EU or whether it is a different pattern of time effects that explains the differences.

3.1.3 EU-15 Data, Sources and Choices

An extensive explanation of the different characteristics of the data sources we considered is available in Appendix C. In our evaluation of different sources we emphasised country comparability and thus the construction of Purchasing Parity Power indices for deflation of GDP measures. But we also found it necessary to question benchmark levels for those indices in some cases. It is not really possible to give any final verdict on what source is the best, since it will to some extent always depend on the purpose of the analysis and the construction of the model. In our case the comparison to the US GDP per capita level becomes crucial due to the construction of the gap variable. This means that differences in benchmark choices of different sources tend to cause estimation problems by creating outliers that may unduly influence the estimates.

3.1.3.1 Demographic Variables from UN WPP 2004

The demographic data are derived from United Nations World Population Prospects 2004. The data used are total population, population aged 15-64 and shares of population divided into the age categories 0-14, 15-29, 30-49, 50-64 and 65 year olds. In our model, age shares are expressed in logarithms to replicate the OECD study, but this also helps to reduce the problem of collinearity in the sample. Unfortunately, this has the drawback of making the individual age share coefficients somewhat harder to interpret, see the detailed explanation in Appendix B. For the calculation of GDP per worker we simply assumed that the workforce is made up of all the individuals between 15-64 years of age, because alternative measures of labour that would be comparable across countries are difficult to find for such a long period. Experimentation with employment variables also showed that this causes unnecessary and uninformative estimation problems due to business cycle noise.

3.1.3.2 Economic Data from Groningen Total Economy Database (GGDC)

From the GGDC we have used GDP per capita (EKS 2002$) to calculate growth rates and the GDP gap to the world technology frontier, i.e., the US. To define GDP per worker we simply multiplied GDP per capita with the share of the population in the 15-64 age group at a given point in time. Data for unified Germany are only available from 1989, so we simply assumed that the historical growth rate follows the path of the growth rate for West Germany. While this is almost certainly wrong, the error seems to be more or less random since we can distinguish no systematic estimation problem resulting from this. Excluding Germany has almost no effect.

3.1.3.3 Combined Investment Time Series (OECD and World Bank)

Finding sufficiently long time series on investment data was the most problematic part of the data-collecting process. Investment data can be found in many international databases, such as OECD, World Development Indicators (WDI), GGDC and Penn World Table (PWT), but none of these sources provide sufficiently long time-series for the purpose of our investigation. Therefore, we had to combine two different sources of data. We chose to use a combination of OECD and World Bank data, namely OECD’s “total fixed investment excluding stockbuilding as percentage of GDP” derived from Economic Outlook No 78 and World Bank’s “total domestic fixed investment share of GDP” derived from the Nehru dataset. The series are overlapping for more than 15 years and the correlation is quite high. Even if they differ in absolute values they change in the same direction over time. As with GDP, unified Germany is assumed to follow the historical path of West Germany also for the investment share of GDP.

3.1.3.4 Alternative Data Used

In our analysis we tested both PWT and GGDC data for comparative reasons. The different datasets did not produce significantly different results and we therefore chose only to present the estimations based on the GGDC dataset, since this covers the period from 1950 up until 2004 while the PWT only covers the period up until the year 2000.

We also tested other sources of data. Focusing on data from the PWT we estimated the model and found that the change in data source did not have a significant effect on the results. The signs and the relative size of the coefficients remain similar independent of the source of data used. We therefore conclude that our results do not depend on the way the data are constructed, and that we can choose the most appropriate set of data for our analysis, in this case the source providing the longest time series.

3.1.4 Age Structure Effects and Growth in the EU-14, 1950-2005

In Table 4 we present a replication on the data described above of the specifications reported in Table 3 and compare them to the EU-14 results in that table. The general features of the pooled OECD regressions in terms of the age humped coefficients etc. are easily recognised but the hump seems to have been tilted towards a more negative effect from the young adults, moving closer to the original OECD results. The adjusted R^2 is lower but the coefficient on initial income actually becomes highly statistically significant when adding the period dummy. The coefficient on $1/\Gamma$ is much closer to the OECD sample than in the shorter EU sample of Table 3. The implied mean rates of convergence are somewhat lower than in the full OECD case but higher than in the shorter EU subsample.

The mean of the capital elasticities α and β now are much closer to the conventional stylised facts and the restriction on investment and workforce growth coefficients is clearly accepted by the data. The general impression is therefore that adding three more 5-year periods to the data brings us much closer to the original OECD estimates. We conclude that the differences in Table 3 to the EU subsample over the period 1950-1990 are mostly due to insufficient variation in the smaller sample.

The model generally seems to work better using the longer period of the new sample with one important exception. Although the pattern of age coefficients is still recognisable as we add the period dummy none of the age coefficients is now statistically significant nor are they jointly significant on conventional levels. In contrast, the 50-64 coefficient is strongly significant without the period dummy and the negative 65+ coefficient is at least weakly significant. Obviously we have an interaction with time variation causing an identification problem. This is not unexpected since age distributions within EU have stronger similarities in their ageing trends than the corresponding OECD sample.

Could it be that the periods 1960-1970 and 1985-1990 by chance coincide with age structure variation in the EU in such a way that events in the world business cycle are spuriously picked up by the age structure variables? This merits some further investigation in order to be sorted out.

As argued by Attanasio et al. (2000) the common use of 5-year averages to get rid of business cycle effects may not be so well advised in panels since it implicitly assumes that business cycles are well synchronised in 5-year periods across countries, an obviously false assumption. The averaging thus introduces business cycle distortions in the cross-country variation as well as distorting the time variation by sampling at different phases of the cycle both within and between countries. To continue our investigation we therefore move to annual data. With annual data, however, other problems arise. Business cycle noise is now no longer muted and the obvious simultaneity of investment and GDP measures (including the gap variable) becomes more problematic so we also try going in the other direction by using ten-year periods instead.

In Table 5 we report in the first two columns unrestricted estimates on annual and ten-year data, respectively. The basic hump shape of the age coefficients is preserved although looking more tilted towards positive ageing effects as we use ten-year periods. In the ten-year case we get fairly similar results for other parameters as well. But in the annual case we clearly get into trouble both with the investment restriction which is just barely accepted, and even more seriously with a positive although insignificant coefficient for initial income.

It helps, however, to apply the restriction. Then we get fairly similar results both on the annual sample and the ten-year period sample, without much change in the age coefficients. Adding the previous period dummy on annual data again robs the individual coefficients of their significance but this time joint significance for the age shares as a group is preserved, if only just barely. While the ten-year results essentially confirm the five-year results, the age variables are only weakly significant and the strongly negative effect on young adults look suspicious in comparison to results on 5-year and annual data. On the other hand we know that with only 70 available observations precise estimates of highly collinear variables are hard to obtain.

In order to increase the degrees of freedom and still suppress unnecessary business cycle noise we also experimented with rolling averages (defined as the average value over $[t, t+4]$ for the dependent variable, the gap variable and the capital and worker flows). This gives a trade-off in terms of moving averages in the residuals (and a loss of some observations) but the fairly similar point estimates (not reported here) and improved precision reassures us that the basic conclusions from the 5-year panel actually goes through in the annual dataset also.

Table 4:

Replication of 5-year regressions on new data sample using two more periods up to 2000-2005. For comparison the regressions in Table 1 on the old sample up to 1990-1995 are included. Using EU-15 (excluding Luxembourg).

Full sample: 154 obs (Old 112 obs)	**Base regression**					
Dep. variable: g/Γ	**Unrestricted**		**Restriction** $b_1+b_2=0$		**Period dummy**	
	New	**Old**	**New**	**Old**	**New**	**Old**
Constant	3.478	**2.13**	6.82	**9.74**	9.18	**8.63**
	(0.36)	**(0.31)**	(0.98)	**(1.98)***	(1.36)	**(1.94)**
$1/\Gamma$	0.015	**.77E-4**	0.015	**9.27E-4**	0.015	**0.003**
	(4.58)**	**(0.02)**	(5.23)**	**(0.20)**	(5.58)**	**(0.83)**
$\ln n_{15-29}$	-0.69	**-0.16**	-0.79	**-0.39**	-0.80	**-0.81**
	(0.55)	**(0.15)**	(0.64)	**(0.36)**	(0.62)	**(0.83)**
$\ln n_{30-49}$	-0.40	**0.97**	-0.20	**1.27**	1.18	**1.53**
	(0.32)	**(0.92)**	(0.16)	**(1.15)**	(1.02)	**(1.49)**
$\ln n_{50-64}$	4.26	**4.28**	4.28	**4.01**	2.41	**2.52**
	(3.08)**	**(4.10)****	(3.16)**	**(3.85)****	(1.71)	**(2.62)****
$\ln n_{65+}$	-2.482	**-1.49**	-2.26	**-0.88**	-1.26	**-0.56**
	(2.63)**	**(1.92)**	(2.41)*	**(1.09)**	(1.30)	**(0.73)**
$\ln i$	0.92	**1.62**				
	(1.78)	**(3.93)****				
Rest: $\ln i - \ln(\delta + w)$			1.07	**2.20**	0.71	**1.99**
			(2.32)*	**(6.19)****	(1.62)	**(6.06)****
$\ln(\delta + w)$	-1.432	**-2.93**				
	(1.52)	**(4.09)****				
$\ln y_0$	-0.468	**-0.21**	-0.60	**-0.58**	-0.76	**-0.71**
	(0.91)	**(0.66)**	(1.29)	**(2.42)***	(1.60)	**(3.10)****
60-70, 85-90					1.19	**0.77**
(dummy)					(6.00)**	**(4.84)****
adj R^2	0.31	**0.41**	0.31	**0.40**	0.41	**0.49**
χ^2 **age shares**	0.004	**0.000**	0.006	**0.000**	0.100	**0.001**
χ^2 $\ln i = -\ln w$	0.651	**0.131**			0.853	**0.159**
F-test. country eff	0.002	**0.611**	0.002	**0.606**	0.016	**0.502**
F-test. time eff	0.000	**0.001**	0.000	**0.000**	0.000	**0.084**
$\alpha + \beta$ **implied**	0.662	**0.887**	0.640	**0.792**	0.484	**0.737**
$\tilde{\lambda}$ **implied**	0.010	**0.003**	0.012	**0.009**	0.016	**0.012**

Notes: Pooled OLS estimates with Newey-West error estimates corrected for heteroskedasticity and autocorrelation. Absolute *t*-values in parentheses. Significance at the 5% level indicated by * and at the 1% level by **. Wald test p-values for joint significance of the four age shares and the restriction $b_1 = -b_2$. F-test p-values for common country and time intercepts in the residuals. $\tilde{\lambda}$ is the mean convergence parameter with $(1-\alpha-\beta)b_5$ added to compensate for the approximation error.

It is clear, however, that potentially endogenous variables ($1/\Gamma$, $\ln i$, $\ln y_0$) may cause biased estimates. Nor can we exclude that some common time-varying or country-specific variables have been incorrectly omitted in the regressions. In the next subsection we therefore go on to estimate models where we instrument for endogenous variables, as well as testing plausible control variables for sensitivity. That is, we try to find exogenous variables that can predict the endogenous variables in order to get rid of the troublesome correlation between residuals and independent variables in the regression.

Summing up the evidence so far, the replication of the OECD study indicates:

1. Convergence parameters are not substantially different in the EU sample.
2. The age profiles seem fairly similar but dependent on the period length the negative emphasis may be either on the young or the old.
3. There seems to be more evidence in the time-extended sample of omitted country-specific effects.

Table 5:
Annual and ten-year average regressions on new data sample using EU-15 (excluding Luxembourg).

Annual: 770 obs	**Base regression**				
Ten-year: 70 obs					
Dep. variable: g/Γ	**Unrestricted**		**Restriction** $b_1 + b_2 = 0$		**Period dummy**
	Annual	**Ten-year**	**Annual**	**Ten-year**	**Annual**
Constant	-8.14	**5.95**	1.61	**2.99**	4.78
	(0.77)	**(0.62)**	(0.21)	**(0.45)**	(0.64)
$1/\Gamma$	0.011	**0.017**	0.013	**0.017**	0.013
	(3.65)**	**(7.04)****	(4.47)**	**(6.81)****	(4.89)**
$\ln n_{15-29}$	-0.67	**-3.24**	-1.46	**-3.30**	-1.67
	(0.44)	**(2.37)***	(1.06)	**(2.43)***	(1.17)
$\ln n_{30-49}$	-1.36	**1.69**	-0.88	**1.53**	0.61
	(0.98)	**(1.29)**	(0.67)	**(1.24)**	(0.49)
$\ln n_{50-64}$	4.41	**2.83**	4.22	**2.81**	2.65
	(2.91)**	**(2.02)***	(2.91)**	**(2.01)***	(1.67)
$\ln n_{65+}$	-3.41	**-1.80**	-2.64	**-2.00**	-1.76
	(2.83)**	**(2.00)***	(2.43)*	**(2.35)***	(1.58)
$\ln i$	0.31	**1.00**			
	(0.44)	**(2.10)***			
Rest: $\ln i - \ln(\delta + w)$			0.82	**0.91**	0.25
			(1.39)	**(1.91)**	(0.43)
$\ln(\delta + w)$	-1.98	**-0.60**			
	(1.90)	**(0.61)**			
$\ln y_0$	0.16	**-0.67**	-0.29	**-0.56**	-0.48
	(0.26)	**(1.72)**	(0.53)	**(1.50)**	(0.89)
60-70, 85-90					1.32
(dummy)					(6.36)**
adj R ^{2}	0.09	**0.61**	0.09	**0.61**	0.13
χ^2 **age shares**	0.000	**0.000**	0.001	**0.000**	0.019
χ^2 $\ln i = -\ln w$	0.078	**0.712**			0.16
F-test. Country eff	0.001	**0.002**	0.000	**0.009**	0.019
F-test. time eff	0.000	**0.000**	0.000	**0.000**	0.000
$\alpha + \beta$ **implied**	2.09	**0.60**	0.74	**0.62**	0.346
$\tilde{\lambda}$ **implied**	-0.014	**0.015**	0.007	**0.013**	0.014

Notes: Pooled OLS estimates with Newey-West error estimates corrected for heteroskedasticity and autocorrelation. Absolute *t*-values in parentheses. Significance at the 5% level indicated by * and at the 1% level by **. Wald test p-values for joint significance of the four age shares and the restriction $b_1 = -b_2$. F-test p-values for common country and time intercepts in the residuals. $\tilde{\lambda}$ is the mean convergence parameter with $(1-\alpha-\beta)b_5$ added to compensate for the approximation error.

3.1.4.1 Controls and Tests

Some of the economic variables we use are without doubt potential problems regarding the exogeneity assumption behind a classical regression model, i.e., the assumption that the independent variables are uncorrelated with the residual error. Regarding initial income as well as the gap variable used here this is a virtual certainty. (To really put the model to the test we also used, in the instrument regressions, GDP/worker to define the gap variable, in this way almost assuring that some endogeneity bias will be present.) Investment is also likely to be jointly determined with the dependent variable. Our supply of instruments is limited, however, and below we only report estimates using demographic variables as instruments since these are not rejected by the tests..

In Table 6 we report IV estimates on annual data (where the problem should be most serious) using sets of lagged demographic variables as instruments for the endogenous variables. There are substantial problems in finding suitable instruments that the overidentifying restrictions are accepted but some combinations are not rejected by the tests and thus we at least lack evidence that they are invalid. We report three instrument combinations with and without restriction where the overidentifying restrictions of a GMM estimate are accepted and the first-step regressions have a decent explanatory value.

From Table 6 it is clear that if anything, the IV estimates rather emphasise the age coefficient patterns; in particular the hump shape of the age coefficients becomes steeper. The factor flow restriction is not rejected but the p-values are rather marginal—and the coefficient on initial income gets the wrong sign when we implement the restriction—but are in any case insignificant. The Sargan test also becomes marginal under the restriction (except in case III where we also use second lags of age share variables as instruments).

Obviously we cannot claim that these IV regressions successfully solve the problem of endogeneity since the coefficient estimates of the endogenous variables seems to be either inflated or insignificant and with the wrong sign on initial income as we let the factor flow restriction bind. One of our problems is that our measure for workforce growth is not independent of the changes in dependency rates, since the dependency rate and the workforce share of population add up to one. But the set of regressions in Table 6 does demonstrate that if there is endogeneity bias in the plain OLS estimates it is towards underplaying rather than creating the hump-shaped age pattern.

We have made extensive tests with different control variables (see below). In many cases these variables enter insignificantly or with the “wrong” sign, i.e., with unexpected effects on the dependent variable, for example higher capital stocks have negative effects.

Table 6:
Annual IV regressions (GMM) of the specification above using lagged demographic variables as instruments for the gap variable (see below), initial income and factor flows.

714 obs	Instruments I		Instruments II		Instruments III	
Dep. variable: g/Γ						
	Unrestricted	$b_1+b_2=0$	Unrestricted	$b_1+b_2=0$	Unrestricted	$b_1+b_2=0$
Constant	-16.4	-34.1	-4.16	-25.8	-1.01	-18.1
	(0.61)	(1.43)	(0.21)	(1.51)	(0.05)	(1.12)
$1/\Gamma$	0.054	0.042	0.042	0.032	0.050	0.023
	(2.33)*	(2.20)*	(2.54)*	(2.42)*	(2.00)*	(1.29)
$\ln n_{15-29}$	-4.84	-3.15	-3.57	-2.75	-4.17	-2.50
	(2.29)*	(2.06)*	(2.34)*	(2.16)*	(2.30)*	(2.06)*
$\ln n_{30-49}$	-1.40	-2.56	-0.84	-2.21	-0.84	-1.98
	(0.69)	(1.54)	(0.52)	(1.69)	(0.48)	(1.57)
$\ln n_{50-64}$	4.15	3.84	3.54	3.59	3.69	3.28
	(2.61)**	(2.86)**	(2.84)**	(3.04)**	(2.58)**	(2.68)**
$\ln n_{65+}$	-7.61	-7.95	-5.13	-6.25	-5.51	-4.56
	(1.79)	(2.01)*	(1.76)	(2.10)*	(1.65)	(1.43)
$\ln i$	5.51		3.89		4.84	
Restr: $\ln i - \ln(\delta + w)$	(2.40)*	3.32	(2.64)**	2.86	(2.49)*	2.58
$\ln(\delta + w)$	-1.46	(2.43)*	-1.08	(2.72)**	-0.78	(2.75)**
	(0.97)		(0.92)		(0.53)	
$\ln y_0$	-0.04	0.87	-0.60	0.64	-0.89	0.37
	(0.03)	(0.70)	(0.53)	(0.73)	(0.72)	(0.45)
Uncentred R ^{2}	0.24	0.37	0.41	0.47	0.33	0.52
Sargan test	0.272	0.055	0.252	0.103	0.288	0.027
χ^2 age shares						
χ^2 $\ln i = -\ln w$	0.106		0.145		0.105	

Notes: Pooled IV estimates with Newey-West error estimates corrected for heteroskedasticity and autocorrelation. Absolute z - values (robust errors) in parentheses. Significance at the 5% level indicated by * and at the 1% level by **. Wald test p-values for joint significance of the four age shares and the restriction $b_1 = -b_2$. F-test p-values for common country and time intercepts in the residuals. $\tilde{\lambda}$ is the mean convergence parameter with $(1-\alpha-\beta)b_5$ added to compensate for the approximation error.

Instruments	I	II	III
1 lag of $\ln n_{65-79}$			X
2 lag of $\ln n_{15-29}$, $\ln n_{30-49}$, $\ln n_{50-64}$ and $\ln n_{80+}$			X
3 lag of $\ln n_{15-29}$, $\ln n_{30-49}$, $\ln n_{65-79}$ and $\ln n_{80+}$	X	X	
3 lag of $\ln n_{50-74}$	X	X	X
2 and 3 lag of $\ln workpop$		X	
1 lag of *net migration*			X

In addition to such counterintuitive results many of the control regressions need to be estimated by instrumental variables methods where substantial difficulties arise in finding valid instruments. Mostly only lags of demographic variables passed the Sargan tests. The interpretation of the impact of the demographic variables already in the equation was thereby complicated by multiple interaction effects from the prediction equations. We have therefore chosen not to report these regressions in detail but instead give some more details about what we used below.

These controls have been made up of demographic, infrastructural, economic and science/technology variables, some with long time-series (~ 50 years) and some with much shorter ones (< 15 years). Not many of our controls have entered significantly into our models, but a few of them appear to be significant in many different model variants. Using science/technology variables leaves us with an insufficient time dimension that makes it impossible to analyse the demographic effects on the growth rate, but even so, the variables do not provide significant explanatory power to be of use. The infrastructural variables (see Appendix C) have many unreliable values and are not very trustworthy.

Controls that enter the equations significantly are Life Expectancy at Birth (UN), Hours Worked (GGDC), Employment Rate (OECD), Phone Lines (WDI-Canning), Crude Birth Rate (UN), Total Fertility Rate (UN), and Capital Stock (GGDC-WDI). These controls are, however, not significant in all the different model specifications (annual/five-year/IV-GMM). Also, Education (we have used two sources of corrected data due to De la Fuente and Doménech 2000 and Cohen and Soto 2001) in combination with Education squared enters significantly in some specifications, indicating diminishing returns to further increases in average years of schooling.

Controls that were tested but did not enter significantly are Rail Lines, Education linearly entered, Urbanisation, Openness (trade as share of GDP), Density, Urban Density, Energy Power Loss (percentage), Energy Consumption per Capita, Population, Working Age Population, University Attainment, Migration, Patents per Capita, R&D expenditures, among others. Also, a number of possible control interactions were tested for, but did not prove to affect the equations significantly. It is not prudent to present all these results since due to differences in sample size etc. it is impossible to make straightforward comparisons, but the results are available on request, of course.

Time effects and country-specific effects have also been tested for and are significant in a number of different model specifications. Especially, in the IV/GMM regressions inclusion of time effects, either as dummies or as vectors, turn the age structure effect upside-down in comparison to the original models. The reason for this is not exactly clear, but is probably due to the difficulties of separate identification of age/cohort/time effects due to their linear dependence.

Some general features of these sensitivity tests can be noted in order to draw some conclusions from the experiments:

First, significant differences between the positive coefficient for age 50-64 and the negative coefficient for the 65+ group were nearly always preserved and mostly both coefficients were also significantly different from zero. In instrumented regressions, the order of magnitude of these coefficients was about the same as in Table 4. Thus we could conclude that this specific feature was robust to the inclusion of control variables.

Second, we could note that the 30-49 group coefficients were quite varying in sign and size but almost never significantly different from zero. This is more or less in line with the results presented in previous tables. The conclusion is that this group has small or vaguely defined effects relative to the two older groups.

Third, the group of young adults aged 15-29 in some cases showed significantly negative effects as apparent in Table 4 but in many other cases could not be differentiated from zero as in the non-instrumented regressions. Thus controls were affecting the influence of this group to some extent. For example, controlling for fertility tended to make its impact more positive, thus some of the negative impact may be due to the fact that the prime fertility age falls within this age interval.

To sum up the only age group coefficient estimates that insertion of control variables affects to any substantial degree is the young adults. In some cases we can find reasonable explanations, in other cases we cannot. Part of the difficulty is that several of the controls had rather large consequences for the convergence parameters associated with the coefficient on initial income, which only rarely had the expected negative sign. Thus most controls were to some extent proxies also for the distance to steady state, and their impact on coefficients for young adults may be spurious.

As a final test we checked whether the addition of more OECD countries to increase the cross-sectional variation would affect the results in any unexpected way. Annual data results then became a little more unstable but results on five-year periods were fairly similar to those using only EU countries so we refrain from reporting detailed results from this.

3.1.4.2 Discussion of the Results

The question now is how to interpret the empirical results we have presented here. The estimated regressions point to a stable and robust connection between variations in the age distribution of the population and the growth process contingent on a variety of different controls. We have one set of controls for broad factor flows (capital investment and potential workforce changes) and technological convergence which we include consistently although they do not always turn out significant nor with expected signs according to the theory. Other controls have been added more ad hoc. Some controls do affect the impact from the younger part of the age distribution and then mostly the initial income variable as well.

This pattern suggests that young adults play a role in the convergence process and as shown in Section 3.3 they seem to be important for the rate of absorption of new technology from abroad. The most likely explanation therefore seems to be that their education is more recent—and often higher than in the older workforce. The older workforce may for several reasons be more reluctant to learn and adopt new methods of production. One naturally comes to think of IT technology and computers where younger persons have obvious advantages from being educated with the technology. In a broad survey of studies on the capabilities of individuals at different ages, Skirbekk (2004) has pointed out that some capacities and abilities start to deteriorate at very early ages (for example learning abilities) while others keep growing with age (for example verbal abilities and social skills) well into middle age and can compensate as the individual ages and changes jobs in the career. Thus the young and the old have different skill profiles and there is some evidence that young and older (at least prime-age) labour therefore are complements to each other (Macunovich 2002).

One hypothesis based on this reasoning would therefore be that the efficiency of standard production tends to increase with experience because it mainly requires managerial skills like good organisation, a stable and not too mobile workforce. The efficiency of technology adoption requires fast learning skills and flexible labour that can easily be moved around as experimentation with the new techniques require. The combination of both of these factors provides synergies by promoting stability as well as innovation.

While this is speculative and hard to prove it does provide one potential venue for explanation of the empirical results of this study. From our macroeconomic perspective we cannot really determine how reasonable such explanations may be, only that the age-growth relations we uncover at least do not refute the possibility that this young-old complementarity may be an important ingredient behind economic growth. Wasmer (2004) argues that we may find similar explanations for why the more rigid European labour markets seem more efficient in exploiting mature technologies while the more flexible American labour market has its comparative advantage in innovative technologies.

If so it follows however that changing proportions of different age groups in the workforce are likely to require changes in both labour market institutions and policies in order to take advantage of different types of growth opportunities.

But our results may be explained also from other perspectives than the changing composition of labour supply. Also the composition of supply and demand of capital changes with the age structure. Ageing populations require a shift towards generally more labour-intensive services with often rather different technological characteristics than large-scale production of goods. That may well explain why increases in the elderly dependency rates have deleterious effects on productivity growth. But again this cannot be proved from the macroeconomic vantage point. It could also be crowding out effects on private investment by public investment where we have no solid measure of the productivity effects. GDP measures from the National Accounts will typically have an arbitrarily assumed rate of public productivity growth, often set to zero in the absence of information to the contrary. Increasing demand for non-market production in terms of care provided by relatives and family may provide another channel with similar consequences.

The decrease of domestic saving when the population retires to a higher degree could—through some as yet uncovered mechanism—depress investment. This is often taken for granted in the growth literature due to closed-economy assumptions. That assumption is blatantly false and no one as yet has been able to provide any generally accepted explanation of the puzzling and unexplained correlation between domestic saving and investment (Feldstein and Horioka 1980).

It is fairly easy to come up with stories like this which are more or less convincing in different institutional contexts and countries. The fact that we actually find pervasive and stable results when replicating the old OECD study on new data with a European sample of countries suggests that there may well be a diversity of channels which are country-specific but which in the end lead to similar results.

By and large, the magnitudes reported by Kelley and Schmidt are consistent with many other results. Krueger (1968) finds that age structure and education can account for close to half of the differences in country per capita income at that time. Bloom and Williamson (1998) find that 30 to 40 per cent of East Asian per capita growth is explained by the demographic dividend (cf. Section 2.6.2 of this report).

An analyst may view the explanatory value of demography in different ways. One could maintain that only the demographic core constitutes a purely demographic explanatory effect, since the translational effect is just a matter of more precise measurement and human capital is only proxied by life expectancy, thus constituting no explanation per se. Or one could also object that not only are the demographic variables the ultimate causes of per capita growth but with a high probability the country-specific effects as well and the financial and political variables are to some extent influenced by demography. Evidence for this could easily be obtained since there are systematic differences between countries with young and old population structures. Or another analyst might take the view that also the demographic core is proxying for some more behavioural economic measure (such as savings). There is really no clear resolution from aggregate studies to this question of causality and explanation. The exact nature of the mechanisms behind these correlations needs to be studied more closely in micro data.

No matter what position one may take on this issue, however, the overall results indicate that one-third of growth can be predicted by country-specific effects (assumed to be constant) and one-third can be predicted by demographic variables which can be projected with fairly high certainty. Regardless of its explanatory value this finding is valuable for forecasting purposes. For policy design a deeper understanding of the mechanisms behind the correlations is, of course, a necessity.

While details regarding the estimates and the interpretations are certainly debatable and, in view of the methodological difficulties discussed above, need to be interpreted very cautiously one must concede that demographic factors seem to matter just as much or more than the factors commonly stressed in the growth literature, such as technological change, innovation and political/institutional explanations. At the very least this indicates that any economic growth study which does not control for demography is very likely to suffer from omitted variables bias. Agell et al. (1997) provide an illustration of this in the context of government expenditure and growth where the negative correlation between the government expenditure share of GDP and GDP growth disappears as soon as the population share above 65 is controlled for.

The causal interpretation is, as noted, a much more contentious issue. First, the identification of causal relations in cross-country growth regressions is in itself a very difficult issue, not least illustrated by the Bils and Klenow (2000) paper that strongly questions whether human capital measures cause growth as an input in production, or whether education increases due to higher income that allows people to afford more education as a consumption good. One can test for endogeneity though and thus at least give some guidance as to whether variables are simultaneously determined or not. The high inertia of demographic structures and of most demographic variables makes it unlikely that they are subject to any substantial endogeneity bias. In any case, to the extent to which it can be determined by instrumental variables approaches there is little evidence that the demographic variables are affected by endogeneity bias, see e.g., Brander and Dowrick (1994) who extensively test whether birth rates are caused by income growth. Since birth rates together with migration may be the two demographic variables most likely to be endogenous with respect to growth, this result is rather strong. Still, failure to reject the exogeneity hypothesis by econometric tests is far from being a reliable indicator of actual causal relations. Consider for example birth rates. The decision to have a child (or to ensure its survival if pregnancy was accidental) is a very long-term decision that, as we would assume, depends on future expectations of economic opportunities that may well differ among individuals of different social status and thus are systematically related to contemporary economic variables in very complex ways that cannot be readily unveiled by contemporary correlations.

Although caution is called for it bears emphasising that in comparison to nearly all other variables that at one time or another have been included into cross-country growth regressions, the demographic variables are mostly better measured and more well-defined and in all likelihood suffer from less endogeneity problems. In comparison to factors such as political stability, technological change and innovation, democracy and financial market depth—to take but a few examples—which are all measured by more or less rough proxies or dummies, the demographic variables are data of considerably higher quality.

Forecasting studies using demographic variables have been made. McMillan and Baesel (1990) and Fair and Dominguez (1992) can be mentioned here. To our knowledge, there are few systematic studies doing out-of-sample evaluation of the forecasts.

Lindh (2004) is a study of Swedish data where GDP and inflation forecasts based on demographic variables are evaluated by the performance of recursive out-of-sample forecasts during the 1990s. It is demonstrated that the forecasts beat the naïve alternative of unchanged levels which is a minimum requirement for usefulness but actually the demographically based forecasts are in many instances comparable or even better at longer horizons than one year to those of professional forecasters. Lindh and Malmberg (2004) estimate a global panel model and again show that this model on average beats the naïve forecast in out-of-sample tests.

Part of the explanation is that in forecasting you need to predict the independent variables and demographic forecasts are simply much better than forecasts of independent economic variables due to the high inertia inherent in demographic structures. This immediately improves the forecasting precision. The stability and robustness of the correlations which have been demonstrated here also contribute towards more reliable long-term forecasts. Lindh and Malmberg (2004) demonstrate, however, that there is a slowly shifting impact of the age structure with the level of development. The model used in this paper assumes that the shift in impact is related to the convergence process, which essentially implies that the demographic variables have a higher proportional impact on the growth rate in countries with a lower level of income. In the global estimation one also has to take account of a drift in the peak of the hump-shaped age effects. The peak effects are at lower ages in less developed countries and shift towards the middle age in the more developed countries. In the estimation this can be modelled by interacting age structure with life expectancy. As life expectancy rises, the peak shifts towards higher ages.

The reason for this shift is twofold. A high life expectancy implies increased pay-off to human capital investments in the beginning of the life cycle. This tends to shift the start of working life upwards: from around age 15 to age 20 or even above in some EU countries, for example. The other reason is that a higher life expectancy is also associated with better health and lower morbidity and mortality over the whole working life period, increasing the proportion of fit workers available in the middle-aged section of the age distribution. In the initial stages of the demographic transition this is very important. Boucekkine et al. (2003) show that it was of consequence even in the budding industrialisation in Europe in the 18th century and before. As mortality generally decreased at adult ages in the 19th and the beginning of the 20th century in Europe and North America, it was followed—with a more or less long lag—by decreases in fertility that drew down dependency rates and accelerated economic growth rates to levels never observed before.

In the late 20th century, however, mortality gains are predominantly taking place at ages above retirement age. This means that dependency rates start increasing again but now it is the elderly dependency rate that dominates the process. According to the estimates reported here this has had a dampening effect on growth rates, and it follows that the continued population ageing in the EU will dampen growth rates as we move further into the 21st century. The global income study referred to above shows, besides an overall dampening effect of age structure like the one observed in this EU study, that the higher life expectancy effect also tends to tilt the hump in such a way that the negative effect of the elderly proportion becomes smaller and may even become positive eventually.

Since our experience and observations so far only encompass young populations in the less developed countries, mature populations in the emerging economies, and middle-aged populations in the highly developed countries (with less than one-fifth of the population above 65), we do not really have any firm evidence on how the relation between age distribution and economic growth will appear as really old economies start having a quarter or even a third of the population above 65. This is beyond our horizon and thus extrapolation of results to this era is necessarily tentative and contingent on the historical correlations.

Caution nevertheless suggests that in the absence of evidence to the contrary we prepare for a rather negative GDP growth in the future. This still leaves us at a rather comfortable overall level of living so it should not be depicted as anything catastrophic. However, even so it is still interesting to consider how possible improvements of this slightly gloomy perspective could be achieved.

For institutional and traditional reasons as well as through somewhat perverse incentives in many pension systems the actual retirement ages have actually been decreasing in Europe, which may well be a contributory factor behind the negative elderly effects described above. It is, however, difficult to believe that this trend cannot be reversed given more reasonable incentives and ever-increasing health. In fact, for Sweden there is now solid evidence for an increasing labour force participation among the elderly. In that case it may well be that the more optimistic global results will be prevailing over the results in this study. Some results from microstudies at plant level do suggest that such increases in elderly labour force participation may be highly beneficial to future productivity growth. Evidence pro and contra is available in Prskawetz et al. (2006). Our attempts to control for labour force participation in terms of hours worked and employment did not turn up any evidence in favour of higher elderly participation rates, rather the insertion of such controls pointed in the direction that problems were associated with the younger part of the age distribution. It is therefore important to note that due to lack of relevant, reliable and comprehensive data on labour force participation in different age groups we were not really able to go into this question here.

In a previous report (Institute for Futures Studies 2006), attempts to assess this issue proved unsuccessful as well. This indicates that the issue is perhaps not as decisive as intuition would suggest. One should observe in this context that a great deal of work in the economy is household production of goods and services, and it is not a foregone conclusion that transferring this into the accounted-for market sector necessarily increases growth. In fact one could argue that some such services are better performed outside the market sector. Of course, since we lack the data to assess that, we do not really know. But it is remarkable that trying to control for actually supplied labour does not yield any decisive changes in the model estimated here.

Before concluding this discussion some as yet unmentioned technical points need to be illuminated. While endogeneity problems turned out rather troublesome for many of the economic variables in the regression above, the demographic variables seemed to be even strengthened in the IV regressions. It is obviously the case that demographic structure, even if clearly determined by economic resources in the very long run, will be predetermined to a considerable extent when looking at short- or even medium-term relations. That does not hold for all demographic variables though. Both fertility and migration can react rather promptly to changes in the economic conditions. The point to observe is that this only slowly affects the demographic structure, beginning with the younger age groups and impacting on the older section of the age structure only after several decades. This fact may explain why we find the younger section of the age structure to be more sensitive to different controls, specifications and instruments.

The demographic inertia does, on the other hand, imply that age share variables appear trended over fairly long time intervals. Although it is theoretically clear that age shares per se in the long run cannot be unit root processes since they are naturally bounded, there is still a certain risk that the high persistence can cause spurious regression results. As has been a constant worry in the macroeconomic modelling literature for the past decades spurious regression results invalidate inference in many models unless it can be shown that variables are cointegrated (Granger 1981, Nelson and Plosser 1982). However, Österholm (2004) showed that in OECD data, GDP per capita and age structure are indeed cointegrated variables thus alleviating the fear of spurious regression results. Even if that result should be a fluke econometric theory, Phillips and Moon (1999) show that this concern is much less in the case of panel data since spurious results from integrated data generating processes (DGP) only arise under fairly special circumstances because country heterogeneity actually aids in achieving correct identification.

3.1.5 Conclusions

In this part of the study we reported a replication of a previously published model (Lindh and Malmberg 1999) on OECD data. The model is designed to evaluate how changing age structures affect the rate of economic growth. As expected from other empirical studies, increasing dependency rates in the population will have negative effects on per capita GDP growth. Partly this is a simple accounting effect but the 1999 study as well as other studies strongly suggest that per worker GDP will also be adversely affected by increasing dependency rates. The mechanisms at work here may be quite diverse, ranging from time constraints on a working population having to spend more time on unaccounted-for household chores to demand shifts towards services with slower productivity growth and possibly also involving increasing relative prices for capital due to lower saving rates. Even if there is by no means a consensus on how important those mechanisms may be under different circumstances, it seems generally accepted that an ageing population will trigger a dampening of the economic growth process.

The 1999 study by Lindh and Malmberg goes one step further by subdividing the working population and somewhat surprisingly finds that it is the oldest part of the working population that has the most clearly growth-stimulating effect contingent on controls for technological gaps and convergence processes (and factor accumulation in terms of investment and potential workforce growth). Although some other supporting results are available most analysts remain sceptical about this result. For the countries in the European Union that are facing an ageing workforce it matters quite a lot for both policy and future prospects for financing the care of ageing populations whether the stimulating effect of an elderly workforce is a stable and robust result or fragile and contingent on a specific sample of OECD countries as well as the given time period and data source.

What we have shown here is that the result of the 1999 paper can indeed be replicated in EU-14 over a longer time period. This result is robust to a number of checks and tests performed in order to study the stability and validity of the estimates. Adding controls for other demographic, economic or structural factors the qualitative pattern emerges again and again except for young adults which are sensitive to some controls. The effect of young adults may vary from clearly negative to insignificant, depending on what controls are added. As shown in Section 3.3. below, there is a positive effect of young adults on the absorptive capacity or rate of convergence to best-practice countries. Since this is controlled for in this part, there is no contradiction between these results.

That middle-aged adults aged 50-64 years have a positive effect and retirees aged 65+ have a negative effect is, however, a very robust result. Thus, a fairly safe prediction is that as the baby boomers get older, an ageing workforce seems to pose little problems for the general EU growth—until they start to retire, of course. In most countries this is still some years into the future, although there are some countries, like Sweden where it is imminent, or Germany where that stage has already been passed.

In Section 4 of this report an analysis of growth prospects based on the results obtained here is undertaken. But even without any detailed quantitative analysis the policy perspectives that open up are clearly somewhat worrying. Most analysts have been hoping for increasing rather than decreasing growth in order to deal with the future increases in elderly dependency rates. If such hopes turn out to be untrue there will clearly be problems in financing pensions or elderly care—in fact, in some countries both. While this is the bad news, the good news is that for most countries there is still some delay before they have to brace themselves for budgetary problems. Exploiting that period of time to prepare for, and invest in, the future is therefore on the top of the European agenda.

As emphasised above, demographic structures are not set in stone. Although it is hard to do much about the older part of the distribution (except for extreme and barbaric measures that need not be discussed), the younger part of the age distribution can be affected quite substantially through fertility and migration. Alas, this cannot be done without costs and a central policy problem brought to the fore by ageing is to balance these current costs against future benefits. The practical consequences of different demographic scenarios will be further explored in the prospective analysis in Section 4 of this report.

3.2 Demography and Growth in the EU-15: How Robust is the Link?

The empirical exercise carried out in Section 3.1 is derived from a theoretical model in the spirit of neoclassical growth theory. The empirical literature on cross-country growth regressions, however, tends to use a wide range of other variables (not necessarily stemming from any particular theory) in order to explain differences in economic growth across countries. In this section we investigate whether demographic variables (proportions of population in different age groups and their change in time) are robust determinants of long-run economic growth in the EU-15 by taking into account the variation in parameter estimates depending on the set of variables which is controlled for in the regression. This exercise presents several difficulties, since the number of observations is limited (if long-run patterns are taken to represent sustained differences across countries over very long periods of time) and model uncertainty plays a very important role in the assessment of robustness in growth determinants (see Levine and Renelt 1992; Sala-i-Martin 1997a, 1997b; Sala-i-Martin et al. 2004; Crespo-Cuaresma 2002; Crespo-Cuaresma and Doppelhofer 2006).

Since the influential contributions of Kormendi and Meguire (1985) and Barro (1991), the use of cross-country regressions in order to identify variables that are robustly (partially) correlated to growth of GDP per capita has become a fundamental part of the empirical agenda in economic growth research. The empirical literature on economic growth has used an incredibly vast amount of economic, social and political variables with the aim of finding robust determinants of GDP per capita growth. Durlauf and Quah (1999), for instance, name more than eighty variables that have been included at least once in a cross-country growth regression. Levine and Renelt (1992) applied Leamer's (1983) extreme bounds analysis to check the robustness of the determinants of long-run growth to changes in the information set that the researcher conditions upon when obtaining estimates of the partial correlation. The analysis concluded that practically no variable among those used by Kormendi and Meguire (1985) and Barro (1991) is robustly correlated with average GDP per capita growth. Sala-i-Martin (1997a, 1997b), however, considers that the robustness test implied by extreme bounds analysis is too strong for any variable to pass it in the framework of empirical growth research, and proposes analysing the entire distribution of estimates of the partial correlation of a given variable and long-run growth. Adopting such an approach, Sala-i-Martin (1997a, 1997b) attaches a "confidence level" (in terms of the probability mass on one side of zero in the empirical distribution of the estimate of the partial correlation) to each variable, and proposes to consider those variables with a confidence level of 95% or more as robustly correlated with long-run growth. Using this method, the conclusion is that there exists a considerable number of economic, political and demographic variables that are actually (partially) correlated to growth in a robust fashion.

Bayesian model averaging methods allow to account for model uncertainty both in the size of the model and in the choice of explanatory variables. Sala-i-Martin, Doppelhofer and Miller (2004) introduce an alternative approach, Bayesian Averaging of Classical Estimates/BACE, that builds upon Bayesian model averaging without needing to specify prior distributions for all parameters in the econometric specification.[9] The method can be applied simply by repeated OLS estimations and presents a tractable setting aimed at accounting for model uncertainty in linear growth regressions. The results in Sala-i-Martin, Doppelhofer and Miller (2004) are in line with Sala-i-Martin (1997a, 1997b), indicating that there is a sizeable group of variables which are robust explanatory factors for economic growth.

None of the studies above include the relative size of age groups or their change in time as potential growth determinants. In this section we will apply the method put forward by Sala-i-Martin (1997a, 1997b) in order to assess the robustness of these demographic variables as determinants of growth differences in Europe for the period 1960-1990. The methodology is implemented as follows. We consider a growth regression with the annual average growth rate of GDP per capita in the period 1960-1990 as endogenous variable and a fixed set of regressors formed by three variables which tend to be included systematically as covariates in the empirical growth literature (initial level of GDP per capita, initial level of primary schooling and initial life expectancy) and by a demographic variable (alternatively, the proportion of workforce in age groups 15-29, 30-49 and 50-64 in 1960 and their growth rates for the period 1960-1990). To this specification we will add iteratively two variables from the pool of growth covariates considered by Sala-i-Martin (1997a, 1997b), formed by the 59 variables specified in Table 8. The basic specification is thus

$$y_i = \alpha + \gamma_1 GDP60_i + \gamma_2 LIFEX60_i + \gamma_3 PRIM60_i + \beta\ X_i + \sum_{j=1}^{2} \phi_j Z_{j,i} + \varepsilon_i$$

where y is the average growth rate of GDP per capita in the period 1960-90, *GDP60* is the initial level of GDP per capita (in logs), *LIFEX60* is the initial life expectancy and *PRIM60* is the initial level of primary school enrolment. X denotes the demographic variable the robustness of which we are interested in measuring, and the Z variables are chosen from the pool of potential growth covariates in Table 8. For a given pair of Z variables, an estimate of β is obtained using the sample of 15 EU countries, together with an estimate of the variance of β. This is repeated for all possible pairs of Z variables, and meta-estimates of β and its variance are computed by averaging the estimates obtained over all models. Alternatively, each model can be weighted by its relative likelihood with respect to the sum of likelihoods in all estimated models in order to weigh up those estimates that fit the data better and

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[9] See also Fernández, Ley and Steel (2001) and Crespo Cuaresma and Doppelhofer (2006) for other approaches to robustness evaluation in cross-country growth regressions using Bayesian model averaging.

penalise those that fail to reproduce the cross-country growth patterns of the sample. The results of the robustness exercise are presented in Table 7. It should be noted that, although the single estimates are based only on 15 observations, the meta-estimates are computed using 1275 different estimates of β . Notice that the small number of data points for each estimate would tend to bias our results towards finding less robust covariates, which therefore reinforces the evidence of robustness if found. The set of Z variables, furthermore, also contains demographic variables which could be correlated with our variables of interest. It could be argued in addition that the initial life expectancy variable, which belongs to the group of fixed covariates in the robustness exercise, correlates with age group shares. The potential existence of multicolinearity would also tend to bias our results towards finding no robustness, and should be seen as reinforcing the evidence of robustness.

The first column in Table 7 shows the average estimate of β, both weighted by the relative likelihood and unweighted. Column 2 shows the square root of the meta-estimate of the variance of β. Column 3 presents the corresponding meta-estimate of the t-ratio for robustness, together with the corresponding level of significance. The fourth column shows the proportion of estimates of β which appeared positive in the full set of estimated models. This figure can be interpreted as measuring the robustness of the estimate if we consider the empirical distribution of actual estimates instead of the asymptotic distribution, which would be the relevant one if we use the meta-estimate of the t-ratio. For positive (negative) meta-estimates, figures higher (lower) than 0.9 (0.1) (indicating more than "90% robustness") are in bold.

Table 7:
Robustness exercise. Results.

Unweighted results	β	$\sigma(\beta)$	t_β	**#(β>0)**
n_{15-29}	-0.016	0.022	-0.730	**0.064**
n_{30-49}	0.025	0.037	0.656	**0.918**
n_{50-64}	0.006	0.021	0.280	0.794
Δn_{15-29}	0.016	0.014	1.190	**0.956**
Δn_{30-49}	-0.044	0.022	**-2.053****	**0.003**
Δn_{50-64}	-0.003	0.016	-0.200	0.299

Weighted results	β	$\sigma(\beta)$	t_β	**#(β>0)**
n_{15-29}	-0.008	0.007	-1.031	**0.064**
n_{30-49}	0.023	0.007	**3.251*****	**0.918**
n_{50-64}	0.002	0.007	0.248	0.794
Δn_{15-29}	0.002	0.005	0.367	**0.956**
Δn_{30-49}	-0.028	0.006	**4.775*****	**0.003**
Δn_{50-64}	0.009	0.003	**2.532*****	0.299

/* stands for significance at the 5%/1% level.

The results based on the empirical distribution of estimates indicate a robust positive partial correlation between the initial proportion of the active population in the age group 30-49 and growth and a robust negative partial correlation for the case of the proportion of the active population in the age group 15-29. This is coupled with robust partial correlations with opposite signs of their respective changes in the period. The change in the 50-64 age group appears only robust if the t-ratio in the weighted results is considered. Although the sign of the meta-estimates may at first sight seem puzzling, a closer look at the convergence patterns in the demographic structure across European countries may shed some light on the nature of the relationship between demography and economic growth which is quantified in Table 7. Figure 2 presents the scatterplot of initial size of each age group against its change in the period 1960-1990, together with a regression line. The negative slope of all estimated lines implies convergence within each age group across EU-15 countries. Those countries that started with low proportions of a given age group tended to increase the size of that group, while the opposite is true for countries that started with a high proportion, thus leading to a homogeneisation of the demographic structure across European nations. Against this background, the results presented in Table 7 paint a clear-cut picture of the nature of the effects of demography on economic growth for the sample of EU-15 countries. Countries that started with a relatively low proportion of the workforce in the 15-29 age group—and therefore tended to expand this age group in the period being considered—experienced relatively higher growth rates of GDP per capita. The strong correlations existing among countries and in time for demographic variables imply that this group corresponds with those countries with a high initial proportion of the workforce in the 30-49 age group, and therefore a low (or negative) change in this age group for the period 1960-1990. The nature of this effect will be studied in depth in the following section.

Figure 2:
Convergence in age structure 1960-1990, EU-15.

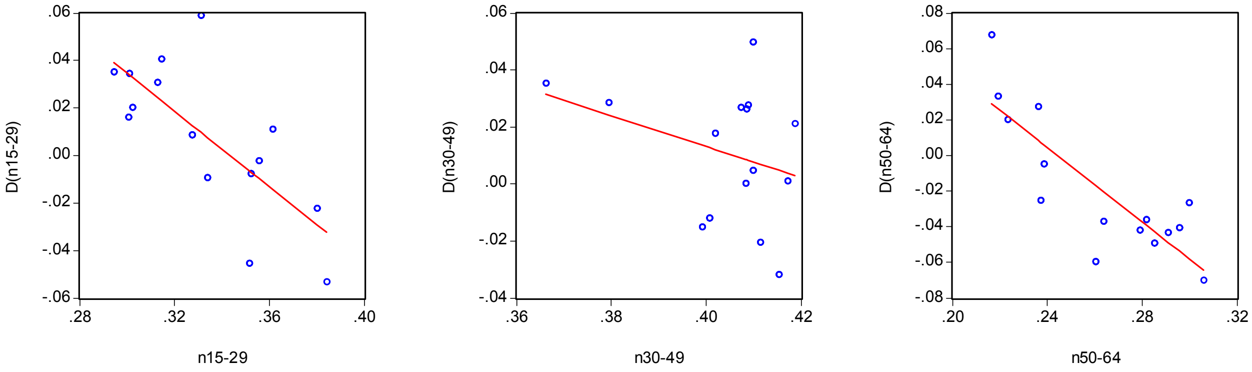

Table 8:
Potential growth covariates.

1	**Equipment Investment**. See Delong and Summers (1991)
2	**Number of Years Open Economy**. Index computed by Sachs and Warner (1996)
3	**Fraction of Confucius**. Fraction of population that follows Confucius' religion/Taoism (see Barro 1996)
4	**Rule of Law.** See Barro (1996)
5	**Fraction of Muslims.** See Barro (1996)
6	**Political Rights.** See Barro (1996)
7	**Latin American Dummy.** Dummy for Latin American countries.
8	**Sub-Sahara African Dummy.** Dummy for sub-Saharan African Countries.
9	**Civil Liberties.** Index of civil liberties from Knack and Keefer (1995)
10	**Revolutions and Coups.** Number of military coups and revolutions. (Barro and Lee (1995), from now on BL95).
11	**Fraction of GDP in Mining**. From Hall and Jones (1996).
12	**S.D. Black Market Premium.** Standard Deviation of Black Market Premium 1960-89. Levine & Renelt (1992)
13	**Primary Exports in 1970.** Fraction of primary exports in total exports in 1970. From Sachs and Warner (1996b)
14	**Degree of Capitalism**. Index of degree in which economies favour capitalist forms of production. From Hall and Jones (1996)
15	**War Dummy.** Dummy for countries that have been involved in war at any time between 1960 and 1990. BL93.
16	**Non-Equipment Investment.** See Delong and Summers (1991).
17	**Absolute Latitude**. See Barro (1996)
18	**Exch. Rate Distortions.** See BL93.
19	**Fraction of Protestants**. See Barro (1996)
20	**Fraction of Buddhists.** See Barro (1996)
21	**Fraction of Catholics.** See Barro (1996)
22	**Spanish Colony.** Dummy variable for former Spanish colonies. See Barro (1996)
23	**Public Investment Share.** Investment share as fraction of GDP (BL93).
24	**Frac. Pop. Spk. English.** Fraction of the population capable of speaking English. From Hall and Jones (1996)
25	**Defense Spending Share.** Public Expenditures in defence as fraction of GDP (BL93).
26	**Age.** Average age of the population. BL93.
27	**Public Consumption Share.** Public consumption minus education and defence as fraction of GDP (BL93).

28	**Average Inflation Rate 60-90.** See Levine and Renelt (1992).
29	**Size Labour Force (Scale Effect).** See BL93.
30	**Frac. Pop. Spk. Foreign Language**
31	**Black Market Premium.** Log of (1+Black Market Premium). (BL93)
32	**S.D. Inflation 60-90.** Standard deviation of the inflation rate 1960-1990. Levine and Renelt (1992).
33	**Growth Rate of Population.** Average rate between 1960 and 1990. BL93**.**
34	**Ratio Workers to Population.** BL93.
35	**Fraction of Jewish.** See Barro (1996).
36	**Liquid Liabilities to GDP.** Ratio of liquid liabilities to GDP (a measure of financial development). King and Levine (1993)
37	**Average Years of Primary School.** Average years of primary schooling of total population in 1960 (BL 93).
38	**French Colony.** Dummy variable for former French colonies. See Barro (1996).
39	**Political Assassinations.** Number of political assassinations. Taken from BL93.
40	**S.D. Domestic Credit.** Standard deviation of domestic credit 1960-89 (King and Levine (1993)).
41	**H*log(GDP60).** Product of average years of schooling and log of GDP per capita in 1960. (BL93)
42	**Fraction of Hindus**. See Barro (1996)
43	**Avg. Years of Schooling = H.** Average years of education of total population in 1960. (BL93)
44	**Secondary School Enrolment.** See BL93
45	**Ethnolinguistic Fractionalisation.** Probability of two random persons in a country not speaking same language. See Easterly and Levine (1996).
46	**Outward Orientation.** Measure of outward orientation. From Levine and Renelt (1992).
47	**Index of Democracy 1965. Qualitative index of democratic freedom.** From Knack and Keefer
48	**Tariff Restrictions.** Degree of tariff barriers. From BL93.
49	**Free Trade Openness.** Measure of free trade. From BL93
50	**Avg. Years of Higher School.** Average years of higher education in the total population in 1960. (BL 93)
51	**Avg. Years of Sec. School.** Averge years of secondary schooling in the total population in 1960 (BL93).
52	**Political Instability.** From Knack and Keefer (1995)
53	**Gov. Education Spending Share**. Public expenditures in education as fraction of GDP (BL93).
54	**Higher Educ. Enrolment.** Enrolment rates in higher education in 1960 (BL93).
55	**British Colony**. Dummy variable for former British colonies. See Barro (1996)
56	**Urbanisation Rate.** Fraction of population living in cities. See BL93.
57	**Growth of Domestic Credit 60-90.** Growth rate of domestic credit 1960-90. Levine and Renelt (1992)
58	**Area (Scale Effect)** Total area of the country. BL93.

59	**Terms of Trade Growth.** Growth of terms of trade between 1960 and 1990. BL93.
Log (GDP per capita 1960). Log of Summers-Heston GDP per capita in 1960. From BL93.	
Life Expectancy. Life expectancy in 1960 (BL93).	
Primary School Enrolment. Secondary school enrolment rate in 1960. BL93.	

Source: Sala-i-Martin (1997b)

3.3 Demography, Growth and Technology Adoption in the EU-15

The results in Sections 3.1 and 3.2 indicate differential effects of various age groups on economic growth. In this section we will look more deeply at the nature of such effects by empirically analysing the influence of age structure on technology adoption (and, subsequently, on GDP per capita growth) in the EU-15 using a panel setting that spans 55 years (1950-2005). From the point of view of the modelling strategy, we will now deal with interaction effects of age structure and initial development, so as to better understand the nature of the direct and indirect effects that were unveiled in Sections 3.1 and 3.2.

The theoretical setting is kept as parsimonious as possible so as to prevent the analysis from becoming a pure data-mining exercise. In this sense, we specify a simple production function where the distance to the technological frontier (proxied by the ratio of GDP per capita of a given country in a period to the income level of the US) determines the speed of technology adoption. Furthermore, we will hypothesise that the age structure of the economy can have an effect on the technology adoption parameter. This hypothesis will be empirically tested, making use of recent developments in the econometric literature of threshold estimation (see, e.g., Hansen 1996, 2000).

3.3.1 Theoretical and Empirical Setting: Demography and Technology Adoption

Consider a Cobb-Douglas production function with constant returns to scale[10] and Harrod-neutral technological progress,

$$Y(t) = A(t)K(t)^{\alpha} L(t)^{1-\alpha} .$$

The growth rate of GDP per-capita (*y(t)*) can thus be written as

$$\Delta \ln y(t) = \Delta \ln A(t) + \alpha(\Delta \ln K(t) - \Delta \ln L(t)) ,$$

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[10] In the empirical specification, we also estimated an alternative model without constant returns to scale in the Cobb-Douglas specification, that is, for a production function such as $Y(t) = A(t)K(t)^{\alpha} L(t)^{\beta}$. An F-test for $\alpha+\beta=1$ could not reject the null hypothesis of constant returns to scale, so we keep the assumption throughout the text. Detailed results on the estimates of the general Cobb-Douglas function are available from the authors upon request.

where $y(t)=Y(t)/L(t)$. Assume, furthermore, that the change in technology is a function of the distance to the technological frontier, which is proxied by the (log) difference in GDP per-capita between the country in question and the US. This leads to the following discrete version of the specification above that can be estimated,

$$(\ln y_{i,t+\tau} - \ln y_{i,t})/\tau = \lambda(\ln y_{US} - \ln y_{i,t}) + \alpha(\ln K_{i,t+\tau} - \ln K_{i,t})/\tau - \alpha(\ln L_{i,t+\tau} - \ln L_{i,t})/\tau + \varepsilon_{i,t}$$

where the variables are growth rates between period t and period $t+\tau$ and the error term is in principle formed by a fixed country-specific constant, a time-specific effect and a random i.i.d. shock. We will study the effect of the age structure of the labour force on the absorption of technology, materialised in the parameter λ. The idea is to obtain a "demographic radiography" of the countries that have been more (less) successful in catching up with the technological frontier. This will be done by assessing differences in the absorption parameter depending on the demographic structure of the workforce in the sample under study. The models we will implement are therefore of the following type,

$$\begin{aligned}&(\ln y_{i,t+\tau} - \ln y_{i,t})/\tau = \left[\lambda_1 I(D_{i,t} \leq \phi) + \lambda_2 I(D_{i,t} > \phi)\right](\ln y_{US} - \ln y_{i,t}) + \\ &+\alpha(\ln K_{i,t+\tau} - \ln K_{i,t})/\tau - \alpha(\ln L_{i,t+\tau} - \ln L_{i,t})/\tau + \varepsilon_{i,t}\end{aligned} \tag{10}$$

where $D_{i,t}$ is a demographic variable, ϕ is a threshold value that will be estimated from the data and $I(x)$ is the indicator function, taking value one if x is true and zero otherwise.

The estimation of ϕ can be carried out in a relatively simple manner once a demographic variable is chosen as $D_{i,t}$. If some value for ϕ was set exogenously, equation (10) could be estimated in a straightforward fashion using least squares after identifying the two subsamples which are implied by this threshold value. This estimation can be repeated for values of $D_{i,t}$ spanning the full range of values which are realised in the sample at hand and an estimate of ϕ can be obtained as the threshold value that minimises the sum of squared residuals across all potential threshold candidates (namely, all values of $D_{i,t}$ in the sample). The threshold estimate is thus given by

$$\hat{\phi} = arg\, min_{\{D_{i,t}\}} \sum_i \sum_t \hat{\varepsilon}^2_{i,t}(\phi = D_{i,t}),$$

that is, for a given demographic variable, the threshold value is estimated by choosing the cutting point that minimises the sum of squared residuals in a grid search over the realised values of $D_{i,t}$.[11] The rest of the parameters of the model can then be estimated conditional on this estimate of the threshold value.

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[11] In practice the search is done after trimming some proportion of the observations of the extremes of the empirical distribution of $D_{i,t}$, in order to avoid regimes containing too few variables.

With the estimated model, a test for differential technological adoption parameters corresponding to the different demographic clusters can be implemented by testing the null hypothesis H_0: $\lambda_1=\lambda_2$ against H_1: $\lambda_1\neq\lambda_2$. Such a testing problem is not elementary due to the presence of a nuisance parameter (ϕ) which is only present under the alternative hypothesis and distorts the asymptotic distribution of the classical F-test. Based on the change-point literature, Hansen (1996) develops a method of testing the null of linearity against the alternative of a specific threshold model, and shows that using a simple bootstrapping procedure, asymptotically correct p-values for the test can be found. In the empirical application we will perform the likelihood ratio test and approximate the distribution of the test statistic under the null hypothesis using bootstrapping methods.

3.3.2 Empirical Implementation and Estimation Results

Table 9 presents the results for the estimation of (10) using different (single) demographic variables as threshold variables. The model is estimated using 5-year averages for the sample of EU-15 countries in the period 1950-2005, that is, τ is set to be equal to 5 years. The sample is therefore composed of 11 observations per country, leading to a panel formed by 165 observations. The data on GDP per worker for the EU-15 countries are sourced from the Groningen Growth and Development Centre, the growth rate of the capital stock is proxied using investment rates (source: OECD) and the working age population and data on other demographic variables are sourced from the United Nation's World Population Prospects database.[12]

We started modelling the panel using a two-way fixed effect error term, which implies the assumption of different intercepts for each cross-section of the panel and common period dummies for the whole set of EU-15 countries. Using the estimates of the two-way fixed effect model, the null hypothesis of a single intercept could not be rejected for any of the specifications used, so the results presented correspond to models with a single intercept and the full set of common time dummies (which are jointly significant in all specifications tried). We also present the results of a likelihood ratio test for the restriction $\lambda_1=\lambda_2$. As explained above, since the parameter ϕ is only identified under the alternative hypothesis of a differential absorption rate depending on the level of $D_{i,t}$, the distribution of the test statistic under the null hypothesis is derived using a bootstrapping procedure in the spirit of Hansen (1996). The demographic variables used alternatively as threshold variables are: the proportion of the workforce aged 15 to 29 in the initial year of each period (L1529), the proportion of the workforce aged 30 to 49 in the initial year of each period (L3049), the proportion of the workforce aged 50 to 64 in the initial year of each

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[12] Several robustness checks were performed using different sources, such as the World Bank's World Development Indicators dataset and the Penn World Tables for the economic variables, and the results reported below remained qualitatively unchanged.

period (L5064), the ratio of L5064 to L1529 (RATIO) and the standard deviation of L1529, L3049 and L5064 (STDV).

The results indicate that, with the exception of STDV, the demographic variables used as threshold variables induce significant differences in the absorption parameters, as tested by the LR test. Given the high correlation among the demographic variables, the message of the estimations for threshold variables L1529, L3049 and L5064 is a relatively similar one: Economies with a relatively low proportion of the workforce in the youngest age group (with the threshold given by the 15th percentile of the distribution of L1529) present insignificant absorption rates, as opposed to economies above the threshold that tend to catch up with the technological frontier. Since L1529 correlates strongly (negatively) with L3049, this result reappears in the estimations using L3049 as a threshold variable, where the countries in the lower regime (defined as below the 74th percentile) profit most from technological absorption. Only economies with a low L5064 (the threshold being the 21st percentile of L5064) present positive and significant absorption parameters. The result is not surprising given the negative correlation existing between L1529 and L5064, and reappears in the estimation using RATIO as a threshold variable.

Table 9:
Demographics and catching up.

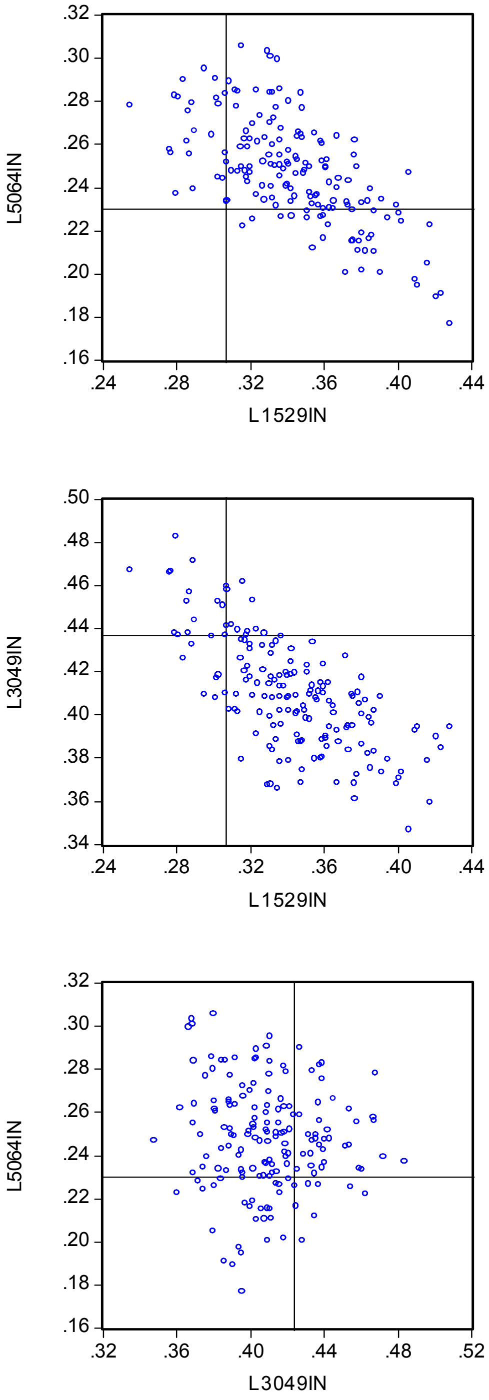
	No threshold	L1529	L3049	L5064	RATIO	STDV
. α	0.074265	0.053717**	0.069446***	0.064919**	0.056028**	0.07421***
	(0.027155)	(0.027209)	(0.026177)	(0.026391)	(0.027054)	(0.027076)
λ	0.019006	-	-	-	-	-
	(0.00572)					
λ_1	-	-0.012542	0.02045***	0.028088***	0.023292***	0.014971**
		(0.01152)	(0.005521)	(0.006134)	(0.005731)	(0.006414)
λ_2	-	0.02098***	-0.00787	0.009509	0.006234	0.022721***
		(0.005597)	(0.009266)	(0.006187)	(0.00691)	(0.006311)
ϕ	-	0.3071211	0.423789	0.230152	0.66527	0.095818
Percentile	-	0.15	0.74	0.21	0.3	0.69
LR test	-	10.354646	13.63395	12.29927	10.23382	2.052007
p-value	-	0.022	0.01	0.02	0.028	0.736
Adj. R^2	0.5237	0.5497505	0.558611	0.555026	0.549478	0.526515
Obs.	165	165	165	165	165	165

Dependent variable: Average annual growth rate of GDP per capita. Panel formed by 5-year periods. Time dummies included in all specifications. P-value for LR test obtained by bootstrapping the test statistic under the null hypothesis using 500 replications.

As a robustness check, the specifications above were also estimated including the corresponding demographic variable as an extra regressor on the right hand side of equation (10). The results concerning the location of the thresholds and the sign and significance of the technology absorption parameter estimates for the different subsamples did not change as compared to those presented in Table 9. Furthermore, the demographic variables did not appear significant as linear regressors in (10). This can be interpreted to indicate that the effect of age structure on growth takes place through its interaction with the relative level of development of the country, and thus could be understood as an effect whose channel to growth is technology absorption.

Countries with a relatively high proportion of the workforce in the youngest age group, which furthermore tend to be economies where the values of L3049 and L5064 are relatively low in the sample, therefore have a significant catching-up towards the technological frontier in store. Figure 3 presents different scatterplots for the values of L1529, L3049 and L5064 in the sample that corroborate the correlations put forward above. The results presented in this section present new insights to the interaction between the convergence process, channeled through technology diffusion, and demography. The demographic structure which facilitates technology adoption according to the regressions presented above can be observed in the classical cohesion countries (Greece, Portugal and Spain) in the first subperiods of our sample and particularly in Ireland for the period starting in 1975. Netherlands and Finland also present age structures in the first part of the period considered that tend to correspond to technology adoption regimes.

Figure 3:
Active population age groups (EU sample, five year periods)



4 PROSPECTIVE ANALYSIS OF THE FUTURE IMPLICATIONS OF DEMOGRAPHIC CHANGE ON ECONOMIC GROWTH AT EU LEVEL

For the prospective analysis it is important to refer to the most parsimonious econometric model that we presented in Section 3.1 of the report in order to reduce uncertainty due to ignorance of the bi-directional causality between economic growth and social infrastructure. Moreover, since population forecasts indicate that continued low fertility and increasing life expectancy will shape the future demography in Europe, it will be important to choose a model specification that takes account of these developments.

4.1 Population-based Forecast of Per Capita Income Growth in EU-25, 2005-2050

The estimated growth model outlined in Section 3.1 of this report is the starting point for the forecasts presented in this section. However, as the model only contains demographic explanatory variables, there are two exceptions, namely the investment rate and the level of GDP per capita in the United States.

The availability of population projections makes it easy to assemble the demographic data needed for the GDP per capita forecast. A different approach is necessary with respect to the non-demographic variables.

In the first step, we re-estimated the model without using the investment rate variable. This deletion shifted the intercept but otherwise had only small effects on the estimated parameters (see Table 10). The increase in the positive effect of the 50-64 group and the strengthening of the negative effect of the 65+ group were in line with what we had found in another study analysing the effect of age structure on investment patterns (Lindh and Malmberg 1999). Thus, we might argue that the model without investment represents a reduced form of the original model.

The second problem to be solved was to make an assumption for the US per capita income level over the forecasting period. Otherwise, the model would be useless, as it is impossible to compute the GAP variable without these data. Our approach was to simply assume a constant growth rate of 1.5% for the per capita income in the United States. This can be taken as a standard assumption and is also in line with an earlier forecast (Malmberg and Lindh 2004).

Table 10:
Parameter estimates for a model with and without investment variable.

Full sample: 154 obs **(Old 112 obs)** **Dep. variable:** g/Γ	**Base regression**	
	With investment	**Without investment**
Constant	3.478	-1.05
	(0.36)	(0.1)
$1/\Gamma$	0.015	0.013
	(4.58)**	(5.67)**
$\ln n_{15-29}$	-0.69	-0.28
	(0.55)	(0.18)
$\ln n_{30-49}$	-0.40	-0.81
	(0.32)	(0.53)
$\ln n_{50-64}$	4.26	4.60
	(3.08)**	(3.36)**
$\ln n_{65+}$	-2.482	-2.95
	(2.63)**	(2.81)**
$\ln i$	0.92	
	(1.78)	
$\ln(\delta + w)$	-1.432	-1.47
	(1.52)	(1.54)
$\ln y_0$	-0.468	-0.185
	(0.91)	(0.39)
adj R ^{2}	0.31	0.309
χ^2 **age shares**	0.004	
χ^2 $\ln i = -\ln w$	0.651	
F-test. country eff	0.002	
F-test. time eff	0.000	
$\alpha + \beta$ **implied**	0.662	
$\tilde{\lambda}$ **implied**	0.010	

Note: For further details see Table 3, Section 3.1

The source of the population data we used for the forecast was Eurostat, which presents seven different population scenarios for the EU-25 countries:

- a baseline scenario and two variants (one with zero net migration, the other with high fertility),

- a high scenario, in which net migration, fertility, and life expectancy are higher than in the baseline,
- a low scenario, in which net migration, fertility, and life expectancy are lower than in the baseline,
- two modifications of the high and low scenarios, in which “Younger” is the high scenario with shorter life expectancy and “Older” is the low scenario with longer life expectancy.

Figure 4 depicts the projected growth rates of GDP per capita for the baseline demographic scenario (growth rates at selected time periods are summarised in Table 11).[13] The graph shows the long-term downward trend of growth rates, which is mainly due to the negative effect of an increasing share of the old-age population. The fact that there are more people in the 65+ group implies that the growth rate in per worker GDP will decline. Moreover, the GDP per capita decreases when the share of the working-age population declines.

The time pattern of the decline in GDP per capita differs from region to region. The GDP per capita will decrease rather soon (i.e., within the next ten years) in Finland, Sweden, Hungary, the Czech Republic, Malta, Denmark, and the Netherlands. A relatively early onset of the decline will also be noted in France, Belgium, the United Kingdom, Ireland, Slovakia, and Slovenia.

Italy, Germany, Spain, Greece, Portugal, and Poland, will see an acceleration in per capita income growth over the next ten year. In fact, the projection for these countries, as well as for Latvia and Lithuania, is that they will experience a boom in per capita income growth that will peak somewhere around 2015-2025.

Some of the countries that will experience an early decline can expect their growth rates to recover somewhat later on. This holds true, for example, for Sweden, Hungary, and Slovakia, although the recovery will be relatively weak.

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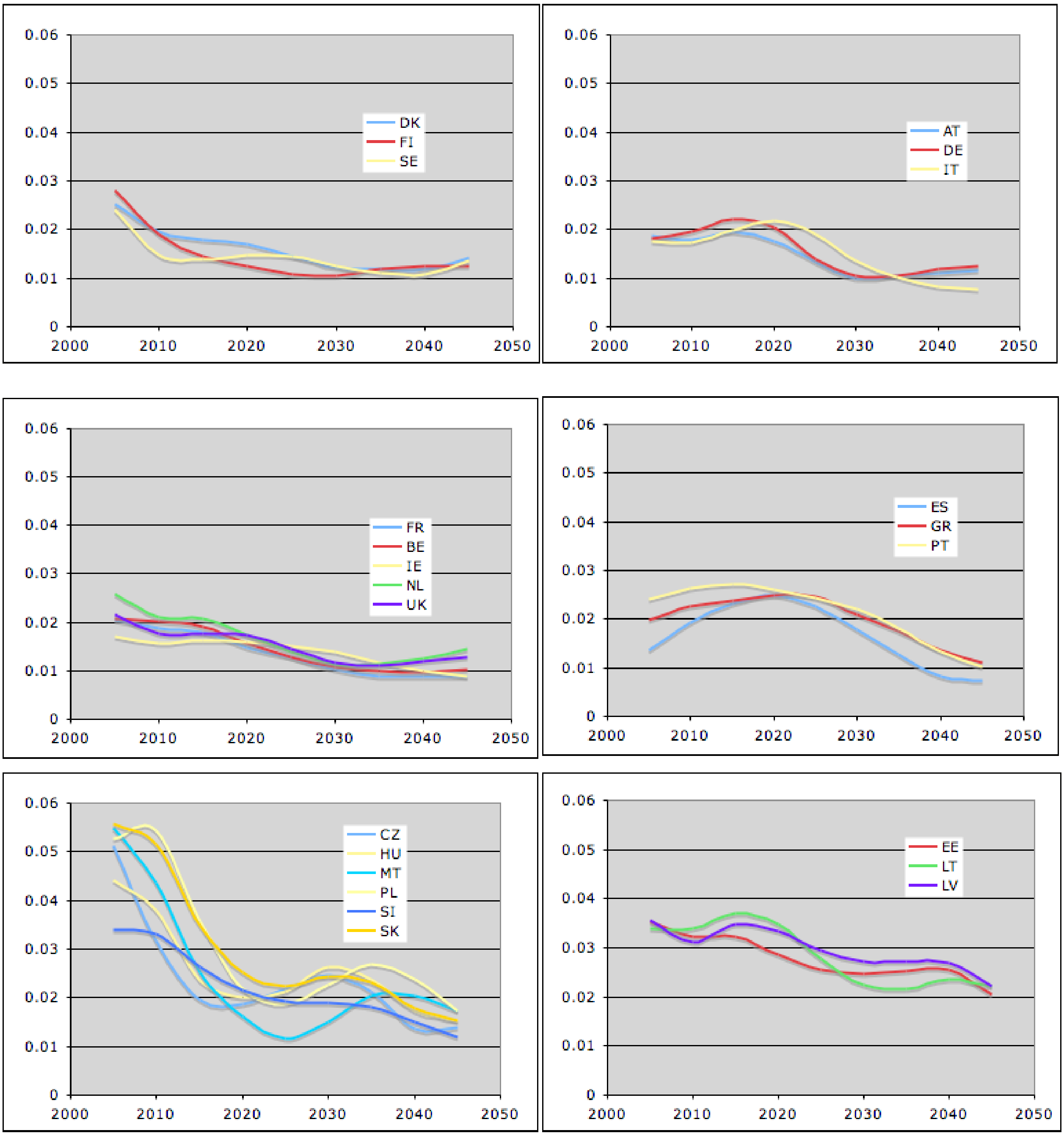
[13] Luxembourg and Cyprus are not included since we lack demographic data for the former and initial income for the latter.

Figure 4:
Per capita income forecast based on Eurostat’s baseline population projection.



The general trend is that most EU-15 countries can expect to end up with a growth rate around or below 1% per year, whereas the GDP per capita will grow somewhat faster (i.e., between 1.5% and 2.0%) in the new Member States.

The baseline scenario assumes continuously low fertility rates in EU-25. In 2050, the total fertility rate is expected to be 1.85 in Sweden and France, and 1.4 to 1.45 in Spain, Italy, Germany, and Austria. The TFRs of other countries are somewhere in between these two values.

The high fertility scenario assumes that, in 2035, the fertility rate will have increased by 0.3 children per woman relative to the baseline. The effect of this increase on the income growth rate will be rather modest for the period 2005-2050. Initially, there will be a small negative effect on income growth, which will disappear by 2020. After 2035, income will once more grow (around 0.15 percentage points)—though at a somewhat slower pace—in the high fertility scenario. The background for this pattern is an initial increase in the child dependency rate as fertility rises, which lowers the per capita income level for a given level of per worker GDP. When the larger birth cohorts reach working age, this dependency rate effect disappears. However, at a later point in time, the combination of a continued increase in TFR and larger birth cohorts that reach ages where their fertility is high, will further increase the child dependency rate, which in turn, will once more lower the per capita GDP. By 2050, the oldest group of the larger cohorts born as a result of higher fertility will be 45 years of age. It will take until 2050 before they will have become the 50-64 age group and thus have a strong positive effect on per worker GDP growth.

Given that the model we use to predict future growth in GDP associates a negative effect with the 65+ age group, it is clear that an increase in life expectancy will have a negative effect on the income growth rate. The reason is that, in low mortality countries, further reductions in mortality imply lower mortality at higher ages. Thus, the direct effect of lower mortality will mainly be an increase in the 65+ population. According to the model, this will reduce the growth rate of per worker GDP. It will also raise the old-age dependency rate, and hence, depress per capita GDP for a given level of per worker GDP.

Over time, this effect becomes quite substantial. This can be seen by comparing the growth forecasts of the high and younger population scenarios, or those of the older and low scenarios. Within these two pairs of projections, the only difference is the life-expectancy assumption. In both cases, the effect of higher life expectancy is a per capita income growth rate that is about a quarter of a percentage point lower by 2050.

Of course, one should be cautious to interpret this finding. It should be taken as a ceteris paribus result based on the assumption that increased life expectancy has no effect on the economic behaviour of individuals. Research during the past decade, however, has demonstrated that such an assumption is unwarranted. Instead, the longer life expectancy can result in both increased investment in education, increased savings rates, and possibly, a higher optimal rate of retirement. Thus, the forecast negative effects on per capita GDP growth should perhaps be seen as the outcome of a scenario where such adaptations to higher life expectancy are impeded by bad policies.

The different Eurostat scenarios also allow us to evaluate the effects of different migration policies by comparing the baseline with the no-migration scenario. A problem that arises in this connection is the fact that the baseline makes very different assumptions about trends in net migration for different countries. Figure 5 shows that Eurostat assumes a strong decline in net migration for a number of countries, among them Spain, Portugal, Italy, and the UK. A slower decline is assumed for Germany, France, Greece, Sweden, Austria, Belgium, Ireland, Denmark, and Cyprus. The countries for which declining net migration is assumed, thus, include 12 of the EU-15 Member States. The exceptions are Finland, for which Eurostat assumes net migration, and the Netherlands, which is assumed to experience increasing net migration.

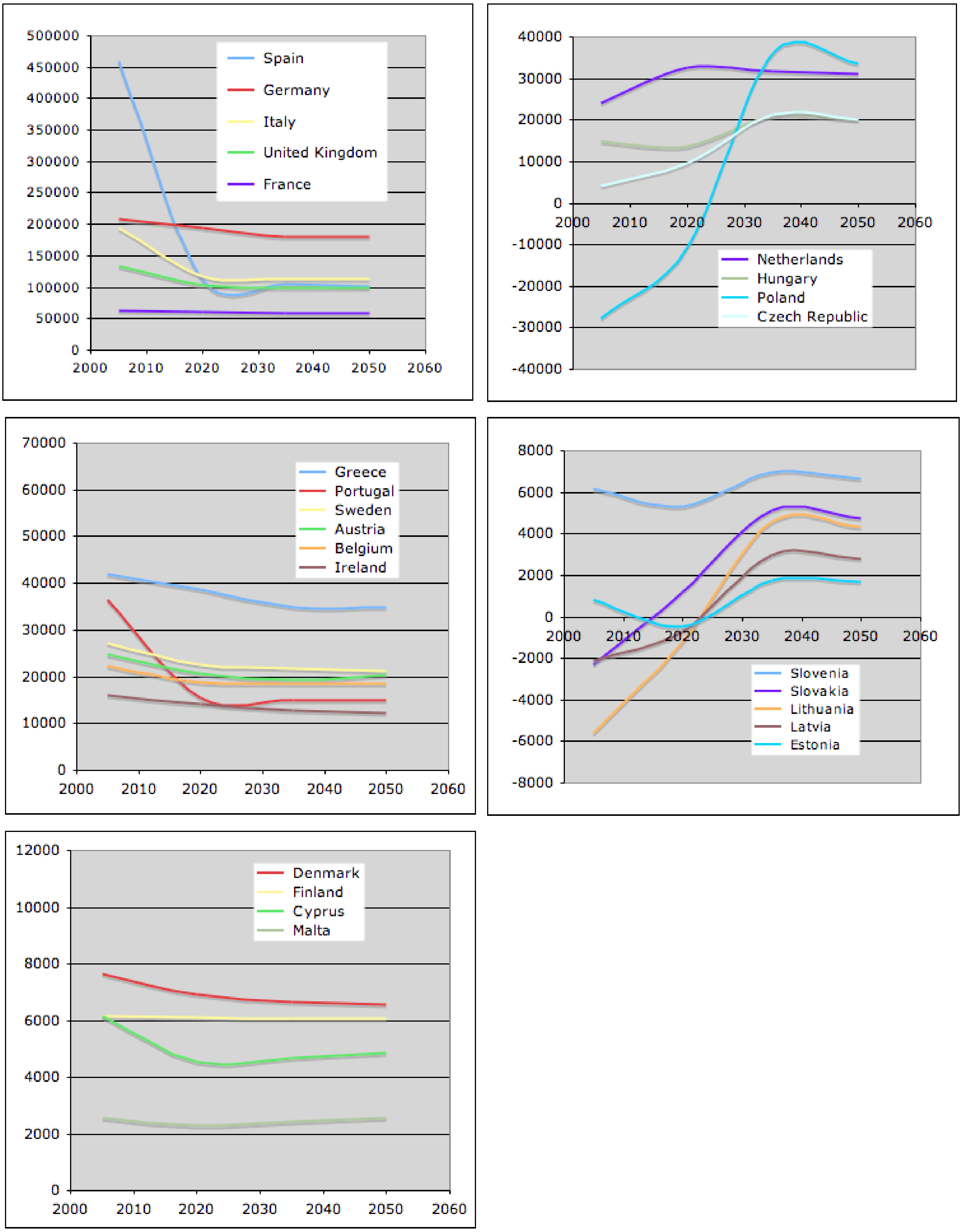
Increasing net migration is also assumed for all the new Member States except Cyprus. For Poland, Lithuania, Latvia, and Slovakia this implies that net out-migration countries will become net immigration countries. The scenario for Poland is particularly dramatic.

In general, the zero migration scenario has a relatively strong negative effect on the per capita income growth rate for countries whose net migration is currently positive. This effect is especially pronounced for Spain, Austria, Italy, and Slovenia. In these countries, zero migration would imply about 3% lower GDP per capita in 2050. For Ireland, Greece, Germany, and the Netherlands the effects are somewhat smaller. For Portugal, Belgium, and the United Kingdom the negative effect of zero net migration would even be weaker. No migration would, however, be an advantage for Poland, since this would deplete its workforce to a lesser extent.

The forecasts presented above imply negative, but not catastrophic effects of population ageing on per capita GDP growth rates. Moreover, analysis of the growth forecasts based on different population scenarios shows that forecast outcomes are not very sensitive to different demographic assumptions. However, restricting immigration could only be done at the price of a somewhat lower per capita income growth.

If we turn our attention from per capita growth rates to growth rates of total GDP, the differences between the population scenarios become more substantial, because high positive net migration and high fertility imply higher growth rates for the working-age population. Since the per worker growth rates do not differ substantially between the scenarios, differences in the growth rate of the working-age population become an important factor.

Figure 5:
Net migration to the EU countries according to Eurostat's baseline projection.



This is clearly shown in Figure 6. Over the next 15 years, the differences are not very large, but at the end of the forecasting period, the average GDP growth rate in the high fertility scenario, for example, is more than twice as high as in the older scenario.

Higher GDP growth is important for two reasons. First of all, it has an effect on the total market size that EU-25 will represent in the future. If total demand increases slowly, this may have a negative effect on the demand for investment, and possibly depress the value of European capital stock. Secondly, slower GDP growth implies slower growth in government revenues, and this may have adverse effects on the fiscal balance of European governments.

Thus, the conclusion is that it will be difficult to avoid a decline in GDP growth rates, but that this decline will be more severe in demographic scenarios with slow or even negative rates of work force growth. It is therefore advisable to introduce policies aimed at ensuring an expansion, or at least non-negative growth, of the working-age population. Preferably, such policies should encourage immigration and aim at restoring fertility rates to near-replacement level.

Figure 6:
Average GDP growth in EU-25 for different population scenarios.

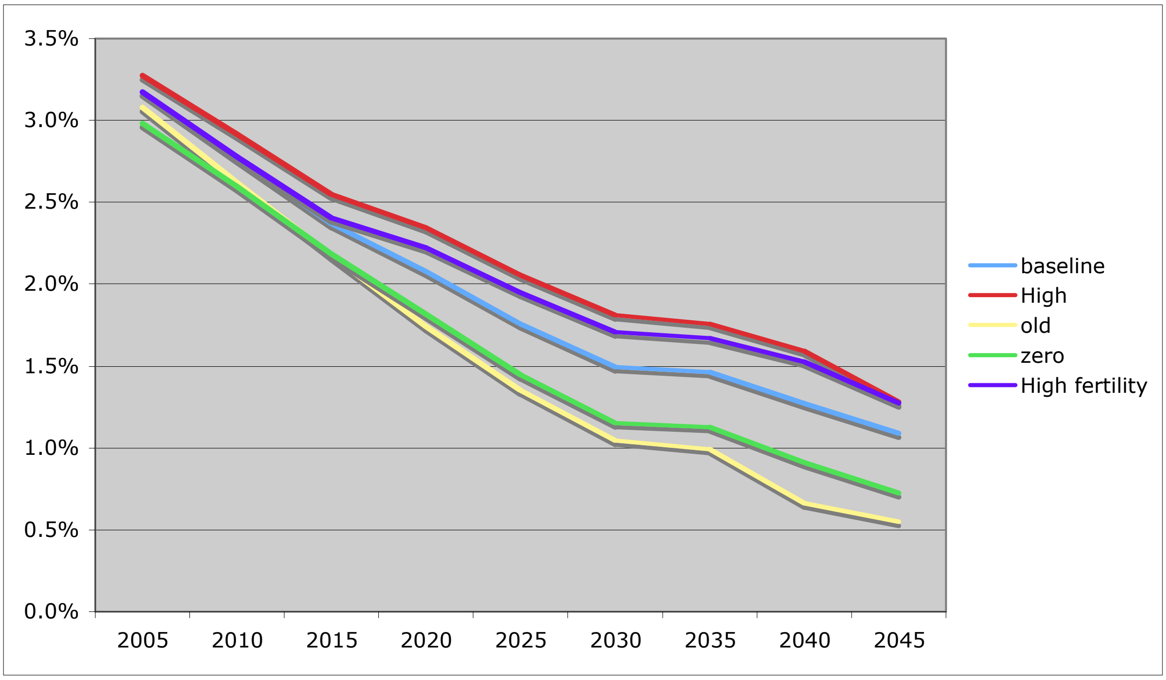


Table 11: Average annual five-year GDP growth rate based on Eurostat's baseline, high and low population projection, by starting year.

		Variant				
Country	Year	Baseline	High	Low	Baseline zero net migration	Baseline high fertility
FR	2015	2.14%	2.22%	2.08%	2.01%	2.16%
	2030	1.20%	1.37%	1.03%	1.03%	1.31%
	2045	0.79%	0.70%	0.75%	0.67%	0.80%
AT	2015	2.22%	2.45%	2.08%	1.79%	2.25%
	2030	0.83%	1.22%	0.38%	0.22%	1.06%
	2045	0.86%	1.08%	0.39%	0.28%	1.01%
BE	2015	2.13%	2.27%	2.02%	1.80%	2.16%
	2030	1.11%	1.29%	0.85%	0.77%	1.24%
	2045	0.91%	0.91%	0.70%	0.53%	0.95%
CZ	2015	1.42%	1.63%	1.21%	1.38%	1.47%
	2030	1.85%	2.47%	1.23%	1.46%	2.25%
	2045	0.95%	1.27%	0.37%	0.58%	1.22%
DE	2015	2.24%	2.43%	2.01%	1.84%	2.26%
	2030	0.70%	1.07%	0.29%	0.21%	0.91%
	2045	0.73%	0.83%	0.42%	0.28%	0.83%
DK	2015	1.70%	1.79%	1.60%	1.51%	1.72%
	2030	1.22%	1.43%	0.90%	0.99%	1.35%
	2045	1.15%	1.15%	0.90%	0.93%	1.24%
EE	2015	2.86%	3.25%	2.44%	3.10%	2.90%
	2030	1.86%	2.26%	1.44%	1.74%	2.06%
	2045	1.79%	2.31%	1.13%	1.48%	2.17%
ES	2015	2.15%	2.26%	2.03%	1.74%	2.18%
	2030	1.62%	2.06%	1.15%	1.03%	1.93%
	2045	0.20%	0.27%	-0.09%	-0.19%	0.29%
FI	2015	1.63%	1.73%	1.55%	1.47%	1.65%
	2030	0.84%	0.93%	0.67%	0.70%	0.92%
	2045	1.04%	1.03%	0.82%	0.89%	1.12%
GR	2015	2.32%	2.40%	2.22%	1.94%	2.34%
	2030	1.86%	2.13%	1.27%	1.30%	2.05%
	2045	0.66%	0.72%	0.14%	0.20%	0.77%
HU	2015	1.78%	1.93%	1.62%	1.73%	1.84%
	2030	2.21%	2.65%	1.66%	1.89%	2.54%
	2045	1.19%	1.17%	0.75%	0.86%	1.36%

IE	2015	2.43%	2.60%	2.24%	2.07%	2.46%
	2030	1.89%	2.22%	1.50%	1.48%	2.07%
	2045	1.10%	1.37%	0.69%	0.82%	1.29%
IT	2015	1.68%	1.75%	1.63%	1.38%	1.70%
	2030	1.05%	1.40%	0.71%	0.48%	1.30%
	2045	0.19%	0.08%	0.08%	0.17%	0.18%
LT	2015	3.38%	3.64%	3.10%	3.65%	3.42%
	2030	1.68%	2.08%	1.17%	1.52%	1.93%
	2045	1.89%	2.44%	1.14%	1.61%	2.26%
LV	2015	3.06%	3.27%	2.82%	3.28%	3.10%
	2030	1.88%	2.25%	1.38%	1.70%	2.17%
	2045	1.97%	2.51%	1.18%	1.68%	2.35%
MT	2015	3.19%	3.50%	2.84%	2.55%	3.26%
	2030	1.72%	1.60%	1.55%	1.29%	1.79%
	2045	1.99%	2.08%	1.31%	1.03%	2.20%
NL	2015	2.37%	2.52%	2.21%	2.07%	2.40%
	2030	1.22%	1.52%	0.88%	0.84%	1.39%
	2045	1.26%	1.38%	0.97%	0.86%	1.37%
PL	2015	3.48%	3.76%	3.25%	3.74%	3.55%
	2030	1.79%	2.02%	1.41%	1.69%	2.00%
	2045	1.30%	1.97%	0.35%	1.00%	1.82%
PT	2015	2.57%	2.73%	2.46%	2.37%	2.59%
	2030	2.00%	2.31%	1.49%	1.74%	2.17%
	2045	0.53%	0.60%	0.09%	0.32%	0.58%
SE	2015	1.78%	1.85%	1.67%	1.46%	1.79%
	2030	1.17%	1.32%	0.83%	0.75%	1.31%
	2045	1.50%	1.50%	1.22%	1.09%	1.58%
SI	2015	2.54%	2.93%	2.13%	2.13%	2.60%
	2030	1.64%	2.16%	1.13%	1.11%	1.93%
	2045	0.92%	1.06%	0.46%	0.39%	1.11%
SK	2015	3.25%	3.43%	2.99%	3.31%	3.33%
	2030	1.87%	2.43%	1.23%	1.71%	2.24%
	2045	0.97%	1.71%	0.03%	0.73%	1.49%
UK	2015	2.15%	2.26%	2.00%	1.90%	2.17%
	2030	1.16%	1.41%	0.80%	0.88%	1.34%
	2045	1.19%	1.32%	0.81%	0.84%	1.34%

4.2 Comparison with EU Long-Run Projections

In this section, we compare the results presented in Section 4.1 with the findings of the European Policy Committee (EPC) report (2005, Section 3.3) on age-related expenditures. First, we shall briefly discuss the underlying assumptions and the methodology used in this report.

Background and general approach

Labour productivity is defined as output per worker. The ‘production function approach’ is used “to calculate potential output over the long run using established time series methods to extrapolate short-term developments and a combination of reasonable ad hoc assumptions for the longer-run” (EPC, p. 74). Furthermore, the production function allows us to assess the main components of labour productivity, TFP and capital stock per worker. Based on historical US and EU-15 labour productivity growth, all countries are supposed to converge to an output per worker growth rate of 1.7% at the end of the projection.

Specific assumptions regarding the underlying population projections

The population projections underlying the EPC projections of age-related expenditure for the EU-25 Member States were provided by Eurostat with close involvement of the national statistical institutes. These institutions together provided a common AWG scenario[14] population projection for the period 2004 to 2050 which is based on the baseline scenario of EUROPOP 2004 (see Eurostat, 2004b, 2004c, and 2004d) but with adjustments for some of the Member States under consideration.

The assumptions underlying the EPC projections of age-related expenditures are the same as in the baseline scenario of EUROPOP 2004. Hence, there is no assumption on convergence in fertility rates among the EU-15 Member States but most of them (EU-10) are assumed to converge toward the EU average with respect to mean age at childbearing. Fertility assumptions for the EU-15 take into consideration postponement and recuperation of childbearing. This is achieved by extrapolating observed cumulated fertility at certain ages.

The assumptions on life expectancy at birth remained unchanged for the EU-10 Member States but for the EU-15 the AWG scenario differs from the EUROPOP 2004 projections where the observed trends of decreasing mortality rates from 1985 to 2002 are assumed to continue until 2018 while from 2019 to 2050 these trends are assumed to slow down. For the EU-10 countries the speed of mortality improvements was assumed to converge towards the average patterns of improvements in the EU-15. In the baseline scenario of EUROPOP 2004 countries

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[14] EPC Working Group on Ageing Populations (AWG)

initially experiencing a life expectancy above average may drop below average and vice versa. Therefore, in the AWG scenario a moderate convergence in life expectancy at birth is also assumed for the EU-10.

The assumptions regarding net migration are the same as in the EUROPOP 2004 projections for all EU Member States except Germany, Italy, and Spain. The net flows to Spain have not been changed but the age structure of migrants was slightly modified. For Germany and Italy not only the underlying age structure but also the number of migrants was adjusted.

For Germany the net inflows are higher than in the EUROPOP 2004 projections for the whole projection period; for Italy the net inflow assumed in the AWG scenario in 2004 is lower while from 2010 onwards it is always higher than in the EUROPOP 2004 baseline scenario.

Specific assumptions on the components of the production function in the short to medium term (2005-2009)

Historical data and existing short-term forecasts for 2005-2006 allow us to calculate TFP trends, which are then forecast for 2007-2009 by stochastic trend methodology. Investment into potential GDP is an exogenous variable whose projection for 2007-2009 is based on an autoregressive process.

Specific assumptions on the components of the production function in the longer run (2010-2050)

The projections presented in the EPC report are based on the assumption of long-term convergence of labour productivity across countries. Whether this convergence takes place in terms of growth rates or absolute levels of labour productivity is a key issue. The empirical literature does not provide evidence of convergence in absolute levels. Consequently, the EPC projections assume convergence with respect to growth rates. However, the absolute level of labour productivity has an impact on the speed of convergence and on the need for specific TFP growth adjustments required in countries with low initial levels of TFP. Furthermore, TFP projections could quickly converge to the same growth rate. Average hours worked per person are supposed to be constant after 2010.

TFP: the key driving force of labour productivity growth at the end of the projection horizon

Assumptions about TFP are the most important element, because, in the long run (2010-2050), growth in labour productivity broadly equals TFP growth divided by the labour share. It is assumed that "TFP growth rates will converge to 1.1% by 2030 for all EU-15 Member States, with different speeds of convergence for individual Member States depending on the gap in TFP levels" (EPC, p. 79). TFP is supposed to be exogenous, neglecting some possible influences of ageing populations. Increasing participation rates, for instance, may result in an increasing share of workers with less skills or work experience as opposed to a projected rise in educational attainment.

Capital formation: transition to steady state

Up to 2009, capital stocks are derived from the extrapolated and thus broadly constant ratio between investment and GDP. Afterwards, the constant capital to labour ratio assumption is gradually introduced after a linear adjustment. Eventually, the capital to labour ratio in efficiency units is supposed to be constant from 2030–50.

Main results of baseline projections

Whereas Table III.2 in the EPC report shows annual average labour productivity growth rates, Tables III.4 and III.5 show the growth rates of its determinants, i.e., TFP and capital deepening. While productivity in the EU-15 grows by 1.3% each year in the period 2004-10, it increases to 1.9% in 2011-20, decreases to 1.8% in 2021-30 and rests at 1.7% in the three following periods from 2031 to 2050. In the total period 2004-50, labour productivity growth is supposed to be 1.7%. Projected GDP per capita growth rates in period averages are presented in Table III.6 of the EPC report. GDP per capita growth rates decline from a growth rate of 1.9% during the intervals 2004-10 and 2011-20 to a growth rate of 1.4% in 2021-30, and 1.3% in 2031-40. Afterwards, they increase to a growth rate of 1.6% in 2041-50 and account for 1.6% in the total period 2004-50.

In Table 12 we contrast the growth rates of GDP per capita in terms of average annual growth rates as reported in the EPC report (Section 3.3, Table III.6) with the findings presented in Section 4.1 of our report. Since the EU projections are based on the assumption of convergence, albeit in terms of labour productivity, the annual growth rate of GDP per capita reaches 0.6 in all countries in the period 2041-2050. Thus, our projections (see Section 4.1) exhibit more heterogeneity among countries and more fluctuations during the projection period. Moreover, our projections with respect to the annual growth rates are, in general, slightly more optimistic—in particular with respect to the next two decades—than the EU projections and exhibit more pronounced fluctuations.

Table 12: Annual growth rate of GDP per capita, EU projections vs. projections as discussed in Section 4.1.

Year	2005-2010	2010-2015	2015-2020	2020-2025	2025-230	2030-2035	2035-2040	2040-2045	2045-2050
	2004-2010		2011-2020		2021-2030		2031-2040		2041-2050
Austria	1.88	1.77	1.96	1.75	1.33	1.00	1.04	1.09	1.15
	0.60		0.70		0.70		0.60		0.60
Belgium	2.07	2.03	1.92	1.58	1.29	1.08	1.00	0.98	1.04
	0.30		0.60		0.70		0.60		0.60
Cyprus	1.10		1.30		1.10		0.70		0.60
Czech Republic	5.12	3.17	1.96	1.88	2.18	2.47	2.11	1.36	1.38
	2.20		1.60		1.10		0.70		0.60
Denmark	2.51	1.97	1.78	1.69	1.43	1.23	1.18	1.19	1.41
	0.70		0.70		0.60		0.60		0.60
Estonia	3.53	3.23	3.23	2.85	2.55	2.47	2.53	2.55	2.05
	2.80		2.10		1.30		0.70		0.60
Finland	2.81	1.90	1.43	1.26	1.08	1.05	1.18	1.24	1.26
	0.10		0.50		0.60		0.60		0.60
France	2.04	1.88	1.79	1.49	1.28	1.03	0.89	0.89	0.89
	0.40		0.60		0.60		0.60		0.60
Germany	1.80	1.95	2.21	2.05	1.39	1.05	1.05	1.18	1.25
	0.10		0.40		0.60		0.60		0.60
Greece	1.97	2.27	2.36	2.49	2.47	2.09	1.75	1.35	1.09
	1.20		1.00		0.70		0.60		0.60
Hungary	4.43	3.79	2.35	2.02	2.12	2.63	2.39	1.74	1.53
	2.00		1.50		1.10		0.70		0.60
Ireland	1.70	1.58	1.62	1.60	1.50	1.38	1.17	0.99	0.89
	0.80		1.00		0.70		0.60		0.60
Italy	1.76	1.72	1.98	2.17	1.89	1.35	1.02	0.83	0.78
	0.20		0.60		0.60		0.60		0.60
Latvia	3.56	3.10	3.47	3.33	2.96	2.71	2.71	2.69	2.22
	3.40		2.60		1.40		0.70		0.60
Lithuania	3.38	3.38	3.70	3.48	2.77	2.25	2.17	2.37	2.23
	2.70		2.00		1.30		0.70		0.60
Luxembourg	1.00		1.00		0.70		0.60		0.60
Malta	5.50	4.35	2.52	1.61	1.17	1.49	2.03	2.04	1.74
	0.90		0.80		0.90		0.70		0.60
Poland	5.26	5.45	3.57	2.17	1.86	2.26	2.69	2.38	1.74
	1.40		1.30		1.10		0.70		0.60
Portugal	2.41	2.62	2.71	2.61	2.43	2.21	1.82	1.32	1.01
	0.50		0.90		0.80		0.60		0.60
Slovakia	5.58	5.14	3.47	2.52	2.25	2.42	2.32	1.78	1.52
	1.60		1.50		1.20		0.70		0.60
Slovenia	3.39	3.32	2.62	2.14	1.91	1.88	1.82	1.49	1.19
	2.10		1.60		1.10		0.70		0.60
Spain	1.36	1.91	2.31	2.49	2.28	1.77	1.27	0.82	0.73

	0.80		0.90		0.70		0.60		0.60
Sweden	2.40	1.47	1.37	1.47	1.44	1.25	1.10	1.09	1.35
	0.40		0.70		0.70		0.60		0.60
The Netherlands	2.60	2.10	2.08	1.74	1.39	1.15	1.13	1.25	1.44
	0.40		0.60		0.60		0.60		0.60
United Kingdom	2.17	1.78	1.76	1.74	1.44	1.16	1.10	1.20	1.28
	0.70		0.80		0.70		0.60		0.60

Note: The first row for each country represents the projections as summarised in Section 4.1, while the second row depicts the EU projections. Due to data limitations, projections for Cyprus and Luxembourg are missing in the projections of Section 4.1.

5 SUMMARY AND DISCUSSION

Over the last few years there has been an increasing awareness of a direct influence of population age structure on the macroeconomy and in particular on economic growth. In this report we provide a review of the recent literature that links changes in the demographic structure to economic growth and introduce three new empirical growth regressions for the EU-15 countries over the last decades (1950-2005). Since we identify demographic age structure as an important and robust determinant (with respect to the inclusion of various economic variables) of past economic growth rates it is straightforward to include demographic forecasts when projecting economic growth rates. Compared to forecasts of economic and social indicators (that also determine past economic growth rates), the age structure is relatively easy to forecast during the next two to three decades. We therefore choose one of our empirical estimations to conduct a prospective analysis of the future implications of demographic change on economic growth for the EU-25 countries up to 2050.

Though the neoclassical growth model by Solow (1956) predicts a negative correlation between population and economic growth, studies based on cross-country data found an insignificant effect of population growth in empirical growth regressions. With the work of Barro (1991), who introduced demographic variables into "convergence" models of economic growth, and the use of pooled time series methods, the role of demographic variables could be empirically verified. In general, fertility, population growth and mortality turned out to be negatively and population size and density to be positively related to per capita output growth. In growth equations with the growth rate of the total population as the only demographic variable, however, population growth turned out to have still no effect on economic growth. During the last decades several authors have indicated that demography indeed matters but what must be abandoned is the assumption of a constant age distribution of the population as it is implicitly assumed in most economic growth regressions. Once one considers the age structure of the population, empirical growth regressions indicate a significant and robust correlation between demographic change and economic growth. As nicely summarised by Kelley and Schmidt (2005, p. 277), "What has changed with the evolution of modeling in the 1990s is a clearer interpretation of the channels and sizes of demographic changes on the economy".

In Section 2.2 of the report we review the concept of the demographic transition and its implications for economic growth. Although industrialised countries have passed the "classical" demographic transition of decreasing mortality rates followed by a decline in fertility some time ago, the baby boom and bust period in the post-WWII period confers similar demographic dividends as in developing countries nowadays. In industrialised countries the demographic change in the period after World War II first led to a demographic dividend (starting in the 1970s in the industrialised countries) when the baby boom generation entered the labour market because the growth rate of population was slower than the growth rate of the working age population. Indeed, this demographic dividend has recently been termed the "first demographic dividend" since there might be yet a second demographic dividend when the population ages. The first demographic dividend can be decomposed into an accounting and a behavioural effect. While the former denotes the difference in the growth rates of working and total population, the latter focuses on the role of demographic change for the output-per-worker ratio (often termed the productivity component). Demography may affect the productivity component through its impact on savings, investments, human capital formation, technological change, etc. In Section 2.3 of the report we review one of the key arguments in the literature on economic and demographic change: the link between savings, economic growth and demographic change. Since fertility will continue to decline, a demographic burden is foreseen as the growth rate of the working age population will fall short of the growth rate of the total population. However, as argued by Mason (2005) this demographic burden may result in a second demographic dividend. The second demographic dividend denotes the increase in the wealth to output ratio that may result as a consequence of increased savings as caused by higher life expectancy and lack of labour income in retirement.

An important distinction in recent economic growth regressions that test for demographic effects is the distinction between the productivity component (output per worker) and the translational component (the difference in the growth rate of workers and total population). In Section 2.4 we review this decomposition based on the paper by Kelley and Schmidt (2005). We also present the evolution of the accounting effect for the EU-25. Among western European countries we find the peak of the positive accounting effect during the 1980s, while the accounting effect will turn negative during the 2030s. A similar but more volatile pattern can be found for the Nordic countries where the baby boom took place during different time spans. For southern European countries we find a similar but much less pronounced pattern as recorded for the western European countries. The ten new EU member states in central and eastern Europe have not experienced a similar baby boom phenomenon and hence did not profit from the same positive accounting effect as the EU-15 countries. Up through 2010 the accounting effect is rather erratic and for some countries negative most of the time. Starting in 2010 most of the new EU-10 countries will experience a positive accounting effect.

To test whether demographic structure also plays a role for output per worker (in addition to the accounting effect), economic growth regressions that include demographic variables as important explanatory factors were tested. Most of the literature applies the framework of the convergence model where the growth rate of output per worker is modelled to be proportional to the gap between the logarithms of the current and the long-run level of output per worker. The growth rate is assumed to be constant, while the steady-state equilibrium of output per worker is modelled to be country- and time-specific and to depend on country-specific characteristics. In Section 2.6 of the report we review recent studies on the empirical testing of demography and economic growth. Although the setup of the models (with respect to the choice of explanatory variables and time periods) and the methods of estimation (cross-country vs. panel regressions) differ, the results of the various studies are generally compatible. An important finding of the review paper by Kelley and Schmidt (2005) is the fact that the growth rate of the working age population has a positive effect on the growth rate of output per worker, i.e., the growth rate of the working age population not only determines the accounting effect but also influences the behavioural component (the productivity term). Among the various demographic variables introduced, only the youth dependency ratio turned out to be significant. Evaluating the role of demography, Kelley and Schmidt (2005) find that for Europe the accounting effect was exhausted in the 1970s while the youth dependency ratio had a strong positive effect on the growth rate of output per worker during the 1970s and 1980s. Among the other explanatory variables included, Kelley and Schmidt note that human capital (as measured by life expectancy and education) was strongly growth-inducing over periods and regions while financial and political components had more ambiguous impacts. Similar findings as in Kelley and Schmidt have been obtained by other authors as well. Bloom and Williamson (1998) found a positive effect of the growth rate of the economically active population on output per capita growth. Unlike Kelley and Schmidt, they applied cross-country regressions as opposed to panel data methods. Moreover, the fact that Bloom and Williamson choose output per capita instead of output per worker as their dependent variable implies that their demographic effect coefficients cannot distinguish between the accounting and behavioural effects. As an alternative demographic representation they choose the growth rate of the young and the elderly population and find out that the former affects economic growth significantly negatively while the latter does so without significance. In their final assessment they note that population dynamics explain almost 20 per cent of the growth observed in Europe over the time period 1965-1990. Kelley and Schmidt arrive at similar estimates since they note that core demographic variables account for 24% of the variability in the growth rate of output per capita for Europe over the time span 1960-1995. Bloom and Williamson (1998) propose two distinct channels through which demography may influence growth: through the labour force and through savings and investment. For East Asia they show that the total demographic impact on economic growth can be decomposed into an effect through the labour force and one through investment in the relation of 6:10. An important aspect taken up in the paper by Bloom and Canning (2001a) is the problem of reverse causality, i.e., how demography and economy are affecting each other over time and how this relationship changes over time. In addition to the channels previously mentioned (labour force and savings), the authors add a third channel through which demography may affect economic growth: educational enrolment and human capital. The authors propose a systems approach where demography, output and capital accumulation are endogenous variables, influencing each other in both directions and where changes to exogenous factors such as politics will have repercussions for all endogenous variables. Consequently they estimate economic growth regressions for the period 1965-1990 applying an instrumental variable approach to account for endogeneity of the regressors. Their findings are in accordance with those of Kelley and Schmidt and Bloom and Williamson since they also find that population growth is not significant alone but becomes so after introducing working age growth. Interestingly they find that education loses its significance once demographic factors are accounted for. Moreover they find a significant interaction between demographic variables and policies. Good policies lead to higher growth and the impact of demographic change is greater when institutions are of higher quality. They even argue that the interaction of faster demographic transition and better economic policy in East Asia can account for 40% of the growth differential between East Asia and Latin America. One of the most comprehensive surveys is the RAND study by Bloom, Canning and Sevilla (2003b) which includes case studies on the role of the demographic transition for economic growth for aggregate world regions. In their conclusions the authors stress that open economies, flexible labour force and modern institutions assure that a country can reap the demographic dividend. So far, most of the studies apply either cross-country or panel data regressions to a sample of countries of all world regions. In a recent paper by Beaudry and Collard (2003) only the richest industrialised countries are considered (allowing for the assumption that all countries are affected by the same technological factors) and cross-country growth regressions are run for two different periods: 1960-1974 and 1975-1997. Similar to the other studies, the most important variable assigned to capture demographic influences is the annual average growth rate of the working age population. The main finding of the paper is that the growth rate of the working age population is insignificant for the first period and significant and negatively correlated to economic growth for the second period. The authors offer a theoretical model and explain their results by the fact that during the second period countries with lower growth rates of the working age population could adopt capital-intensive technologies more quickly since they needed fewer resources to endow workers with capital. While most of the studies use either the growth rate of the dependent or working age population or dependency ratios as core demographic variables that influence economic growth rates, Feyrer (2004) takes the internal demographic composition of the workforce into account. As additional demographic control factors he also includes the dependency ratio. His findings indicate that the share of workers aged 40-49 is associated with higher output while the dependency ratio has no significant influence. A decomposition of output into three components furthermore yields that demographic change mainly affects the productivity channel while demographic regressors are jointly insignificant in the regressions of capital output ratios and human capital (i.e., the other two components). As the review of the various empirical studies indicates, one of the most robust demographic variables that is positively and significantly linked to output per worker growth in most of the studies is the growth rate of the working age population. Combined with the fact that the growth rate of the working age population also positively affects the accounting effect, the overall demographic role of the working age population for economic growth is even higher. A similar consistent finding can be verified for the youth dependency ratio. If added as an additional demographic regressor it turned out to be significant and negatively related to economic growth in most of the studies. The overall conclusion from this review is that independent of the method applied and independent of the set of additional control variables considered, the important role of the growth rate of the working age population and the youth dependency ratio is robust. Many authors have noted the importance of the policy and social environment and its interaction with demographic changes as an important determinant of long-run economic growth.

We conclude our review by a brief summary of alternative specifications of age structure effects used in the literature in Section 2.7 of our report. While the pioneering work of Fair and Dominguez (1991) aimed at a full representation of the age structure, recent studies mostly apply aggregate measures of age structure such as the growth rates of specific age groups or dependency ratios. As noted in the paper by Bloom and Canning (2001b) one should start with a rather flexible representation of the age structure and test the level of aggregation that is appropriate. In particular, as the authors stress, the optimal age structure representation will depend on the specific problem considered (e.g., whether one aims to explain savings or output growth rates). Moreover, based on theoretical models of economic-demographic developments a non-monotonic age representation might be adequate. In a recent contribution, An and Jeon (2006) have indeed verified an inverted U-shape relationship between the share of the elderly and economic growth as well as between the old-age dependency ratio and economic growth.

The focus of the current report is Section 3 where we introduce three new empirical studies that model economic growth in the EU and its relation to changes in the demographic structure over the past six decades. The three empirical exercises in Section 3 are meant to provide us with a deep understanding of the effects of demographic factors on growth, as well as the nature of the interaction between demography and development. In this sense, we carried out different empirical studies which highlight selected channels of the effect of demography on growth.

In Section 3.1 of the report we replicate a previous study of economic growth and demographic structure (that was based on OECD data and limited to the period 1950-1990, Lindh and Malmberg 1999) for the EU-15 and a longer available time series: 1950-2005. The empirical approach is based on a human capital augmented Solow model. Other than in the framework of Mankiw, Romer and Weil (1992) we assume that technology is different across countries and we postulate a convergence of technology levels to an exogenous world technology. In sum, our results are similar to our previous findings for the OECD and the shorter time period. By applying a more detailed age structure we find that it is again the 50-64 age group that positively contributes to economic growth. Depending on the period length the negative emphasis may be either on the young (for 10 year periods) or the old (for annual data). These results were robust to a set of sensitivity tests where we controlled for endogeneity of the regressors. Demographic variables seemed to be strengthened in the instrumental variable regressions. One exception was the younger part of the age structure that was more sensitive to different controls, specifications and instruments. This may be explained by the fact that the young age groups are less predetermined and more likely to be affected by endogeneity bias. While the negative effect on growth of a large old-age population and a large young population, respectively, fits well with conventional ideas, the positive middle-age effect is more surprising. As we argue in our report, these age effects may support our hypothesis that for convergence highly educated youngsters drive the absorption process while mature adults drive the mature productivity process. Although we cannot identify the validity of our hypothesis, the age-growth relations we uncover at least do not refute this young-old complementarity that may also be present in the labour market due to their different skill profiles. As we argue in the report, these results imply that changing proportions of different age groups in the workforce require changes in labour market institutions and policies in order to take advantage of different types of growth opportunities. However, it is not only the composition of the labour supply that will change. The change in the composition of demand and supply of capital as the age structure changes will have an impact on economic growth as well. Most importantly it must be kept in mind that the exact nature of the various mechanisms proposed behind these correlations needs to be studied with micro data.

In Section 3.2 we test whether demographic variables like proportions in different age groups and their change over time are robust determinants of long-run economic growth in the EU-15 by taking into account the variation in parameter estimates depending on the set of variables which is controlled for in the regressions. Several approaches can be used to test the robustness of the various explanatory variables to changes in the set of controls used in the growth regression. The literature on measuring the robustness of growth determinants tends to rely on extreme bound analysis, or on other techniques based upon the same methodology. The rationale to this approach is to obtain the estimates of the parameter attached to a given explanatory variable for all possible combinations of other potential controls available. A level of robustness for the variable under study can then be obtained by evaluating the full distribution of all these estimates. Several refinements of this methodology, including the use of Bayesian techniques (Bayesian averaging of classical estimates, BACE) and nonlinear regression models with threshold effects have recently been developed . We implemented a robustness exercise in our piece of research in order to evaluate the robustness of demographic variables as growth determinants in Europe for the period under study. Through the robustness analysis we identified the key demographic variables that were related to economic growth during the period 1960-1990. Our results based on the empirical distribution of estimates indicate a robust positive partial correlation between the initial proportion of the workforce in the 30-49 age group and economic growth and a robust negative partial correlation for the proportion of the workforce in the 15-29 age group. These results are coupled with robust partial correlations with opposite signs of their respective changes in the period. Compared to the study in Section 4.1 the results on the demographic variables are similar although the hump-shaped pattern of the age effects has shifted to the left. It is now the middle age group of 30-49 (as also identified by Feyrer 2004) and not the 50-64 age group that is significantly positively linked to economic growth. This, however, implies that in the middle of the period (15 years later) the 45-64 age group represents the initial 30-49 age group. The results for the young age group are similar. Thus the results are actually completely compatible with the first study. However, as previously shown by Lindh and Malmberg (2004) and several other authors, the hump-shaped pattern of the age structure effects does shift to the right as life expectancy increases. Since increases in life expectancy are to be expected with certainty for the future we opted to take our results from our first study as the baseline for forecasts we presented in Section 4 of this report. The results for the young age group are similar. It may well be that the different time periods (we restricted our sample to three decades in Section 3.2) as well as the different method (we applied cross-country regressions in Section 3.2 as opposed to panel data methods as applied in Section 3.1) can partly explain the different results with respect to the middle age groups. However, as previously shown by Lindh and Malmberg and several other authors, the hump-shaped pattern of the age structure effects may shift to the right as life expectancy increases. Since increases in life expectancy are to be expected with certainty in the future, we opted to take our results from Section 3.1. as the baseline for the forecasts we present in Section 4 of this report.

While Sections 3.1 and 3.2 indicate differential effects of various age groups on economic growth, in Section 3.3 of this report we investigated the nature of such effects by empirically analysing the influence of age structure on technology adoption (and, subsequently, on GDP per capita growth) in the EU for a panel setting from 1950 to 2005. Our estimates are based on the convergence model and we additionally assume that the distance to the technological frontier determines the speed of technology adoption. We then test whether the age structure of the economy can have an effect on the adoption parameter. This hypothesis has been empirically tested making use of recent developments in the econometric literature of threshold estimation. The demographic variables used are the proportion of the workforce aged 15-29, 30-49 and 50-64, respectively, in the initial year of each period, the ratio of the age groups 50-64 to 15-29 and the standard deviation of the three workforce age groups. While our results do not indicate any significant effects for the variables measuring the standard deviation of age groups, we find that economies with a relatively low proportion of the workforce in the youngest age group present insignificant absorption rates, as opposed to economies above the threshold, which tend to catch up with the technological frontier. For the other age groups (that are of course closely correlated with the youngest age group) we find that countries in the lower regime of the 30-49 and the 50-64 age groups have positive and significant absorption parameters. We find similar results for the ratio variable. These results support our hypothesis that for convergence it is highly educated youngsters who drive the absorption process, while mature adults drive the mature productivity process. Inclusion of demographic variables as extra regressors did not change the results concerning the location of the thresholds and the sign and significance of the technology absorption parameter estimates. However, the demographic variables did not appear significant as linear regressors. This can be interpreted to mean that the effect of age structure on growth in this case takes place through its interaction with the relative level of development of a given country, and thus might be understood as an effect whose channel to growth is technology absorption.

In Section 4 of the report we apply our econometric setup of Section 3.1 to forecast economic growth rates for EU-25 assuming population forecasts as provided by EUROSTAT. For all countries we find that the long-term trend in the growth rates is downward, which is caused by the negative effect of an increasing share of the old-age population. However, the time pattern of this decline differs between regions. Applying the baseline scenario of the population projections, the general trend is that most countries in EU-15 can expect to end up with a growth rate around or below 1% per year, whereas the new member states can expect a somewhat faster annual growth, between 1.5 and 2.0%. Applying alternative population projections we find almost no effect on projected income growth rates for the high-fertility scenario since it is only after 2050 that the bigger birth cohorts will enter into the 50-64 age group and have a strong positive effect on per worker GDP growth. An increase in the life expectancy by increasing the share of the 65+ age group will have a negative effect on income growth rates. However, all these results are to be understood as ceteris paribus results where it is assumed that increased life expectancy has no effect on the economic behaviour of individuals. A comparison of the baseline and the no-migration scenario indicates that a zero migration scenario has a relatively strong negative effect on per-capita income growth for countries that today have a positive net migration. While economic forecasts are not very sensitive to different demographic assumptions when we consider per capita GDP growth rates, differences between the population scenarios become more substantial when we consider total GDP growth rates.

In Section 4.2 of the report we compared our projections with the EUROSTAT productivity forecasts (EPC 2005) for the baseline population projections. Our results exhibit more heterogeneity among countries and more fluctuations during the projection period. Moreover, our projections with respect to annual growth rates are in general slightly more optimistic—in particular with respect to the next two decades—than the EU projections and exhibit more pronounced fluctuations.

Summing up, our report supports the argument that demographic factors matter for economic growth just as much as, or sometimes even more than, the factors commonly stressed in the growth literature, such as technological change, innovation and political/institutional explanations. At the very least this indicates that any economic growth study which does not control for heterogeneity is very likely to suffer from omitted variables bias. Most importantly, through a series of sensitivity tests we found that demographic effects turned out to be extremely robust, independent of the economic variables included and the specific method (cross-country vs. panel data regressions) applied. We found a significant hump-shaped pattern for the workforce age structure on economic growth. The peak of this hump, however, seems to be sensitive to the time period on which the estimates are based. By including more recent time periods it seems that the peak of the hump-shaped age pattern moves to the right. The potential role of demographic variables is doubtlessly the fact that they are better measured and more well-defined and suffer from less endogeneity problems (except possibly the younger age groups). Combining our econometric estimates with the recent EUROSTAT population projections, we may conclude that it will be hard to avoid a decline in GDP growth rates but that this decline will be more severe in demographic scenarios that imply slow or even negative rates of workforce growth. It needs to be said that our forecasts only offer a possible alternative scenario to be compared with the recent EPC (2005) productivity forecasts. However, it seems to be rather promising that even within such a simple stylised econometric model we chose for forecasting future economic growth that mainly relies on the projections of the future age structure, we arrive at a rather convincing productivity forecast as compared to the EPC (2005) productivity estimates. One could even argue that the assumption of convergence in productivity forecasts inherent in the EPC (2005) forecasts might be too strong, at least for the next two to three decades, since it hides the demographic diversity across the EU-25 countries that may be important for the demographic dividend still to be reaped by many of them. Our results might also imply that many of the economic processes over the next five decades might be closely correlated to the demographic structure and hence can be captured by forecasts of the age structure. Nevertheless it needs to be kept in mind that macro-level econometric studies as presented in this report are not adequate to identify the mechanisms and causalities that operate between the link of economic and demographic factors (although our results in Section 4.3 partly offer such an explanation where we have shown that the absorptive capacity is related to the age structure). The next steps in the research agenda are clearly in/depth micro studies on economic-demographic interactions.

References

Agell, J., T. Lindh, and H. Ohlsson. 1997. "Growth and the public sector: A critical review essay." *European Journal of Political Economy* 13(1): 33-52.

Aghion, P. and P. Howitt. 1992. "A model of growth through creative destruction." *Econometrica* 60: 323-351.

An, C.-B. and S.-H. Jeon. 2006. "Demographic change and economic growth: An inverted-U shape relationship." *Economics Letters* 92: 447-454.

Asian Development Bank. 1997. *Emerging Asia*. Manila.

Attanasio, O. P. and M. Browning. 1995. "Consumption over the Life Cycle and over the Business Cycle." *American Economic Review* 85(5): 1118-1137.

Attanasio, O. P., L. Picci, and A. E. Scorcu. 2000. "Saving, Growth, and Investment: A Macroeconomic Analysis Using a Panel of Countries." *Review of Economics and Statistics* 82(2): 182-211.

Barro, R. J., N. G. Mankiw, and X. Sala-i-Martin. 1995. "Capital Mobility in Neoclassical Models of Growth." *American Economic Review* 85(1): 103-115.

Barro, R. J. 1991. "Economic Growth in a Cross Section of Countries." *Quarterly Journal of Economics* 106(2): 407-444.

Barro, R. J. 1997. *Determinants of Economic Growth: A Cross-Country Empirical Study*. Cambridge, MA: MIT Press.

Baumol, W. J. 1952. "The transactions demand for cash: An inventory theoretic approach." *The Quarterly Journal of Economics* 66(4): 545-556.

Beaudry, P. and F. Collard. 2003. "Recent technological and economic change among industrialized countries: insights from population growth." *Scandinavian Journal of Economics* 105(3): 441-463.

Behrman, J. R., S. Duryea, and M. Székely. 1999. "Human capital in Latin America at the end of the 20th century." Mimeo, University of Pennsylvania.

Bils, M. and P. J. Klenow. 2000. "Does Schooling Cause Growth." *American Economic Review* 90(5): 1160-1183.

Bloom, D. E. and D. Canning. 2001a. "Cumulative causality, economic growth, and the demographic transition." In: N. Birdsall, A. Kelley, and S. Sinding. (eds.) *Population Matters: Demographic Change, Economic Growth, and Poverty in the Developing World*. Oxford: Oxford University Press, pp. 165-197.

Bloom, D. E. and D. Canning. 2001b. "Parsimonious Estimation of Age Structure Effects." Mimeo, University of Harvard.

Bloom, D. E., D. Canning, and B. Graham. 2003a. "Longevity and life cycle savings." *Scandinavian Journal of Economics* 105: 319-338.

Bloom, D. E., D. Canning, and J. Sevilla. 2003b. *The Demographic Dividend: A New Perspective on the Economic Consequences of Population Change*. Rand.

Bloom, D. E. and J. G. Williamson. 1998. "Demographic Transitions and Economic Miracles in Emerging Asia." *World Bank Economic Review* 12(3): 419-455.

Caselli, F, G. Esquivel, and F. Lefort. 1996. "Reopening the Convergence Debate: A New Look at Cross-Country Growth Empirics." *Journal of Economic Growth* 1: 1369-389.

Castles, I. and D. Henderson. 2005. "International Comparisons of GDP: Issues of Theory and Practice." *World Economics* 6(1).

Chevalier, M. 2003. "Chain Fischer Volume Index Methodology." *Research Paper, Income and Expenditure Accounts technical series.* Income and Expenditure Accounts Division, Statistics Canada.

Coale, A. J. and E. Hoover. 1958. *Population Growth and Economic Development in Low-Income Countries*. Princeton, N.J.: Princeton University Press.

Crespo Cuaresma, J. 2002. "Some million thresholds: nonlinearity and cross-country growth regressions." *Working Paper* 0210, Department of Economics, University of Vienna.

Crespo Cuaresma, J. and G. Doppelhofer. 2006. "Nonlinearities in Cross-Country Growth Regressions: A Bayesian Averaging of Thresholds. BAT Approach." Mimeo, University of Vienna.

Deaton, A. 1992. *Understanding Consumption*. Oxford: Clarendon Press.

De la Croix, D., B. Malmberg, and T. Lindh. 2006. "Growth and Longevity from the Industrial Revolution to the Future of an Aging Society." *Working Paper* 3, Institute for Futures Studies, Stockholm.

Dowrick, S. 2005. "The Penn World Table: A Review." *The Australian Economic Review* 38(2): 223-8.

Durlauf, S. N. and D. T. Quah. 1999. “The new empirics of economic growth.” In: J. B. Taylor and M. Woodford. (eds.) *Handbook of Macroeconomics,* Vol. IA. North-Holland, Amsterdam, pp. 231-304.

Easterlin, R. A. 1966. “On the relation of economic factors to recent and projected fertility changes.” *Demography* 3: 135-153.

Economic Policy Committee (EPC). 2005. “The 2005 EPC projections of age-related expenditure (2004-2050) for the EU25 Member States: underlying assumptions and projections methodologies.” European Commission, Directorate General for Economic and Financial Affairs.

Eltetö, O. and P. Köves. 1964. “On a problem of index number computation relating to international comparisons.” *Statisztikai Szemle* 42: 507-518.

Eurostat. 2004a. *Annual National Accounts: Main Aggregates, Eurostat Metadata in SDDS format: Summary Methodology*. Eurostat, European Commission.

Eurostat. 2004b. “EUROPOP2004: methodology for drafting fertility assumptions in the EU15 Member States.” ESTAT/F/1/POP/06(2004)/FS REV. 1, 2 December.

Eurostat. 2004c. “EUROPOP2004: methodology for drafting fertility assumptions in the EU15 Member States.” ESTAT/F/1/POP/06(2004)/KG REV. 1, 3 December.

Eurostat. 2004d. “EUROPOP2004: Summary Note on Assumptions and Methodology for International Migration.” ESTAT/F-1/POP/19(2994)/GL.

Fair, R. C. and K. M. Dominguez. 1991. “Effects of the Changing U.S. Age Distribution on Macroeconomic Equations.” *American Economic Review* 81(5): 1276-1294.

Feldstein, M. S. and C. Y. Horioka. 1980. “Domestic Saving and International Capital Flows.” *Economic Journal* 90(358): 314-329.

Fernández, C., E. Ley, and M. F. Steel. 2001. “Model uncertainty in cross-country growth regressions.” *Journal of Applied Econometrics* 16: 563-576.

Feyrer, James. 2004. “Demographics and Productivity.” *Dartmouth College Working Paper.* (forthcoming in Review of Economics and Statistics).

Fry, M. J. and A. Mason. 1982. “The Variable Rate-of-Growth Effect in the Life-Cycle Saving Model.” *Economic Inquiry* 20: 426-442.

Gómez, R. and P. H. de Cos. 2006. “The importance of being mature: the effect of demographic maturation on global per-capita income.” *Working Paper Series* 670, European Central Bank.

Geary, R. G. 1958. “A note on comparison of exchange rates and PPPs between countries.” *Journal of the Royal Statistical Society* Ser. A 121: 97-99.

Granger, C. W. J. 1981. “Some Properties of Time Series Data and their Use in Econometric Model Specification.” *Journal of Econometrics* 16: 121-130.

Grossman, G. M. and E. Helpman. 1991. *Innovation and Growth in the Global Economy*. MIT Press.

Halvarsson, M., B. Malmberg, and T. Lindh. 2005. “Productivity Consequences of Workforce Ageing—Stagnation or a Horndal Effect?” *Working Paper* 17, Institute for Futures Studies, Stockholm.

Hall, R. and C. I. Jones. 1999. “Why do some countries produce so much more output per worker than others?” *Quarterly Journal of Economics* 114: 83-116.

Hansen, B. 1996. “Inference when a nuisance parameter is not identified under the null hypothesis.” *Econometrica* 64: 413-430.

Hansen, B. 2000. “Sample Splitting and Threshold Estimation.” *Econometrica* 68: 575-603.

Helpman, E. (ed.) 1998. *General purpose technologies and economic growth*. Cambridge, Mass.: MIT Press.

Higgins, M. and J. G. Williamson. 1996. “Asian Demography and Foreign Capital Dependence.” *NBER Working Paper* 5560. National Bureau of Economic Research, Cambridge, Mass. Processed.

Higgins, M. and J. G. Williamson. 1997. “Age structure dynamics in Asia and dependence on foreign Capital.” *Population and Development Review* 23: 261-93.

ICP Handbook. 2004. “Introduction to the Comparison Program.” International Comparison Program, World Bank.

Jamison, D. T., E. Bos, and M. T. Vi. 1997. “Poverty and mortality among the elderly: measurement and performance in 33 countries.” *Tropical Medicine and International Health* 2.

Jamison, D. T., J. Wang, J., K. Hill, and J.-L. Londono. 1996. “Income, mortality and fertility in Latin America: country-level performance, 1960-1990.” *Revista de Analisis Economico* 11: 219-261.

Jones, C. I. 1995. “R&D–based models of economic growth.” *Journal of Political Economy* 103: 759-783.

Institute for Futures Studies. 2006. “Study of the Implications of demographic trends on the formation and development of human capital.” Report commissioned European Commission, Directorate for the Employment and Social Affairs. Stockholm, October 5.

Kelley, A. C. and R. M. Schmidt. 1996. “Savings, dependency and development.” *Journal of Population Economics* 9(4): 365-386.

Kelley, A. C. 2001. “The population debate in historical perspective: revisionism revised.” In: N. Birdsall, A.C. Kelley, and S. W. Sinding. (eds.) *Population Matters: Demographic Change, Economic Growth, and Poverty in the Developing World*. Oxford: Oxford University Press, pp. 24-54.

Kelley, A. C. and R. M. Schmidt. 2005. “Evolution of recent economic-demographic modeling: A synthesis.” *Journal of Population Economics* 18(2): 275-300

Khamis, S. H. 1972. “A new system of index numbers for national and international purposes.” *Journal of the Royal Statistical Society* Ser A. 135: 96-121.

Kormendi, R. and P. Meguire. 1985. “Macroeconomic determinants of growth, cross-country evidence.” *Journal of Monetary Economics* 16: 141-163.

Kortum, S. 1997. “Research, patenting and technological change.” *Econometric* 65: 1389-1419.

Leamer, E. 1983. “Let's take the Con out of Econometrics.” *American Economic Review* 73: 31-43.

Levine, R. and D. Renelt. 1992. “A sensitivity analysis of cross-country growth regressions.” *American Economic Review* 82: 942-963.

Lee, R. D. 2003. “The demographic transition: Three centuries of fundamental change.” *Journal of Economic Perspectives* 17(4): 167-190.

Leff, N. H. 1969. “Dependency rates and saving rates.” *American Economic Review* 59: 886-895.

Lindh, T. 1999. “Age Structure and Economic Policy--The Case of Saving and Growth.” *Population Research and Policy Review* 18(3): 261-277.

Lindh, T. 2004. “Medium-Term Forecasts of Potential GDP and Inflation Using Age Structure Information.” *Journal of Forecasting* 23: 19-49.

Lindh, T. and B. Malmberg. 1999. “Age Structure Effects and Growth in the OECD, 1950-90.” *Journal of Population Economics* 12(3): 431-449.

Lindh, T. and B. Malmberg. 2004. “Demographically Based Global Income Forecasts Up to the Year 2050.” *Working Paper* 7, Institute for Futures Studies, Stockholm.

Lindh, T. and B. Malmberg. 1999. *Age distributions and the current account: a changing relation?* Paper provided by Uppsala University, Department of Economics, in its Working Paper Series (number 1999:21). «http://ideas.repec.org/p/hhs/uunewp/1999_021.html».

Lindh, T. and J. Palme. (eds.) 2006. “Sustainable Policies In An Ageing Europe. A Human Capital Response.” Society and the Future Research Report Series 3, Institute for Futures Studies, Stockholm.

Macunovich D. J. 2002. *Birth Quake: the baby boom and its aftershocks*. Chicago, IL, USA: University of Chicago Press.

Maddison, A. 2003. *The World Economy: Historical Statistics*. OECD Development Centre Studies, OECD.

Maddison, A. 1995. *Monitoring the world economy, 1820-1992*. Paris, Organisation for Economic Co-operation.

Mankiw, N. G., D. Romer, and D. N. Weil. 1992. “A Contribution to the Empirics of Economic Growth.” *Quarterly Journal of Economics* 107(2): 407-437.

Malmberg, B. 1994. “Age Structure Effects on Economic Growth: Swedish Evidence.” *Scandinavian Economic History Review* 42(3): 279-295.

Malmberg, B. and T. Lindh. 2004. *Demographically based global income forecasts up to the year 2050*. Institute for Futures Studies, Stockholm.

Mason, A. 1987. “National Saving Rates and Population Growth: A New Model and New Evidence.” In: D. G. Johnson and R. D. Lee. (eds.) *Population Growth and Economic Development: Issues and Evidence*. The University of Wisconsin Press.

Mason, A. 1988. “Saving, economic growth, and demographic change.” *Population and Development Review* 14(1): 113-144.

Mason, A. 2005. Demographic transition and demographic dividends in developed and developing countries. United Nations expert group meeting on social and economic implications of changing population age structure.

Mankiw, N. G., D. Romer, and D. N. Weil. 1992. “A contribution to the empirics of economic growth.” *The Quarterly Journal of Economics* 107(2): 407-437.

McCarthy, P. 2005. “The International Comparison Program and Purchasing Power Parities.” ABS, Australian Economic Indicators 1350.0, December.

McMillan, H. M. and J. B. Baesel. 1990. “The macroeconomic impact of the baby boom generation.” *Journal of Macroeconomics* 12(2): 167-195.

Mitchell, B. R. 1992. *International historical statistics: Europe, 1750-1988*. New York, Stockton Press.

Mitchell, B. R. 1993. *International historical statistics: The Americas: 1750-1988.* New York, Stockton Press.

Mitchell, B. R. 1995. *International historical statistics: Africa, Asia and Oceania, 1750-1988.* New York, Stockton Press.

Nelson, C. R. and C. Plosser. 1982. “Trends and Random Walks in Macroeconomic Time Series.” *Journal of Monetary Economics* 10: 139-162.

Newey, W. K. and K. D. West. 1987. “A Simple, Positive Semi-Definite, Heteroskedasticity and Autocorrelation Consistent Covariance Matrix.” *Econometrica* 55(3): 703-708.

Nordström Skans, O. 2006. “How does the Age Structure Affect Regional Productivity?” forthcoming in *Applied Economics Letters*.

OECD/Eurostat. 2004. *Purchasing Power Parities and Real Expenditures, 2002 Benchmark Year*. Statistics, OECD Publishing.

Österholm, P. 2004. *Time Series and Macroeconomics: Studies in Demography and Monetary Policy*. Ph.D. Thesis, submitted to: Dept. of Economics, Uppsala University.

Phillips, P. C. B. and H. R. Moon. 1999. “Linear Regression Limit Theory for Nonstationary Panel Data.” *Econometrica* 67(5): 1057-1111

Prskawetz, A. and T. Lindh, eds. 2006. “The impact of ageing on innovation and productivity growth in Europe.” *Research Report* 28, Vienna Institute of Demography, Austrian Academy of Sciences.

Penn World Table. 2004. “Data Appendix for a Space-Time System of National Accounts: Penn World Table 6.1. PWT 6.1).

Romer, P. M. 1986. “Increasing returns and long-run growth.” *The Journal of Political Economy* 94(5): 1002-1037.

Romer, P. M. 1990. “Endogenous technological change.” *The Journal of Political Economy* 98(5): 71-102.

Quah, D. 1993. “Galton's Fallacy and Tests of the Convergence Hypothesis.” *Scandinavian Journal of Economics* 95(4): 427-443.

Sala-i-Martin, X. 1997a. “I just ran two million regressions.” *American Economic Review* 87: 178-183.

Sala-i-Martin, X. 1997b. “I just ran four million regressions.” *NBER Working Paper* 6252.

Sala-i-Martin, X., G. Doppelhofer, and R. Miller. 2004. “Determinants of Long-Term Growth, A Bayesian Averaging of Classical Estimates (BACE) Approach.” *American Economic Review* 94: 813-835.

Schreyer, P. and F. Koechlin. 2002. “OECD Purchasing Power Parities 1999 Benchmark Results.” OECD Statistics Directorate, OECD.

Segerström, P. S. 1999. “Endogenous growth without scale effects.” *American Economic Review* 88: 1290-1310.

Sergeev, S. 2005. “Calculation of the results of the Eurostat GDP comparison with the use of fixity.” Methodological paper, Statistik Austria.

Skirbekk, V. 2004. “Age and individual productivity: A literature survey.” *Vienna Yearbook of Population Research* 2004: 133-154.

Solow, R. M. 1956. “A contribution to the theory of economic growth.” *The Quarterly Journal of Economics* 70(1): 65-94.

Stapel, S., J. Pasanen, and S. Reinecke. 2004. “Purchasing power parities and related economic indicators for EU, Candidate Countries and EFTA.” *Statistics in Focus, Economy and Finance* 37. European Communities, Eurostat.

Statistics Sweden. 1991. Statistiska Meddelanden F 13 SM 9102, Stockholm.

Summers, R. and A. Heston. 1991. “The Penn World Table. Mark 5: An Expanded Set of International Comparisons, 1950-1988.” *Quarterly Journal of Economics* 106(2): 327-368.

Tobin, J. 1967. “Life cycle saving and balanced economic growth.” In: W. Fellner (ed.) *Ten Economic Studies in the Tradition of Irving Fisher*, Wiley Press, pp. 231-256.

Tobin, J. 1956. “The interest-elasticity of transactions demand for cash.” *The Review of Economics and Statistics* 38(3): 241-247.

United Nations. 1990. *Global Estimates and Projections of Population by Sex and Age: the 1990 Revision*. New York: United Nations.

Szulc, B. 1964. “Indices for multiregional comparisons.” *Przeglad Statystyczny* 3 [Statistical Review 3]: 239-254.

Vogel, F. 2005. “Purchasing Power Parities: Statistics to Describe the World”, International Comparison Program (ICP), Development Economics Data Group. DECDG), World Bank, January.

Wasmer, E. 2004. “Interpreting Europe-US Labour Market Differences : The Specificity of Human Capital Investments.” *American Economic Review* 96(3): 811-831.

Zhang, J., J. Zhang, and R. Lee. 2003. “Rising longevity, education, savings, and growth.” *Journal of Development Economics* 70: 83-101.

Appendix A: Transitional Growth Approximation

Equation (7) is derived here. Since it is not the standard approximation that is used, the formal details are made clear here. So as not to repeat too many details, we refer to the equations in the text by number.

First rewrite $\ln y^* - \ln y$ using equation (6) for k^* and h^*

$$\ln y^* - \ln y = \frac{1}{1-\alpha-\beta}\ln A^* + \frac{\alpha+\beta}{1-\alpha-\beta}\ln\frac{s}{\delta+w} + \frac{\beta}{1-\alpha-\beta}\ln N - \ln y.$$

By using the dynamic equations for the technique factor (5) and the two types of capital accumulation in (4) and decomposing $\ln y$, we arrive with some manipulation at

$$\ln y^* - \ln y = \frac{1}{1-\alpha-\beta}\left[\frac{\ln\left(A+\frac{\dot{A}}{\gamma}\right)-\ln A}{\frac{\dot{A}}{\gamma}}\cdot\frac{\dot{A}}{\gamma} + (\alpha+\beta)\frac{\ln\left(k+\frac{\dot{k}}{\delta+w}\right)-\ln k}{\frac{\dot{k}}{\delta+w}}\cdot\frac{\dot{k}}{\delta+w}\right].$$

Using the definition of the logarithmic derivative, we have

$$\ln y^* - \ln y \approx \frac{1}{(1-\alpha-\beta)\gamma(\delta+w)}\left[(\delta+w)\frac{d\ln A}{dt} + \gamma(\alpha+\beta)\frac{d\ln k}{dt}\right]$$

where the expression in brackets is the directional time derivative of y in the direction $(\delta+w,\gamma)$ in the $A-k$ plane. Since we assume N to be constant over the period in question, this is exactly $\gamma\frac{d\ln y}{dt}$ when $\delta+w$ and γ are equal numbers. It seems a rather innocuous assumption, when lacking information to the contrary, that these two terms are of approximately the same order of magnitude. Let $\lambda = (1-\alpha-\beta)\gamma(\delta+w)$ then

$$\frac{d\ln y}{dt} \approx \lambda\left(\ln y^* - \ln y\right)\cdot D$$

where D is a factor of the same order as the reciprocals of $\delta+w$ and γ. In the text D is ignored since at any rate we measure γ by the GDP per capita gap, assumed to be proportional to γ.

When calculating the estimates of annual rates of convergence from parameter estimates, we need to take into account that our proxy for γ implicitly assumes the US growth rate, g_{US}, to be zero. The error term in (7) is thus really $u = \tilde{u} + g_{US}$, where $\tilde{u}$ is the approximation error above. Assuming this to be distributed with mean zero over our observations, $E(u) = E(g_{US})$, which tallies well with our estimates. Consequently the estimate of

$$\lambda = (1-\alpha-\beta)\left[E(g_{US}) + E(\Gamma\pi)\right] = (1-\alpha-\beta)b_5 - b_3\Gamma.$$

Appendix B: Interpretation of Age Share Parameter Estimates

Some technical remarks are needed in order to understand exactly how to interpret the estimated parameters from the generic regression equation

$$\frac{g_{tj}}{\Gamma_{tj}} = b_0 + b_1 \ln i_{tj} + b_2 \ln\left(\delta + w_{tj}\right) + b_3 \ln y_{tj} + b_4 \sum_m a_m \ln n_{mtj} + b_5 \frac{1}{\Gamma_{tj}} + \varepsilon_{tj}.$$

First of all note that the relevant parameters for the growth effect will differ with the gap variable Γ_{tj}, so the impact on the growth rate for each country and period is approximately given by multiplication with this factor which is less than one. Since the GDP level is part of the gap expression. this is not quite exact but it will do as an approximation. To give some sense of how that will modify the coefficients, Table App. 1 below lists the ten-year values using starting years for the period. While the general tendency is convergence towards the US in such a way that impacts diminish with time, there are exceptions for several countries where the gap starts increasing again.

Table App. 1:
Relative gaps in GDP per capita to the US for the EU-14 countries over ten-year periods from the starting years given in columns.

	1950	1960	1970	1980	1990	2000
Austria	0.55	0.34	0.26	0.16	0.17	0.18
Belgium	0.37	0.32	0.23	0.15	0.19	0.22
Denmark	0.24	0.19	0.13	0.16	0.18	0.18
Finland	0.50	0.38	0.29	0.23	0.19	0.24
France	0.41	0.29	0.17	0.14	0.17	0.21
Germany	0.57	0.26	0.21	0.17	0.20	0.25
Greece	0.75	0.66	0.49	0.42	0.48	0.51
Ireland	0.59	0.57	0.54	0.49	0.43	0.16
Italy	0.59	0.41	0.28	0.22	0.22	0.27
Netherlands	0.29	0.18	0.11	0.12	0.17	0.16
Portugal	0.76	0.71	0.59	0.54	0.50	0.48
Spain	0.72	0.67	0.49	0.41	0.37	0.36
Sweden	0.24	0.18	0.09	0.15	0.19	0.23
United Kingdom	0.18	0.13	0.19	0.22	0.20	0.21

Second it should be noted that the sum of the age shares is restricted to unity, which in effect means that the net impact of a change in the age distribution cannot be directly inferred by looking at the coefficients. That is we cannot interpret the a_k as marginal elasticities. For example, assume that the 50-64 years age share increases by 10 per cent, then the coefficient will tell us that growth increases at approximately $0.1 \cdot a_{50-64}$, i.e., if we take the coefficient 2.4 with period dummies in Table 4 and multiply by the gap this will mean a very substantial impact on the growth rate: by around 5-10 percentage points if that was all that happened. But the marginal effect will also depend on what other age groups are decreased correspondingly. If it is the 65+ group, for example, the negative coefficient for that group will actually add to the positive effect. If it is some of the other groups, such as mature adults, there will in some cases be an offset to the negative effect. Thus marginal effects will always depend on the change in the *whole distribution including children*, although the effect from changes in the children group can only be inferred indirectly. To express this formally, partially differentiate the regression equation and assume all other variables (including the gap variable which is a bit inconsistent though) to remain constant, then the marginal effect from the age distribution is given by

$$\partial g = b_4 \sum_m a_m \partial \ln n_m \qquad \text{subject to the restriction } \partial n_{0-14} + \sum_m \partial n_m = 0$$

Since $\partial \ln n_m = \frac{\partial n_m}{n_m}$, we can—for any given change—compute the impact from this but we have to specify the changes for every age group and it is difficult to give any generally valid intuition. Note that if the children's share decreases, the sum of the changes in the other shares must be positive. Typically this is the trend case and the consistently increasing age share will be 65+ but there are numerous exceptions due to the ageing of baby boom generations that create aperiodic long waves in the trend growth rate.

Appendix C: Data—Details and Explanations

Introduction to Purchasing Power Parity

This builds heavily on the following sources: Chevalier 2003, Castles and Henderson 2005, ICP Handbook 2004, Vogel 2005, and McCarthy 2005.

The most widely used additive PPP method is Geary (1958) and Khamis (1972). Geary-Khamis (G-K) is used to construct the PWT, it is also used (partly at least) by the ICP, WDI, IMF and OECD. G-K gives greater weight to the price vectors of larger countries when determining the reference price vector. The G-K reference price vector therefore resembles more closely the price vectors of the richer countries in a comparison, hence it follows from the Gerschenkron effect that Geary-Khamis will tend to underestimate per capita income differentials across countries. In contrast, exchange rate comparisons tend to overestimate per capita differentials across countries. This is because nontradables tend to be more labour-intensive and hence relatively cheaper in poorer labour-abundant countries.

The Eltetö and Köves (1964) and Szulc (1964) (EKS) method is the multilateral method used by the Eurostat to make comparisons between the member countries of the European Community. The EKS method is transitive but not additive, in other words, EKS quantity indices are not consistent over different levels of aggregation. The EKS method has gained in status since it is now the preferred method of aggregation for international comparisons at the OECD and Eurostat. The EKS can be defined as an unweighted geometric average of the chained comparisons between countries that uses each of the countries in these comparisons as a link. The EKS method produces comparisons which are transitive, in addition, these indices also satisfy the important least-squares property that deviate the least from the pairwise Fisher binary comparisons.

Growth in the current gross domestic product (GDP) or any other nominal value aggregate can be decomposed into a price effect and a volume effect. Index number theory provides numerous indices that differ in the way the components are weighted. The quantities in the Lasreyres index are weighted with the prices of a previous period, in the Paasche index, on the other hand, they are weighted with the prices of the current period. It can be shown that, in general, a Laspeyres quantity index will generate a larger increase over time than a Paasche quantity index. This occurs when prices and quantities are negatively correlated, i.e., when goods and services that had become relatively more expensive are replaced by goods and services that have become relatively less expensive. This common substitution effect says to economic theory that the Laspeyres and Paasche indices set upper and lower limits for a theoretically ideal, less biased, index. This theoretical index can be approached by a Fisher-type index, representing the geometric mean of the Laspeyres and Paasche indices.

The Fisher index is not only theoretically superior but it also includes a number of desirable properties from the point of view of the National Accounts. It is reversible over time, i.e., the index showing the change between period (b) and period (a) is the reciprocal of the index showing the change between period (a) and period (b). Another interesting feature is the reversibility of factors by which the product of the price and quantity indices is equal to the index of the change in current values.

The framework underlying the national accounts, which influences standards for most economic statistics, including PPPs, is the SNA93. The adoption of the SNA by the majority of national statistical agencies means an internationally comparable set of national accounts data with accepted and well-understood aggregates is available. SNA 93 strongly recommends using PPPs in international comparisons of real production and consumption. When exchange rates are used to convert GDP into a common currency, the prices at which goods and services in high-income countries are valued tend to be higher than in low-income countries, thus exaggerating the differences in real income between them. In practice, the only certainty with exchange rate based comparisons is that, for any point in time, they will significantly overstate the difference in per capita GDP volumes between high and low-income countries. PPPs, therefore, provide the only valid means of making international comparisons in most situations although exchange rates should be used in certain, limited circumstances, such as in calculating the value of imports that can be purchased from a given level of export receipts.

For cross-border comparisons as for intertemporal estimates of real GDP, price and quantity components have to be separated out, so that the respective GDPs are expressed in a common set of prices. This is achieved by the use of PPP ratios or converters, but cross-country PPP-based figures for GDP do not measure, and do not claim to measure, differences in living standards, their purpose is to enable estimates to be made of cross-country differences in real GDP and of movement in the real GDP of country groupings and the world as a whole.

OECD/Eurostat approach

Sources for this section are OECD/Eurostat 2004, Eurostat 2004, Schreyer and Koechlin 2002, Sergeev 2005, and Stapel et al. 2004.

The calculation of PPPs is undertaken in two stages. First, there is the estimation of unweighted PPPs at the basic heading level, and then there is aggregation of the basic PPPs up to the level of GDP. Eurostat-OECD comparisons have always used the EKS method to derive unweighted PPPs at the basic level. Since 1990, the EKS method has also been used to obtain PPPs for the various level of aggregation up to GDPs.

The EKS method provides PPPs for each pair of countries in the comparison that are close to the PPPs which would be obtained if each pair of countries had been compared separately. This is because the EKS procedure in making the Fischer PPPs transitive minimises the difference between them and the resulting EKS PPPs. It also provides real expenditures that are not additive. The real expenditures, however, are not subject to the Gerschenkron effect. The effect applies to aggregation methods that use either a reference price structure or a reference volume structure to compare countries and arises because of the negative correlation between prices and volumes. The EKS method does not use either a reference price structure or a reference volume structure when estimating real expenditures.

PPP price samples tend to be small and variable over time making the temporal comparison of price levels difficult. PPP samples are conceived to maximise comparability of items across countries at a given point in time. Samples for temporal price indices tend to be larger and conceived to maximise comparability over time within a country. But they are not set up to deliver international comparability of items. Thus, when PPP samples change over time, it makes little sense to compare prices and related indicators over time. This is particularly true for disaggregated data, where the underlying PPP samples are even smaller than at GDP level.

PPP-converted GDP data should never be used to establish growth rates of GDP. The appropriate base for growth rate calculations is GDP at constant prices and in national currency, as only this measure is based on temporal price indices, constructed to ensure comparability over time and within a given country. If transitivity over space and time is an indispensable requirement, Eurostat and OECD recommend constant PPPs for time-series analysis. Under constant PPPs, a single year is chosen to provide the benchmark for level comparisons and all other observations are obtained by global extrapolation, using relative rates of GDP growth as provided by the national accounts.

PPP is a concept that is not immediately and easily understood. This has generated misunderstandings as sometimes PPPs are used for purposes to which they are not suited. In essence, PPPs are price comparison in space and therefore the most recommended applications are spatial ones, comparisons of PPP-converted indicators across countries at a given point in time. The most common usage of PPPs is to generate comparable volume measures in per-capita terms across countries and to calculate general price level indices. They can also be used in other areas such as labour productivity comparisons at GDP level and in measuring the relative size of economies. Despite being designed for spatial comparisons, PPPs and related economic indicators can be used for intertemporal comparisons but with certain limitations and exercising the necessary care. In addition, the sampling of items and price collection for PPPs are not designed to capture the pure price change over time as in the case of consumer price indices but instead price differential over space. In effect, GDP converted using PPP should be understood more like current price volume series.

Penn World Table

Sources are Penn World Table 2004 and Dowrick 2005.

Purchasing power parity is the number of currency units required to buy goods equivalent to what can be bought with one unit of the base country. The PPP is the national currency value of GDP divided by the real value of GDP in international dollars. International dollar has the same purchasing power over total US GDP as the US dollar in a given base year (1996 in PWT 6.1).

RGDPCH (Chain) is a chain index obtained by first applying the component growth rates between each pair of consecutive years to the current price component share in year t-1 to obtain the DA growth rate for each year. This DA growth rate for each year t is then applied backwards and forwards from 1996, and summed to the constant price net foreign balance to obtain the chain GDP series. The method used in PWT is the Geary (G-K) multilateral method, and its corollary is a matrix of additive expenditures valued at international prices at the basic heading level, in addition to the price levels of the aggregate components of GDP.

The WDI (2002) were taken as the starting point in the creation of a national accounts series. The 1996 price levels for C, I, and G for the 1996 benchmark data, the non-benchmark data and the previous benchmark data are deflated to all years available in the country's national accounts file (1950-2000). Together with the nominal expenditures on C, I and G for these years, they become inputs to what they term the mighty G-K (a multilateral aggregation across all countries, for each year). The results is a matrix of additive expenditures valued at international prices for each year, in addition to the price level of GDP for all countries in all years.

The data input for the multilateral aggregation are the local currency expenditures and price parities of 31 basic headings for 115 countries provided by the World Bank. The aggregate price levels for each country are obtained using the Geary (G-K) multilateral method. A corollary of the Geary method is a set of international prices for each basic heading. The international price of a heading is the weighted average of the prices relative to the price levels, with weights equal to the quantities; in practise they use expenditures and notional quantities. The international prices are expressed relative to the US dollar, and the reciprocal of the vector of international prices is equal to the price parities of the US.

The difference between PWT estimates and the published work of the OECD is that they have done their aggregation for 51 countries and have used the EKS method, a technique also used by the European Union. PWT also use the super-country weighted Geary method, in an attempt to assign proportional representation of the benchmark countries relative to the world. Super-country weighting simply allocates the expenditures of countries which are not in the benchmark to similar countries that are in the benchmark. The World Bank has used a different weighting scheme, one that assigns equal weight to each country over all of GDP, so that small countries will have the same importance over all headings as larger countries.

PPPs used in the PWT are defined by the G-K method and the fact that the implication of this procedure is that the PWT, valuing the output of all countries at rich-country prices, is likely to overstate the real GDP of poorer countries. The EKS index, which is favoured by the OECD in calculating PPPs, is a multilateral extension of the substitution bias-free Fischer index and is therefore expected to yield more correct estimates.

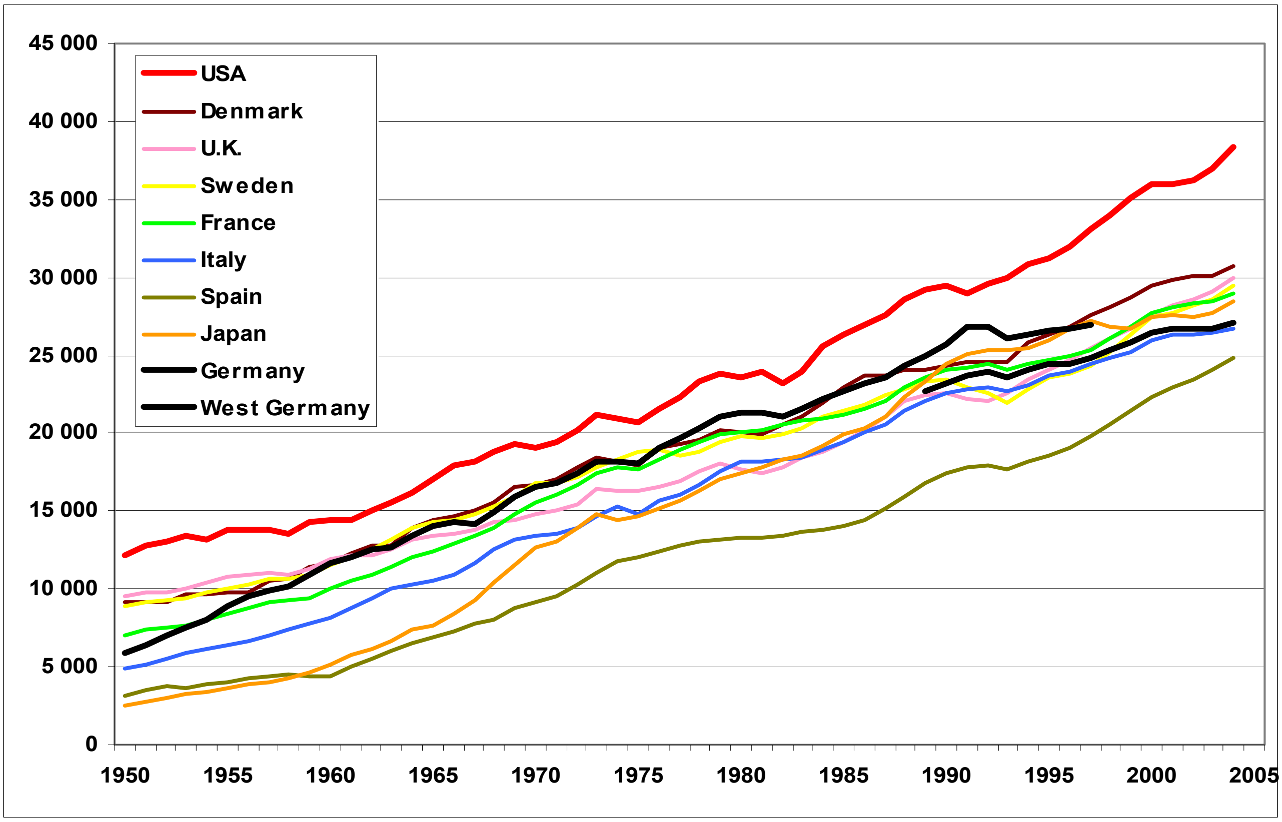
Groningen Total Economy Database (GGDC)

The main source regarding this database is Maddison 2003.

For each country detailed source descriptions are provided, but in general the following sources were used for the trends in real GDP. From 1990 onwards, series for OECD countries are mostly derived from the most recent editions of OECD National Accounts (Paris). For eastern European countries, we made extensive use of published data from the Vienna Institute for Comparative Economic Studies (WIIW) and from United Nations Economic Commission for Europe (UNECE). For Asian countries we used data from the Asian Development Bank,

For OECD countries, other (candidate) European Union member countries and Israel, GDP levels are measured in 2002 US dollars, for which “EKS” purchasing power parities have been used. These PPPs are obtained from OECD, Purchasing Power Parities 2002, Paris January 2005.

Figure App. 1:
GGDC data on GDP per capita data, measured in 2002 EKS USD.



Highest GDP per capita in Figure App. 1 belongs to USA with Denmark second highest. General data stretch over the period 1950-2004. German data are available for West Germany 1950-1997, Germany 1989-2004.

PPP comparisons (OECD, WDI, GGDC, PWT)

In this comparison we use purchasing power parity GDP data to analyse the difference between the series possible to use in our upcoming project. The OECD data is based on PPPs for 2000 US dollar, the WDI on PPPs for constant 2000 international dollar, the GGDC on PPPs in 2002 EKS dollar, and the PWT on PPPs for the 1996 Chain Series also expressed in dollar. As can be seen in the figures, the growth rates are very similar between most of the series included, especially between the series from GGDC and OECD, based on the same PPPs. The WDI differ somewhat with regard to the other series depending on the country in focus: for Germany and the US the series is more or less identical to the OECD's, while for the UK, the WDI series annual growth rate does not seem to correspond totally to any of the other series in the analysis. The PWT series in most cases follow the OECD/GGDC annual growth rates quite closely.

Figure App. 2:
Comparison for Germany, United States and United Kingdom of the GDP per capita growth rates from different data sources.