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Demographic change and economic growth in Sweden: 1750–2050

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Abstract

This paper addresses two issues. To what extent can models estimated on modern data be used to account for growth patterns in the past? Can information on historical patterns help to improve long-term forecasting of economic growth? We consider a reduced-form statistical model based on the demographic dividend literature. Assuming that there is a common DGP guiding growth through the demographic transition, we use an estimate from post-war global data to backcast the Swedish historical GDP growth. The results indicate that the assumption of a common DGP can be warranted, at least back to 1870. Given the stability of the relationship between population and growth, we use the model to forecast income for the next 50 years. We compare our approach to a previous attempt to simulate the long-term Swedish growth path with an endogenous growth model. Encompassing tests show that each of the models contains independent information on the Swedish growth path, suggesting that there is a benefit from combining them for long-term forecasting.

JEL classifications: J11; O41; I20; N33

Keywords: Demographic transition; Life-expectancy; Income growth; Population

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1. Introduction

Population aging is an inescapable consequence of lower mortality and fertility. This process will affect all countries on earth, starting with the most developed ones. The consequences of aging for future income growth are of prime importance for the conduct of economic policy, but they are still largely unknown. To shed light on this issue we investigate whether demographically-based models can be used to account for past income growth and to forecast future economic growth using population projections.

Although demographic variables depend on economic development, they are still to a large extent predetermined. This demographic inertia is exploited in demographic projections to yield forecasts that are substantially more reliable than any projection of economic variables. Therefore, using demographic projections as independent variables to forecast economic growth is a promising avenue.

There are two traditions to analyze the interaction between demographic trends and long-run growth prospects. The first one consists in building theoretical models to achieve a consistent view of the mechanisms that can drive the growth process, either qualitatively (Galor and Weil, 2000; Lagerlöf, 2003) or quantitatively (Boucekkine et al., 2003). The second tradition has an agnostic view of the mechanisms actually in place; it analyzes the empirical relationships between demographic variables and growth in income per capita in recent data, and extrapolates growth rates on the basis of demographic projections (see Bloom and Williamson, 1998). Both approaches, however, share the idea that a decline in mortality may serve as a trigger for modern economic growth.

We believe that a good model for long-term forecasting should be able to shed light on the history of growth since the Malthusian stagnation to modern growth, through the industrial revolution and the demographic transition. We will therefore confront both approaches to Swedish long-term data. Looking at Sweden is particularly relevant, not only because the Swedish demographic transition is very typical, but also because excellent demographic data are available from the mid 18th century and onwards. Estimates of per capita GDP stretches back to the 18th century too.

In a previous paper (de la Croix, Lindh, Malmberg, forthcoming), we used these long-term data to calibrate a demographically-based growth model so as to reproduce the take-off process and the rise in growth rates from stagnation prior to the 18th century to 2% growth in the 20th century. The main mechanisms at work are that rises in life-expectancy increase the incentive to get education, which in turn has ever-lasting effects on growth through a human capital externality and there is a scale effect from active population on growth.

Here we consider a demographically-based statistical growth model estimated on global post-war growth data to study whether it can account for the long-term growth process that can be observed in the Swedish data. The global model estimates show a drift in the most productive activity period with life-expectancy. The peak productivity shifts from around 30 years of age when life-expectancy is low to an age around 50 for actual life-expectancies in developed and emerging economies. The model is then used to backcast Swedish economic growth back to 1750 making use of the long-term demographic data that we have available. The backcast shows that the statistical model can account not only for recent changes in per capita income but also for the long-term process of Swedish economic development since the mid 19th century.

Both approaches are used to forecast income growth in Sweden over the period 2000–2050. Given this purpose, we treat demographic variables as exogenous throughout this paper. An assessment of the performance of a combination of the forecasts shows that this leads to smaller expected forecast errors, one reason being that any model specific bias is corrected by the combination (Diebold and Lopez, 1996).

Our conclusion is that the Swedish case provides a valuable test-ground that allows an evaluation of both theoretical and statistical approaches to demographically-based models of long-term economic growth. Our analysis highlights that the correlation between mortality decline, age structure change and income growth is not just a statistical artifact in recent data. This relation also conforms with the theoretically expected effect of mortality change on human capital accumulation and productivity. Our results suggest that a universal and highly regular process connects demographic change and economic development. Provided this connection remains intact in the future reliable methods for long-term forecasts of GDP using demographic projections can be developed.

The paper is organized as follows: Section 2 presents the Swedish demographic transition from 1750 to 2050, which will serve as input in our two models. Section 3 describes the statistical model, its estimation on World data, and the backcast experiment. Section 4 presents forecasts from the statistical model and tests its combination with the previously simulated endogenous growth model in order to improve forecast for the next 50 years. Section 5 concludes.

2. Long-term trends in Sweden

2.1. Population

Already in 1749, Sweden established a public agency with a responsibility for producing population statistics. These statistics were based on population records kept by the parish priests of the Swedish Lutheran church. Thanks to this effort we have access to detailed data of high-quality on how mortality and fertility changed as Sweden developed from a poor agricultural country in the 18th century into a rich, highly industrialized country in the 20th century (Hofsten and Lundström, 1976).

Figs. 1–3 presents how some key mortality indicators in Sweden have developed during the last 250 years. Fig. 1 shows the probability of dying before age 10. Fig. 2 gives expected remaining years of life for people that have reached 65 years of age. Fig. 3 shows the probability for men of surviving to age 65, given that they survived to age 10. All the graphs are based on time series with annual data. By 1850, childhood mortality had been improved considerably. Around 1750, 40% of all children died before age 10. By 1850, this figure was down to about 25%. This is still a high number, but the large decline had generated an acceleration in population growth.

After 1850 the age pattern of mortality improvements changed as adult survival began to improve quite significantly.

From 1870, a period of long-term, essentially uninterrupted improvement in survival for all age groups was initiated. Below 10 mortality fell from about 25% in 1870 to under 0.5% in 2000. Male survival from age 10 to age 65 increased from about 40% in 1850 to 87% in 2000. Life expectancy at age 65 increased from about 10 years in 1850 to almost 19 years in 2000.

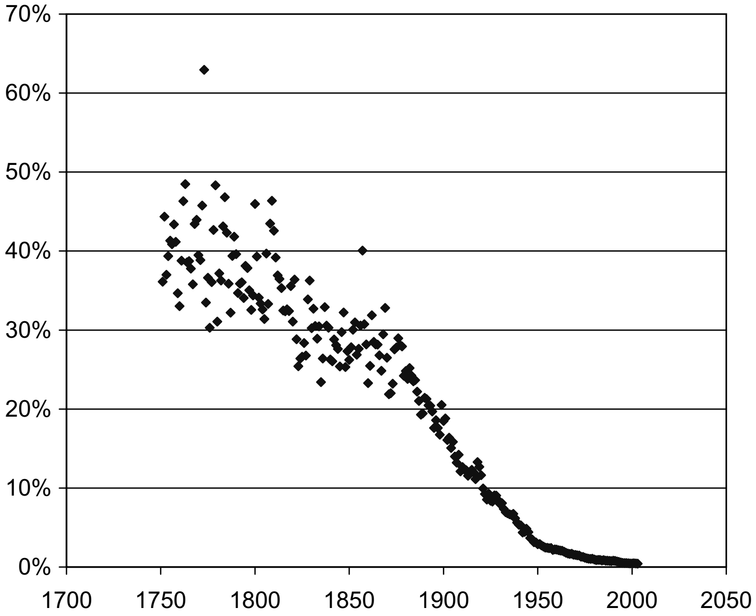

Fig. 1. Mortality under 10.

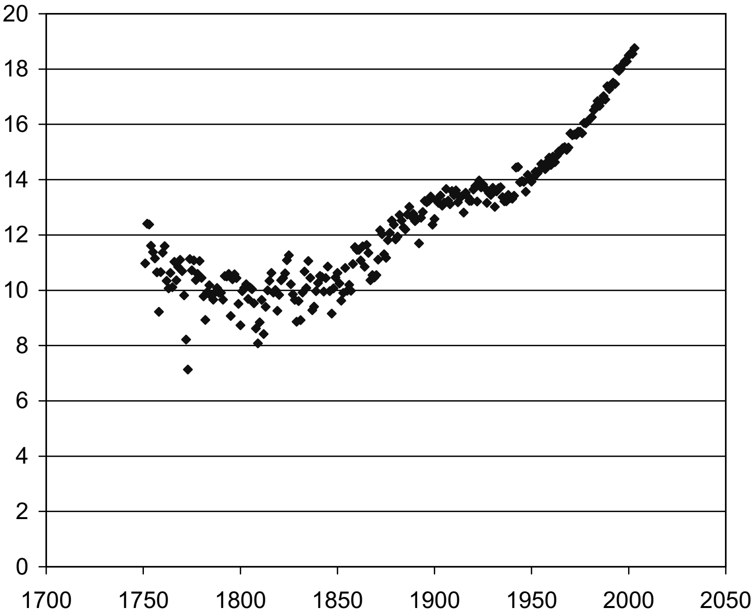

Fig. 2. Life-expectancy at age 65.

Fig. 4 summarizes the mortality changes by two measures: life-expectancy at birth and remaining life-expectancy at age 10. As can be seen in this graph, increases in adult life-expectancy lag behind life-expectancy at birth. When adult life-expectancy slowly starts to increase around 1825, there has already been a quite substantial increase in life-expectancy at birth. The time horizon of Fig. 4 extends to 2100, also showing the assumptions on mortality and fertility we have used in the forecasts of the Swedish economy.

In addition, Fig. 4 also shows changes in the Swedish total fertility rate after 1750. As can be readily seen from this graph, a clear downward trend in Swedish fertility did not materialize until the last quarter of the 19th century. That is, at a time when mortality had been declining for almost a century.

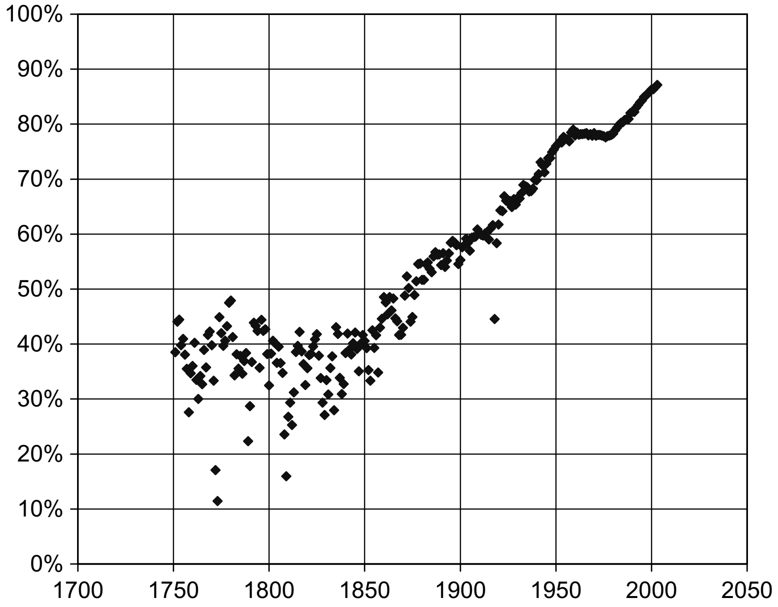

Fig. 3. Male survival from age 10 to age 65.

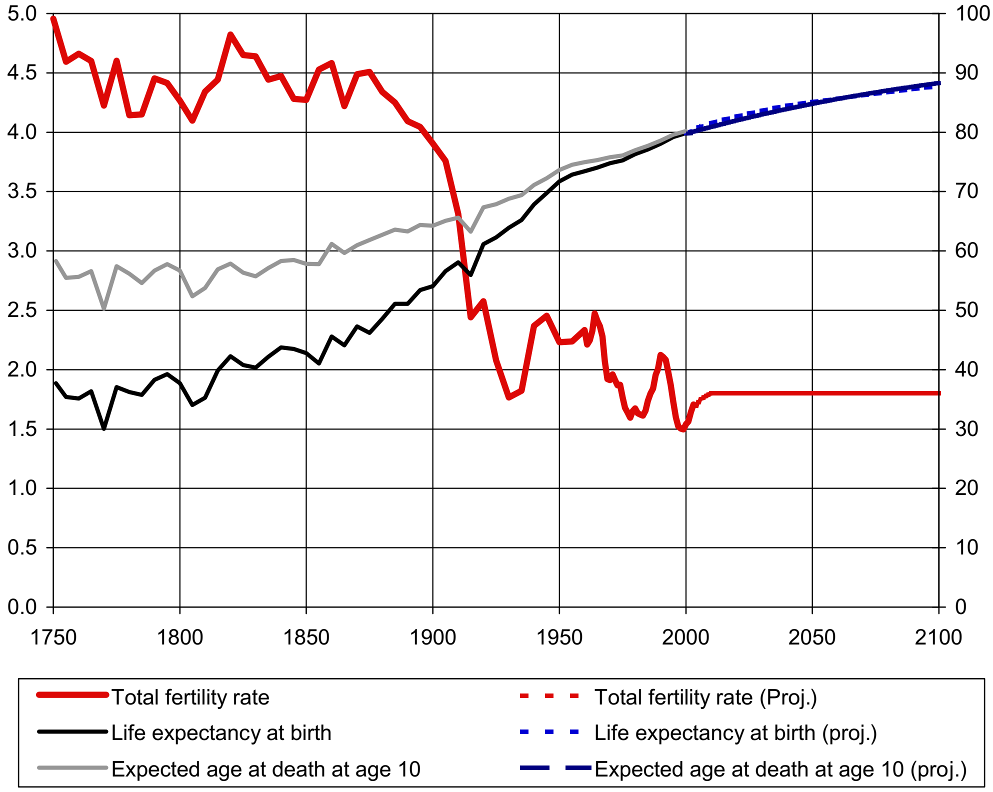

Fig. 4. Summary of the demographic transition.

The long-term trend in mortality and fertility has led to a total transformation of the Swedish age structure (Malmberg and Sommestad, 2000). This is illustrated in Fig. 5. Here the population has been divided into five 20 years age brackets: 0–19, 20–39, 40–59, 60–79 and 80+. Declining mortality and fertility lead to a change in the age structure from a

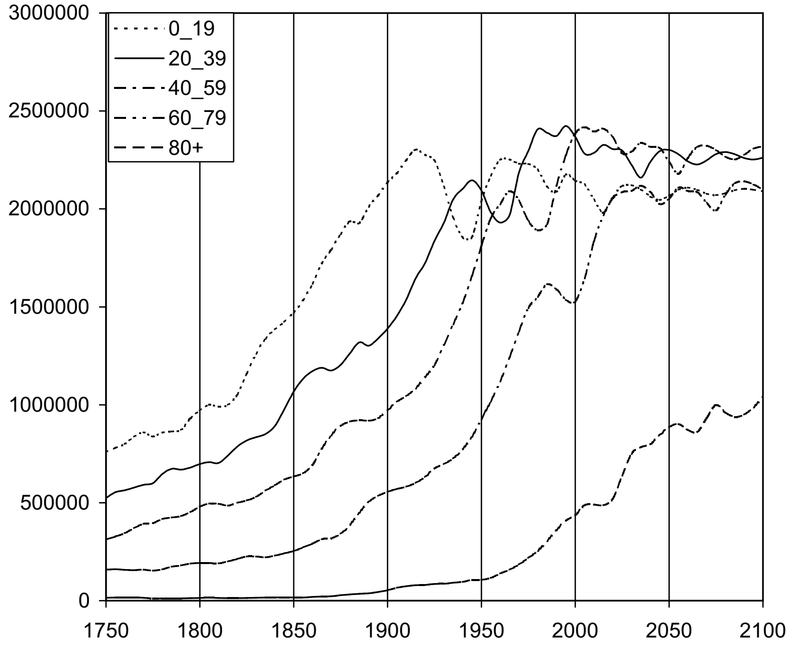

Fig. 5. Changing age structure.

population dominated by children and young adults to a population where all 20 year age brackets except the oldest have about the same size.

The expansion of the 0–19 age group is concentrated to the 1820–1920 period; the young adult groups expand 1840–1940; the middle-aged population multiply fast between 1870 and 1970; whereas the expansion of the 60–79 groups is concentrated to the 20th century. The 80+ group, on the other hand, starts to expand rapidly only after 1970. Since it is well-known that the economic behavior of individuals undergoes profound changes from childhood, youth, early adult years, into middle age and during old age, these shifts in the age structure can be expected to have substantial economic effects (Lee, 2003).

2.2. Income

Historical estimates of GDP per capita in Sweden are available from several sources. Back to 1861 they all build on work done by Lindahl et al. (1937) but lately these estimates have been extended backwards, e.g. Krantz (1997) brings the annual estimates back to 1800 and Edvinsson (2005) all the way back to 1720. Maddison (2003) also has published an estimate—which is based on previous estimates by Krantz. As is clear from Fig. 6 the Maddison estimate differs considerably from those of the two Swedes. Maddison gets the level of real GDP per capita about 50% higher in 1820 than the other two estimates.

Apart from the difference in levels that arise in the turbulent early 1900s the series do actually agree rather well on the growth process in the 19th century. Up to the 1820s we have stagnation in per capita income, then a slight rise in income after the Napoleonic wars is discernible, but at a very modest level averaging around half a percent a year. There is an increasing growth trend though and after 1850 average growth rates start to exceed the 1% level. After a crisis around the 1870s which also sparked off a very substantial emigration out of the country, mainly to the United States, this growth take-off gains strength again to rise above the 2% level in the early 20th century. Apart from temporary

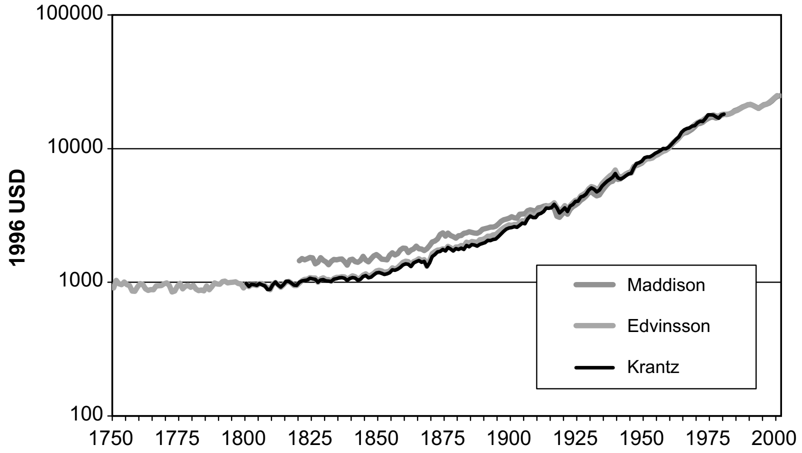

Fig. 6. Historical log GDP per capita estimates in 1996 USD.

setbacks connected to the World wars and later oil crises the long-run averages have remained at those levels ever since.

From a level of around 1000 (in 1996 USD) a year in per capita income in the stagnant period (or close to 1500 according to Maddison) Swedish GDP per capita has today reached 25 000. Depending on which estimate we prefer regarding the initial level this is 20 or 25 times the original subsistence level.

3. The demographic dividend model

In a previous paper (de la Croix, Lindh, Malmberg, forthcoming), we have demonstrated that an endogenous growth model can be used to mimic the effect of observed shifts in mortality, fertility, and age structure on the Swedish long-term per capita income growth. This gives a strong theoretical underpinning to the proposition that demographic change is a key element in the economic development process. Endogenous growth models incorporating demographic elements are not, however, the only approach to assess the importance of demographic factors in the analysis of economic growth. A more direct approach has been to incorporate demographic measures such as life-expectancy and measures of age structure in Barro-type, cross-country growth regressions. In general, demographic variables have been shown to have strong and significant effects on per capita income growth in these estimations. A relevant question, therefore, is if a dividend model would be able to account for long-term economic growth in countries that experienced the demographic transition already in the 19th and early 20th century?

One way to answer this question would be to estimate a time series regression on the long-term demographic and GDP data of a country with an early demographic transition. There are many problems to that approach however: structural breaks, persistence in both dependent and independent variables, and high collinearity among independent variables. It is therefore a risk that the demographic effects on income growth are drowned by such problems. Therefore, the approach taken here is, instead, to employ an empirical dividend model that has been estimated on modern, global, cross-country panel data to backcast Swedish per capita income growth back to 1750. The backcast can then be compared to the available empirical estimates of Swedish per capita GDP as well as to the simulated path of per capita income presented in the preceding section.

Such a backcast, using a model estimated on a different data set, does in fact represent an out-of-sample test of the stability of the original model. An evaluation of the backcasting-performance of the dividend model, therefore, will not only cast light on the possible importance of demographic factors in Swedish economic development. It also shows whether the information from currently developing countries is useful for describing historical experience. Furthermore, such historical stability would add credibility to long-term forecasts by increasing the likelihood of continued stability.

3.1. A cross-country estimation

At least three arguments underscore the importance of age structure for per capita income. One is the savings argument. In countries with high child-dependency rates, savings rates will be low and this may lead to low productivity if domestic capital formation is constrained by savings Bloom et al. (2003). This argument was first put forward by Coale and Hoover (1958). Second, a high dependency rate implies a low worker per capita ratio and this should lead to a lower per capita income in a direct way by a pure accounting effect. Kelley and Schmidt (2005) summarize this argument and review much of the demographic dividend literature up to date. Third, as demonstrated by Lindh and Malmberg (1999) on OECD data age structure within the working-age population is also of importance.

The dividend model here uses levels of per capita GDP instead of growth rates as dependent variable and age shares instead of age group growth rates as explanatory variables. That is, a level regression is used instead of a first-difference estimation. An argument for using a level-specification is evidence showing co-integration between GDP and age structure in a OECD sample (Österholm, 2004). This implies that standard least square estimates of coefficients are superconsistent. If the co-integration assumption does not hold a potential problem is that an estimation using non-stationary time series can result in a spurious regression. However, in a panel context, this problem is substantially ameliorated (Phillips and Moon, 1999). More important, our intention is to use the regression results for out-of-sample backcasting. Failure to produce a successful backcast immediately expose any spurious regression problem.

Dividend models, typically, also includes life-expectancy as one of the explanatory variables. First, increasing life-expectancy is likely to increase savings by increasing the risk for survival into old age dependency. Second, higher life-expectancy increases the expected return of education. A capital externality with life-cycle saving would work in a rather similar way and we will not here attempt to identify these effects separately. From the theory we would expect that increases in the share of the active population are associated with higher income, and more so the higher levels life expectancy reaches, up to the point where the increase in life expectancy mainly increases the retired population. For a single time series changing life-expectancy is reflected directly in the age structure and we would not expect to be able to identify separate effects from increasing longevity and growing shares of elderly in the population. In the country panel with observations from different stages of the demographic transition the effects of different age shares on GDP will shift over time as increasing length of education and increasing longevity pushes the effective working ages upwards. By interacting age group shares with life-expectancy this expected gradual drift in age effects can be compensated and age effects are estimated as varying with life-expectancy.

3.2. Data and specification of model

The details of the cross-country estimation together with extensive regression diagnostics have been presented in Lindh and Malmberg (2007). The presentation here, therefore, will concentrate on the main features of the model.

Our economic data are taken from Penn World Table Version 6.1, Center for International Comparisons at the University of Pennsylvania (CICUP), October 2002. We use 111 countries which had coherent data for at least the period 1961–1996 using the variable RGDPCH (the chain indexed PPP-adjusted real GDP estimate) which is available for many countries since 1950. We deleted countries with shorter time series both because we wanted to maintain a reasonably balanced panel and because we know from time series estimation that too short time series are unreliable when estimating the correlations to age structure. Demographic variables, stretching from 1950 up to the end of the 1990s are from UN World Population Prospects (2000) from which we also have consistent projections up to 2050.

Our estimation model allows for a panel regression with the logarithm of per capita GDP, y, as dependent variable predicted by the independent demographic variables: the logarithms of age shares, a, and the logarithm of life-expectancy at birth, t being the time period, and including interaction terms between life-expectancy, e_0, and age shares to catch the upward drift in the economically active period of the life cycle:

$$y_{it} = \alpha \log e_{0it} + \sum_{k=0-14}^{65+} (\beta_k + \gamma_k \log e_{0it}) a_{kit} + \eta_i + v_t + \varepsilon_{it} \tag{1}$$

We allow for country-specific intercepts through η_i and v_t accounts for time-specific effects. A potential problem is that life-expectancy is highly correlated with age structure, especially the size of older groups, and more seriously with the interaction terms themselves. However, checking the correlation matrix it turns out that log life expectancy is more strongly correlated (about 0.8) with log GDP per capita than with any of the age share variables. Recursive estimation proves that the parameter estimates are robust and stable given that the time series dimension is long enough.

The demographic variables are lagged one step to ensure that they are pre-determined, but these variables are highly persistent so this does not make much difference. Endogeneity therefore may still be an issue for any structural interpretation of the coefficients but for the purpose of forecasting, or in this case backcasting, bias has to be traded for precision anyway. Using instrumental variables thus becomes less of a choice even if we had been able to find good instruments. Without the interaction terms GDP per capita would be described by a Cobb-Douglas index of age shares and life-expectancy to capture ‘‘technological change’’. This is thus essentially a standard production function specification where we use population shares as substitutes for production factor intensities and the interaction with life-expectancy to catch cross effects with human and physical capital, or if you like knowledge capital. The logarithmic form ameliorates problems with heteroskedasticity and also makes it possible to include the whole distribution of age shares in the fixed effect estimation, since the exact linear dependence of the full set of age group shares is broken.

Based on previous work (Lindh and Malmberg, 1999) an aggregation of age groups to children 0–14, young adults 15–29, mature adults 30–49, middle aged 50–64, and old age

65+ is known to work well in growth equations for the OECD without running into collinearity problems. This corresponds roughly to the age intervals in which humans are first dependent on parents, second finding their place in adult life and forming a family, third raising their family, fourth preparing for retirement and fifth retiring. The limits for these functional groups are, of course, not exact. They vary both with time and culture, as well as the institutions that transmit and govern the economic effects of each age group. Nor do we expect effects to be uniform within the limits. This specification is thus a pragmatic approximation for estimating growth effects from the continuous age distribution. The age distribution in turn proxies for the actual functional changes in behavior and resources over the life cycle which are the real causes for the GDP effects.

3.3. Parameter estimates of the dividend model

To simplify the out-of-sample tests below, we have only used data up to 1996 in the estimations reported in Table 1. The estimates show that life-expectancy is positively correlated with per capita income. The estimates of interaction effects also indicate that the basic hypothesis is valid; life-expectancy modifies the correlation with demographic age structure by shifting life phases. In Fig. 7 we visualize this shifting pattern of age elasticities on income that is implied by the interaction model. The effect of young and mature adults decreases with life-expectancy while the negative effects of dependents tend to decrease also. This shifts the hump of the life cycle pattern upwards and makes it flatter and less pronounced as life expectancy rise. This might indicate that increasing length of education in low mortality populations reduces positive effects from young adults while increasing them for middle-aged and even perhaps for the elderly. The latter conclusion is highly uncertain due to the collinearity issue between children and elderly although it is intriguing that we actually see a trend in that direction.

At low and medium levels of life-expectancy the age effects on per capita income are dominated by the balance between children and young adults. Child-rich populations tend to be poor whereas countries with declining child-dependency and an expanding young

Table 1
Estimates of Eq. (1)

	α,β_k	γ_k
$\log e_0$	*5.412*	
	(2.38)	
$\log a_{0-14}$	−5.45	1.062
	(3.01)	(0.69)
$\log a_{15-29}$	3.704	−0.872
	(2.25)	(0.52)
$\log a_{30-49}$	*3.800*	*−0.831*
	(1.79)	(0.42)
$\log a_{50-64}$	0.251	0.017
	(1.02)	(0.24)
$\log a_{65+}$	*−7.597*	*1.873*
	(0.65)	(0.16)
$\bar{R}^2$	0.964	

Note: Model with fixed time and country effects. Italic values indicate that the estimates are significantly different from zero on the 5% level. Standard errors are adjusted for the unbalanced panel.

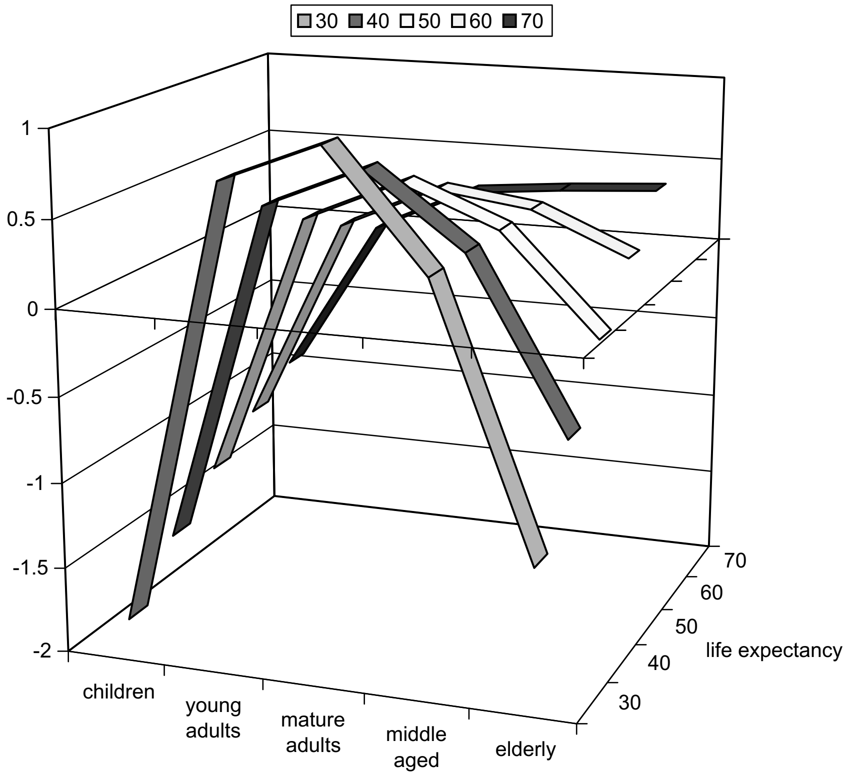

Fig. 7. The pattern of shifting age elasticities from the heterogeneous model.

adult population enjoy rising per capita income. At higher levels of life-expectancy it is instead a high share of middle age adults (30–49 and 50–64 years old) that ensure good economic prospects.

3.4. Long-term growth in Sweden: A backcast experiment

To generate a Swedish projection for the period 1751–2050 we use demographic data taken from the Human Mortality Database (Berkeley and Rostock). We have updated with the latest estimates (fall 2004) up to 2003 and projections up to 2050. Using the coefficients of the interaction model in Table 1 columns 2 and 3 it is then trivial to make the projection. However, since mortality data and thus life expectancy is very volatile in the historical data we have used smoothed series. The confidence intervals have been computed in the standard way only taking account of parameter uncertainty and assuming a normal distribution.

In Fig. 8 we have zoomed in on the period 1820–1950. The backcast level is generally higher than the historical estimates in the period encompassing the World Wars and the Interwar period but on the whole it agrees with the Maddison estimates fairly well down to around 1870 but is higher than Edvinsson's estimates before 1900.

The order of the relative differences between the backcast and Maddison back to 1870 is actually about the same as the differences between the Edvinsson and Maddison estimates but increases somewhat as we go further back in time. In view of the immense changes in available technology that has taken place between the late 19th century and the late 20th century one might have expected that the relation between income level and demographic structure in developing countries in Africa and Asia would look rather different than it did

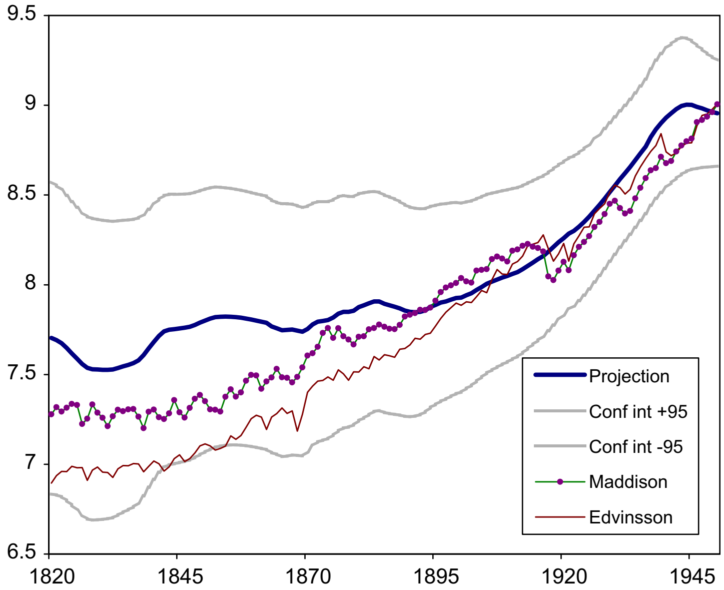

Fig. 8. Backcast over the period 1820–1950.

in Sweden 100 years earlier. But the relation seems to have been essentially the same at least back to the end of the 19th century. This strongly suggests that the economic development associated with the demographic transition is a universal process allowing us to treat global data as stemming from a common non-stationary DGP.

4. Forecasting long-run economic growth

The stability of the relationship between population and growth outlined in the previous section suggests that the demographic dividend model can be useful to forecast income growth in the long-run. However since the seminal paper by Bates and Granger (1969) the literature suggests that considerable reductions of forecast errors can be achieved by using weighted averages of forecasts rather than any particular forecast per se. The question of why that works has not yet been fully answered but, as pointed out by Diebold and Lopez (1996), all forecasting models are in practice mis-specified simplifications of the actual DGPs that generate real data and there is therefore a potential benefit to be had by pooling different biases. A recent evaluation by Hendry and Clements (2001) discuss the potential explanations and confirm that if indeed the correct conditional expectation of a weakly stationary process is known then combination of forecasts is ineffective in reducing forecast errors.

Mis-specification, inefficient use of all available information or non-stationarities then appear as pre-conditions for achieving gains from combination. In practice all three of these sources for combination gains are abundant. Armstrong (1989) in a succinct summary of the then available studies of forecast combination concludes that combination of forecasts seems to be most useful for long-range forecasting and also that combination seems to yield the most gain when the methods used are very different. Extending the simulation in de la Croix, Lindh, Malmberg (forthcoming) to the period 2000–2050, we discovered that it predicts very similar growth rates over the near future as the projection forward of the demographic dividend model, see Fig. 9. Still it leads to a very different forecast at a longer horizon.

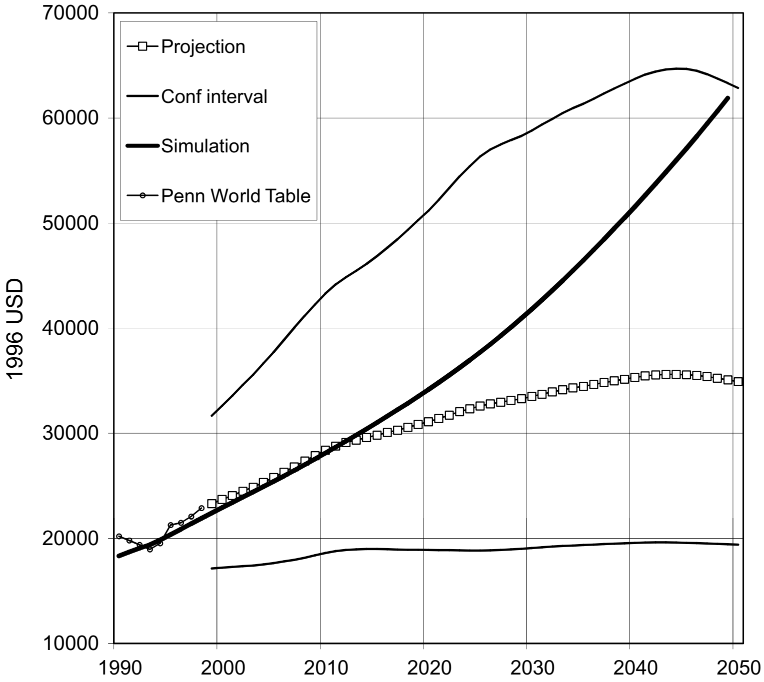

Fig. 9. Forecasted income growth.

The empirical information used to calibrate the simulation model overlaps only slightly in the second half of the 20th century with the global data used to estimate the econometric model and only for one country out of 111. And in fact the Maddison estimate of GDP per capita differs substantially from that of PWT. By assumption the cross-country information on countries early in their development provides information also on the historical time series of Sweden. On the other hand we lack information on the mechanisms in the economy that generates this process, but some of this information has presumedly been built into the simulation model. The crucial question is then whether the two models encompass each other? Or do they both contain independent information useful for predicting actual GDP per capita?

As a first step we assume we can treat the series as weakly stationary and check whether the combination works. In Table 2 we report the results from regressions of the following form:

$$y_t = \alpha_0 + \beta_s \hat{y}_{t,s} + \beta_p \hat{y}_{t,p} + \varepsilon_t \tag{2}$$

where the left hand side are GDP per capita measures while $\hat{y}_{t,s}$ and $\hat{y}_{t,p}$ denote the simulated series and the projected series, respectively. As dependent variable we use both the longer Edvinsson series that has not been used in either estimation or calibration and the shorter Maddison series that has been used in calibration but differs from the PWT data that were used for estimation.

Eq. (2) generates unbiased combination forecasts as a by-product even if the individual forecasts are biased (see Granger and Ramanathan, 1984) and is often referred to as the simple linear combining method by e.g. Deutsch et al. (1994) if t is in the future while Diebold and Lopez consider the same equation as a test of whether the two forecasts encompasses each other or not. If the coefficient vector is (0,1,0) the simulation would be said to encompass the projection model while if it is (0,0,1) then the projection encompasses the

Table 2
Encompassing tests for different models and series

	α_0	β_s	β_p	AR	MA	Test	Test	$\bar{R}^2$	DW
Maddison									
						(0,1,0)	(0,0,1)		
OLS	−1165	0.310	0.846			85.1	202.7	0.983	0.051
	(176.8)	(0.147)	(0.148)			(0.000)	(0.000)		
AR	519.3	0.401	0.630	0.987		12.25	5.86	0.999	1.314
	(1552)	(0.100)	(0.124)	(0.016)		(0.000)	(0.000)		
ARMA	−174.0	0.434	0.628	0.970	0.434	7.76	4.60	0.999	1.992
	(1100)	(0.123)	(0.150)	(0.022)	(0.070)	(0.000)	(0.000)		
Edvinsson									
OLS	−1529	0.247	0.936			93.19	769.0	0.985	0.057
	(198.9)	(0.159)	(0.161)			(0.000)	(0.000)		
AR1	−392.8	0.485	0.597	0.985		11.35	10.12	0.999	1.151
	(1015)	(0.092)	(0.110)	(0.015)		(0.000)	(0.000)		
ARMA	−813.9	0.514	0.610	0.966	0.433	7.44	10.09	0.999	1.921
	(683.8)	(0.113)	(0.139)	(0.020)	(0.059)	(0.000)	(0.000)		

Note: In the OLS case the test is χ^2 in the other models *F*-tests. The full length of the series has been utilized. Maddison's series 1820–2001 and Edvinsson's 1750–2000.

simulation model. For any other values neither model encompasses the other and both forecasts contain useful information about the DGP in question. In our case, of course, neither of the projections are forecasts estimated from a given time series in the usual sense, nor are the historical time series observed data in the usual sense. Nevertheless it is of interest to see whether the projections contain information that is helpful in predicting the available GDP estimates. Indeed we find that to be the case.

In Table 2 the upper half tests against the Maddison series, first using ordinary least squares (though the standard errors are corrected for heteroskedasticity and autocorrelation by the Newey-West method). Clearly the result indicates that both models contain information valuable for the prediction and that they are not encompassing. Using the much longer Edvinsson series as dependent variable yields approximately the same results. Correcting for serial correlation in the residuals both by AR and ARMA corrections does not change the basic impression of that.

In Table 3 we report the mean square relative errors using the full length of the comparison series. When the serial correlation is modeled we achieve unbiased forecasts that reduce the errors quite substantially. When comparing the OLS combination to the simulation there is no real reduction in the error either against the Maddison nor against the Edvinsson series. Thus, it is necessary to take serial correlation into account to achieve a close fit. Still, in spite of the large discrepancy of the projection to the longer Edvinsson

Table 3
Mean square relative errors for forecasts and combined forecasts

No. of obs	Simulation	Projection	Comb OLS	Comb AR	Comb ARMA
Compared to Maddison					
181–182	0.112	0.312	0.151	0.038	0.037
Compared to Edvinsson					
248–251	0.202	0.657	0.218	0.043	0.044

series there is really not much difference in the combination properties. It seems rather obvious that we could make the case for both the approaches being useful even stronger by restricting the tests to a period starting in the later half of the 19th century. Still, provided we model the serial correlation we can achieve quite a strong reduction in MSE.

There may, however, be some stationarity problems apart from autocorrelation since all the series are rather obviously trended in a non-linear way. Then our tests here would not be valid since the parameter estimates in that case would not have a standard distribution. Diebold and Lopez recommend that in such cases one should instead use encompassing tests from a specification due to Fair and Shiller (1990). Instead of estimating Eq. (2) that directly compares the level series one can compare whether the changes in GDP per capita are predicted by the predicted changes.

$$y_{t+k} - y_t = \alpha_0 + \beta_s(\hat{y}_{t+k,s} - y_t) + \beta_p(\hat{y}_{t+k,p} - y_t) + \varepsilon_t \tag{3}$$

Then the risks of spurious regression due to high persistence is removed by the differentation and the tests are reliable tests for whether both series actually provide information for the prediction.

For obvious reasons neither the simulation nor the projection contain much information for predicting business cycle noise. The simulation is a long-term model with no allowance whatsoever for business cycle movements. The projection also ignores business cycles by conditioning on slow-moving demographic variables. We, therefore, redo the encompassing tests successively increasing the horizon. As we let k increase the predictive information in the forecasted changes also increases. This is due to the business cycle errors starting to cancel out when the horizon grows.

In Table 4 we report a sample of results from different horizons using an autoregressive model. The tests for encompassing reject the hypothesis that any of the series encompass the other. The results are very consistent over this broad range of horizons (and in fact the combination coefficients are not too dissimilar for every choice of forecasting period). This holds irrespective of which of the historical estimates we have as dependent variable.

Thus we conclude that a combination of the approaches really is useful and will reduce forecasting errors given some control for the serial correlation in the errors. Both models in fact contribute useful information for predicting the Swedish GDP per capita as far as

Table 4
Results from first-order autoregressive model of GDP per capita changes on forecasted changes

Horizon of forecast	2 years	5 years	10 years	20 years	40 years
Dep: Maddison					
β_s	0.404	0.325	0.283	0.507	0.455
β_p	0.616	0.531	0.493	0.583	0.566
F-test (0,1,0)	0.000	0.000	0.000	0.000	0.000
F-test (0,0,1)	0.001	0.000	0.000	0.002	0.005
$\bar{R}^2$	0.785	0.944	0.979	0.994	0.997
Dep: Edvinsson					
β_s	0.420	0.457	0.378	0.531	0.270
β_p	0.449	0.516	0.448	0.555	0.412
F-test (0,1,0)	0.000	0.000	0.000	0.000	0.000
F-test (0,0,1)	0.005	0.000	0.000	0.000	0.000
$\bar{R}^2$	0.795	0.946	0.980	0.994	0.998

Only the coefficients for the simulated change and the projected change are reported.

we can judge from their ability to predict the historical estimates. As the weights in the linear combination are roughly not significantly different from each other in most cases a forecast somewhere in between the simulation path and the demographic projection should have a lower forecast error and be more likely than either of the paths suggested by the individual models.

5. Conclusion

In this paper we have presented new evidence supporting the idea that demographic change is a key determinant of long-term growth in per capita income. The analysis has used the case of Sweden as a kind of laboratory since this is a country for which high-quality demographic and economic data are available from 1750 and onwards.

We propose an empirical model rooted in the "demographic dividend" literature that focuses on how declining dependency rates have boosted economic growth in countries that have experienced a decline in fertility during the post-war period. We show that shifts in mortality and age structure that account for the growth in per capita income across 111 countries during the last 40 years, also accounts for the long-term increase in Swedish per capita income from the early 19th century and onwards. Hence a demographic dividend model estimated on modern data can be used to successfully track the long-term growth experience of a country that experienced the demographic transition much earlier than the developing countries of today. That a model estimated on modern data can be used to successfully backcast economic growth is evidence of a considerable stability in the empirical relationship between demographic structure and growth in per capita income.

In order to be useful for long-term forecasting, we show that the demographic dividend model should be combined with other approaches incorporating information on technological change in the long-run. We use a simulation model from a previous paper to capture this technological change and combine it with the demographic dividend forecast. The complementarities between the two approaches are demonstrated by the encompassing analysis presented in Section 4. According to the results from this analysis, both models contain useful information about the data generating process. This suggests that a forecast based on a combination of the two models can be expected to perform better than a forecast using just one of the two.

Thus, our analysis of the Swedish growth process has not only considerably strengthened the argument that the fundamental shifts in the human conditions that are associated with the demographic transition are fundamental also for the process of modern economic growth. This leads to a proposal for further research on long-term economic forecasts to be based on a combination of formal modeling and more traditional econometric methods.

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References

Armstrong, J.S., 1989. Combining forecasts – the end of the beginning or the beginning of the end. International Journal of Forecasting 5 (4), 585–588.

Bates, J.M., Granger, C.W.J., 1969. "The Combination of Forecasts". Operations Research Quarterly 20:451–468. Reprinted in Mills, T.C. (Ed.) (1999), Economic Forecasting, Edward Elgar, Cheltenham.

Bloom, D.E., Canning, D., Graham, B., 2003. Longevity and life-cycle savings. Scandinavian Journal of Economics 105 (3), 319–338.

Bloom, D.E., Williamson, J.G., 1998. Demographic transitions and economic miracles in emerging Asia. World Bank Economic Review 12 (3), 419–455.

Boucekkine, R., de la Croix, D., Licandro, O., 2003. Early mortality declines at the dawn of modern growth. Scandinavian Journal of Economics 105 (3), 401–418.

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

de la Croix, D., Lindh, T., Malmberg, B., forthcoming. "Swedish Economic Growth and Education Since 1800". Canadian Journal of Economics.

Deutsch, M., Granger, C.W.J., Teräsvirta, T., 1994. The combination of forecasts using changing weights. International Journal of Forecasting 10 (1), 47–57.

Diebold, F.X., Lopez, J.A., 1996. Forecast Evaluation and Combination". In Statistical Methods of Finance. In: Handbook of Statistics Series, vol. 14. Oxford, Elsevier, New York, North Holland.

Edvinsson, R., 2005. Growth, Accumulation, Crisis. Stockholm Studies in Economic History, vol. 41, PhD thesis. Almqvist & Wiksell International, Stockholm.

Fair, R.C., Shiller, R.J., 1990. Comparing information in forecasts from econometric models. American Economic Review 80 (3), 375–389, June.

Galor, O., Weil, D., 2000. Population, technology, and growth: from the Malthusian regime to the demographic transition and beyond. American Economic Review 90 (4), 806–828.

Granger, C.W.J., Ramanathan, R., 1984. Improved methods of combining forecasts. Journal of Forecasting 3, 197–204.

Hendry, D.F., Clements, M.P., 2001. Pooling of forecasts. Econometrics Journal 7, 1–31.

Hofsten, E., Lundström, H., 1976. Swedish Population History: Main Trends from 1750 to 1970. LiberFörlag, Stockholm.

Kelley, A.C., Schmidt, R.M., 2005. Evolution of recent economic-demographic modeling: a synthesis. Journal of Population Economics 18, 275–300.

Krantz, O., 1997. Swedish Historical National Accounts 1800–1990 – Aggregated Output Series. manuscript.

Lagerlöf, N., 2003. From Malthus to modern growth: can epidemics explain the three regimes? International Economic Review 44 (2), 755–777.

Lee, R., 2003. The demographic transition: three centuries of fundamental change. Journal of Economic Perspectives 17 (4), 167–190.

Lindahl, E., Dahlgren, E., Kock, K., 1937. National Income of Sweden 1861–1930, Part One and Two. In: Wages, Cost of Living and National Income of Sweden, 1860–1930, vol. III. P.S. King & Son, Ltd., London.

Lindh, T., Malmberg, B., 1999. Age structure effects and growth in the OECD, 1950–90. Journal of Population Economics 12 (3), 431–449.

Lindh, T., Malmberg, B., 2007. Demographically based global income forecasts up to the year 2050. International Journal of Forecasting (special issue). Available from: <http://dx.doi.org/10.1016/j.ijforecast.2007.07.005>.

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

Malmberg, B., Sommestad, L., 2000. The hidden pulse of history: population and economic change in Sweden: 1820–2000. Scandinavian Journal of History 25, 131–146.

Österholm, P., 2004. Estimating the Relationship between Age Structure and GDP in the OECD Using Panel Cointegration Methods. Technical Report, Uppsala University, Department of Economics.

Phillips, P.C.B., Moon, H.R., 1999. Linear regression limit theory for nonstationary panel data. Econometrica 67 (5), 1057–1111, September.

United Nations Population Division, 2000. World Population Prospects: The 2000 Revision. UN Department of Economic and Social Affairs.