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by

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The Population Age Distribution, Human Capital, and Economic Growth: The U.S. states 1930-2000 *

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Abstract

This paper introduces age-based population heterogeneity in the Mankiw, Romer, and Weil (1992) model to improve measurement of aggregate labor and aggregate human capital. The estimation results are consistent with this model, and they indicate a hump-shaped and quantitatively important partial relation between the initial population age distribution and the subsequent rate of economic growth for the U.S. states for the period 1930-2000. This paper also finds that the estimated growth effects of the initial level of income per capita, of educational attainment, and of variables measuring the population growth rate are substantially biased if the age distribution is not accounted for.

Keywords:
Population age structure; Regional Economic growth; Human capital; Population Growth; Migration

JEL codes: O11;O18;O47

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1. INTRODUCTION

The age distribution is an obvious potential determinant to the economic growth rate. Age cohorts differ with respect to e.g. hours worked and experience, and the size of the dependent population may affect the labor supply of the working-age population. Nevertheless, the age distribution is largely ignored in empirical growth studies (see e.g. the surveys by Durlauf and Quah, 1999, and Temple, 1999).[1] Demography is typically only accounted for by variables measuring the population growth rate. This shortcoming of the literature provides a motivation for this paper. Moreover, when the age distribution is accounted for in empirical growth studies the estimated effects are often not statistically significant. E.g., Barro and Sala-i-Martin (2004, ch. 12, p.539) find that their two population share variables (for under 15 and over 65) are jointly insignificant in their empirical analysis of countries.

As a theoretical framework, this paper extends the Mankiw, Romer, and Weil (1992) model by allowing the different age cohorts to impact aggregate labor differently. In contrast, neoclassical growth studies typically use one of two very simple measures of aggregate labor: the working-age population (see MRW) or the total population (see Barro and Sala-i-Martin, 1992, hereafter BS). In this age-structure-augmented MRW model, the rate of economic growth is, in addition to the standard explanatory variables, a function of an exogenously given age distribution. This model is tested on panel data for the U.S. states for the period 1930-2000. A second aim of this paper is to analyze, on the basis of this U.S. states sample, whether the estimated growth effects of standard explanatory variables (see MRW; Islam, 1995) are biased if the age distribution is not accounted for.

Thereby, this paper contributes to the empirical growth literature in several ways. First, it improves measurement of aggregate labor and aggregate human capital. A recent survey of the growth literature by Temple (1999, p. 138) notes that despite that a positive effect of schooling on wages is found by micro studies "the failure to discern this effect at the macro level is worrying". Temple (1999) also points out that: "The literature uses somewhat dubious proxies for aggregate

[1] Durlauf and Quah (1999) list eighty-seven different variables used in country growth regressions, among which the growth of the population shares under age 15 and over 65 years are the only age-structure-related variables listed. The survey of Temple (1999) does not mention the age distribution but argues that "in-depth studies are needed to address the links between population growth and macroeconomic outcomes" (p. 142). Sala-i-Martin (1997), on the other hand, does include an age-structure-related variable, the initial ratio of workers to population, among the more than sixty variables analyzed. Moreover, some growth studies account for one dependency ratio (e.g., Galor and Zang, 1997) or one age group (e.g., Perotti, 1996; Panizza, 2002).

human capital. The focus is almost exclusively on schooling rather than training."[2] In other words, macro growth studies often fail to find a positive growth effect from educational attainment, and the part of aggregate human capital that depends on training or experience is typically not accounted for. This paper presents a straightforward way to capture the part of aggregate human capital that is accumulated through training or experience: In view of the micro evidence on age-wage profiles, this paper argues that this part of aggregate human capital is reflected by the age distribution.

Secondly, this paper contributes to the extensive literature that studies the impact of population growth on economic growth. (For empirical surveys, see Fagerberg, 1994; Durlauf and Quah, 1999.) Theoretically, this impact is ambiguous. In the neoclassical growth model (see, e.g., Solow, 1956) a rise in the growth rate of homogenous workers has a negative (transitory) impact on the growth rate of income per worker. Other theories imply scale effects (see, e.g., Kremer, 1993). Bloom and Sachs (1998) and Bloom and Williamson (1999) emphasize that the impact of population growth on the growth rate of income per capita depends on how it impacts the age structure.[3]

There exist a few empirical articles that focus on the impact of the age distribution on the rate of economic growth. McMillan and Baesel (1990) is a times-series study on U.S. postwar data.[4] Sarel (1995) is a panel data study on the Summers-Heston data. This paper differs from Sarel (1995) in several ways. By using a production function approach, Sarel (1995) relates the growth rate of income per capita to *changes* in the age cohorts, whereas this paper relates the growth rate of income per capita to the *levels* of the age cohorts as the estimations are based on the neoclassical growth model. Furthermore, this paper, in addition to the initial level of income and age structure variables, also accounts for other empirical determinants to economic growth, such as educational attainment, as well as uses a regional data set.[5]

The main empirical findings of this paper are: (i) The estimation results are consistent with the age-structure-augmented MRW model developed in this paper. The estimated partial relation

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[2] Life expectancy is together with educational attainment variables sometimes used to measure aggregate human capital (see e.g. Barro, 1996).

[3] Empirically, these two papers regress the growth rate of income per capita on the difference between the growth rate of the working-age population and the population growth rate.

[4] Fair and Dominguez (1994) is another time-series study on postwar U.S. data which reports age structure effects on macroeconomic variables. However, the rate of economic growth is not subject to analysis.

[5] Lindh and Malmberg (1999) is another country panel data study on age structure and growth. However, as their paper uses neither of the standard measures of the economic growth rate, it is difficult to relate its results to the results reported in this paper.

between the initial age distribution and the subsequent growth rate of income per capita over the next ten years is hump-shaped, of quantitative importance, and robust for the U.S. states for the period 1930-2000. A hump-shaped estimated partial relation between the initial age distribution and the subsequent rate of economic growth is obtained also when the model is tested in terms of per working-age person. (ii) It is found that the coefficient estimates of standard explanatory variables in growth regressions (see MRW; Islam, 1995) are substantially biased if the age distribution is not controlled for in the case of the U.S. states. For example, coefficient estimates of educational attainment turn from statistically insignificant to positive and statistically significant, and conditional estimates of the convergence speed substantially increase when the age structure is accounted for.

The next section describes the data, and presents some descriptive statistics. Section 3 describes the model. Section 4 reports the estimation results, and section 5 concludes.

2. DATA

Table 1 reports cross-state sample correlations for variables of this study for the 1960s.[6] It shows that a high population share of young people (0-24 years), not surprisingly, is associated with a high natural population growth rate ($\tilde{n}$). Table 1 also shows that real income per capita (y), which is measured by per capita personal income (excluding government transfers and deflated by national values of the consumer price index[7]), is highly correlated with the age distribution but only weakly correlated with the natural population growth rate. Poor states tend to have young age distributions. Apart from this characteristic, Table 1 reports that poor states tend to have a low (i.e., a negative) net in-migration rate (MR), a high subsequent average annual growth rate of real income per capita ($\Delta y / y$), as reported earlier by BS (1992), and a low level educational level measured by the average years of schooling per labor force person aged 25-65 (h).

[6] Sample correlation matrices for other decades of the period 1880-2000 are reported in Persson (1999). By and large Table 1 is representative for all decades of this period.

TABLE 1: Sample correlation matrix for the 1960s for the 48 contiguous U.S. states.

Variable	$\Delta y / y$	y	0-14	15-24	25-44	45-64	65+	$\tilde{n}$	MR
$\Delta y / y$, 1960-1970	1.00								
y, 1960	-0.72	1.00							
Age group 0-14, 1960	0.19	-0.54	1.00						
Age group 15-24, 1960	0.60	-0.75	0.71	1.00					
Age group 25-44, 1960	-0.36	0.75	-0.32	-0.30	1.00				
Age group 45-64, 1960	-0.19	0.43	-0.92	-0.77	0.07	1.00			
Age group 65+, 1960	-0.10	0.07	-0.65	-0.59	-0.43	0.75	1.00		
$\tilde{n}$, 1960-1970	0.03	-0.08	0.73	0.54	0.22	-0.77	-0.85	1.00	
MR, 1960-1970	-0.10	0.54	-0.38	-0.28	0.61	0.22	-0.12	0.24	1.00
h, 1960	-0.80	0.68	-0.19	-0.56	0.26	0.16	0.21	-0.03	0.27

Definitions: The age groups are expressed as ratios to total population. $\tilde{n}$ = the average annual population growth rate (net of migration) defined over a 10-year period. MR = the net migration rate, defined as net in-migration over a 10-year period as a share of total population at

[7] In other words, this article uses the same income concept as BS (1992) use; see appendix.

3. THE AGE-STRUCTURE-AUGMENTED MRW MODEL

Neoclassical growth studies typically use one of two very simple measures of aggregate labor: the working-age population (see MRW) or the total population (see BS, 1992). Thereby, these studies assume that people of different age categories within the working-age population and the total population, respectively, are perfect substitutes and equally productive; that is, differences across age categories within these two populations in hours worked, experience, etc. are ignored. Apart from the assumption of a constant productivity in the age interval 15-64 years, another potential problem of the approach that uses the working-age population as the empirical measure of aggregate labor is the assumption that the dependent population has no effect on aggregate labor. As this effect is determined both by the dependent population's own contribution to aggregate labor, which typically is low, and by the impact of the dependent population on the contribution of the working-age population, it may obviously differ from zero. E.g., a rise in the number of dependents (when holding the working-age population constant) may lead the working-age population to divert labor away from production toward activities such as child-rearing and care-taking of elderly (that to a large extent is non-market production) to the extent that aggregate production decreases.

In the age-structure-augmented MRW model people of different age intervals are allowed to impact aggregate labor differently. All age groups, including the dependent population, are allowed to have a non-zero impact. The aggregate production function and the aggregate labor function are:

$$Y(t)=K(t)^{a}\cdot H(t)^{l}\cdot(A(t)L(t))^{1-a-l}; \qquad L(t)=\prod_{j=1}^{m-1}N_j(t)^{g_j}\cdot N_m(t)^{1-\sum_{j=1}^{m-1}g_j} \qquad (1), (2)$$

where $a>0$, $l>0$, $a+l<1$, $Y(t)$ is aggregate production at time t, $K(t)$ is aggregate physical capital at time t, $L(t)$ is aggregate labor at time t, and $A(t)$ is the level of the technology at time t, which is assumed to grow at the exogenously given rate g. The number of people in age interval j at time t is denoted $N_j(t)$, and m is the number of age intervals. $N_m(t)$ is the mth age group. Total population at time t, *N(t)*, equals $\sum_{j=1}^{m}N_j(t)$. $H(t)$ is aggregate *educational* human capital at time t. $H(t)$ is distinguished from human capital accumulated through training or experience, which is assumed to be reflected by the age distribution. The age-group-specific parameter, g_j (where $g_j \in (-\infty, \infty)\ \forall j$), is therefore assumed not only to reflect relative differences across age groups in e.g. hours worked, but also relative differences in the endowment of experience-based human capital.[8] Equations (1) and (2) are both assumed to be homogenous of degree one. Thus, if inserting equation (2) into equation (1), aggregate production exhibits constant returns to scale in $K(t)$, $H(t)$, $N_j(t)$, and $N_m(t)$. If, in addition, aggregate production is expressed in terms of per effective unit of capita ($A(t)N(t)$), we obtain:

$$\tilde{y}(t) = \tilde{k}(t)^{a} \cdot \tilde{h}(t)^{l} \cdot q \quad , \qquad q = \left(\prod_{j=1}^{m-1} h_j^{\,g_j} \cdot h_m^{\,1-\sum_{j=1}^{m-1} g_j} \right)^{1-a-l} > 0 \qquad (3), (4)$$

where $\tilde{y}(t) = Y(t)/(A(t)N(t))$, $\tilde{k}(t) = K(t)/(A(t)N(t))$, $\tilde{h}(t) = H(t)/(A(t)N(t))$, $h_j = N_j(t)/N(t)$, and $h_m = N_m(t)/N(t)$. q is assumed to be exogenously given (or, more specifically, it is assumed that the time derivative of $\ln q$ is zero). This paper also makes the assumption that N grows at the constant rate n.[9]

The saving rates for physical capital accumulation, s_k, and for educational human capital accumulation, s_h, are assumed to be exogenously given. Hence, the dynamics of the economy are:

$$\dot{\tilde{k}}(t) = s_k \cdot \tilde{y}(t) - (n + g + d) \cdot \tilde{k}(t), \qquad \dot{\tilde{h}}(t) = s_h \cdot \tilde{y}(t) - (n + g + d) \cdot \tilde{h}(t) \qquad (5a), (5b)$$

where d is the constant rate of depreciation for these two types of capital. Relative to the standard MRW model, the extension made by this paper is thus reflected by q.

Equations (5a) and (5b) imply that the economy converges to a steady state defined by:

$$\tilde{k}^{*} = \left(\frac{s_k^{\,1-l} \cdot s_h^{\,l} \cdot q}{n+g+d} \right)^{1/(1-a-l)}, \qquad \tilde{h}^{*} = \left(\frac{s_k^{\,a} \cdot s_h^{\,1-a} \cdot q}{n+g+d} \right)^{1/(1-a-l)} \qquad (6a), (6b)$$

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[8] One motivation for the assumption that labor of the different age groups are imperfect substitutes is that the typical method for aggregating workers in the educational dimension – by average years of schooling – is critiqued because it assumes perfect substitution between workers of different educational categories (see Mulligan and Sala-i-Martin, 2000). Note also that Durlauf and Quah (1999) use a Cobb-Douglas function to aggregate different types of physical capital.

[9] A constant population growth rate n is consistent with a time derivative of $\ln q$ that is zero if all age groups grow at the constant rate n.

A change in the age distribution is likely to alter the value of q . If this is the case, $\tilde{k}^*$ and $\tilde{h}^*$ change, which then induces (positive or negative) transitional growth in the model.

The transitional dynamics is, following MRW (see Persson 1998; 1999), quantified by an approximation around the steady state, which yields $d \ln \tilde{y}(t) / dt = b \cdot \ln(\tilde{y}^* / \tilde{y}(t))$, where $b = (1 - a - l) \cdot (n + g + d)$ is convergence speed. This differential equation implies that the average growth rate of income per capita between an initial time t to a future time $t + T$ is:

$$\ln\left(\frac{y(t+T)}{y(t)}\right)/T = g + k \cdot \ln A(0) + k \cdot g \cdot t - \frac{k \cdot (a+l)}{1-a-l} \cdot \ln(n+g+d) + \frac{k \cdot a}{1-a-l} \cdot \ln s_k$$

$$+ \frac{k \cdot l}{1-a-l} \cdot \ln s_h + \frac{k}{1-a-l} \cdot \ln q - k \cdot \ln y(t) \qquad (7)$$

where $\ln q /(1-a-l) = \sum_{j=1}^{m-1} g_j \cdot \ln h_j + (1 - \sum_{j=1}^{m-1} g_j) \cdot \ln h_m$, and $k = (1 - e^{-b \cdot T})/T$. The steady state growth rate of income per capita is g. The other terms of equation (7) apply during the transition to the steady state.

As educational attainment data are available, the growth rate of income per capita is expressed as a function of h. By equation (6b), $\tilde{h}^*$ is substituted for s_h in equation (7). Also assuming that $\tilde{h}^* = \tilde{h}(t)$ (see Islam, 1995), and using the identity $\tilde{h}(t) = h(t) / A(t)$, the growth rate of income per capita is:

$$\ln\left(\frac{y(t+T)}{y(t)}\right)/T = \tilde{a} + \frac{k}{1-a} \cdot \ln q + \frac{k \cdot l}{1-a} \cdot \ln h(t) - k \cdot \ln y(t) \qquad (8)$$

where $\ln q = (1-a-l) \cdot (\sum_{j=1}^{m-1} g_j \cdot \ln h_j + (1 - \sum_{j=1}^{m-1} g_j) \cdot \ln h_m)$, and

$$\tilde{a} = g + \frac{k}{1-a}\left((1-a-l) \cdot (\ln A(0) + g \cdot t) + a \cdot \ln s_k - a \cdot \ln(n+g+d)\right) .$$

Invoking the assumption of constant returns to scale (CRS), the number of age group variables is reduced by one, and the last three terms of equation (8) change:

$$\ln\left(\frac{y(t+T)}{y(t)}\right)/T = \tilde{a} + \frac{k\cdot(1-a-l)}{1-a}\cdot\left[\sum_{j=1}^{m-1} g_j \cdot \ln\left(\frac{h_j}{h_m}\right)\right] + \frac{k\cdot l}{1-a}\cdot\ln\left(\frac{h(t)}{h_m}\right) - k\cdot\ln\left(\frac{y(t)}{h_m}\right) \quad (9)$$

Note that $\frac{h_j}{h_m} = \frac{N_j(t)}{N_m(t)}$, $\frac{y(t)}{h_m} = \frac{Y(t)}{N_m(t)}$, $\frac{h(t)}{h_m} = \frac{H(t)}{N_m(t)}$

Empirical Specification

No saving or investment data are available for the whole sample period. A potential effect of the age distribution on the growth rate of income per capita through saving or investment can therefore not be controlled for. However, a panel data study of 131 countries for the period 1960-2000 shows that the estimated growth effects of the different age groups do not change much when the investment rate is controlled for in this sample (Persson and Ahlin, 2004). Data on the average years of schooling per labor force person aged 25-65, which is used to measure *h*, is missing for the whole sample period 1930-2000. When educational attainment is accounted for the sample period is 1940-2000. If the CRS-assumption is not imposed, the nonlinear regression equation, based on equation (8), is:

$$\ln\left(y_{i,t}/y_{i,t-10}\right)/10 = a_t + \frac{\bar{k}\cdot(1-a-l)\cdot g_{0-14}}{(1-a)}\cdot\ln h_{0-14i,t-10} + \ldots + \frac{\bar{k}\cdot(1-a-l)\cdot g_{65+}}{(1-a)}\cdot\ln h_{65+,i\,t-10}$$

$$+ \frac{\bar{k}\cdot l}{1-a}\cdot\ln h_{i,t-10} - \left[(1-e^{-b\cdot 10})/10\right]\cdot\ln y_{i,t-10} + u_{i,t} \quad (10)$$

where $i = 1,\ldots,48$, $t = 1940, 1950, \ldots, 2000$, , $\bar{k} = (1-e^{-b\cdot 10})/10$ (> 0 as $b > 0$), $u_{i,t}$ is the error term, and a_t is a common period-specific effect (that e.g. should capture the time trend (*t)* in equation (8)). When imposing the restriction of CRS, the youngest age group is chosen to be the numeraire (h_m), which means that $g_{0-14} = 1 - \sum_j g_j$ (where j = 15-24, 25-44, 45-64, and 65+).

Thus, for the restricted model in equation (9), the regression equation is:

$$\ln\left(y_{i,t}/y_{i,t-10}\right)/10 = a_t + \frac{\bar{k}\cdot(1-a-l)\cdot g_{15-24}}{(1-a)}\cdot\ln\left(\frac{h_{15-24\,i,t-10}}{h_{0-14\,i,t-10}}\right) + \ldots + \frac{\bar{k}\cdot(1-a-l)\cdot g_{65+}}{(1-a)}\cdot\ln\left(\frac{h_{65+,i\,t-10}}{h_{0-14\,i,t-10}}\right)$$

$$+ \frac{\bar{k}\cdot l}{1-a}\cdot\ln\left(\frac{h_{i,t-10}}{h_{0-14\,i,t-10}}\right) - \left[(1-e^{-b\cdot 10})/10\right]\cdot\ln\left(\frac{y_{i,t-10}}{h_{0-14\,i,t-10}}\right) + u_{i,t} \qquad (11)$$

Note that $\frac{h_{15-24\,i,t}}{h_{0-14\,i,t}} = \frac{N_{15-24\,i,t}}{N_{0-14\,i,t}}, \frac{y_{i,t}}{h_{0-14\,i,t}} = \frac{Y_{i,t}}{N_{0-14\,i,t}}$.

4. EMPIRICAL RESULTS

The Age-Structure-Augmented MRW Model

Column 1 of Table 2 reports the unconditional nonlinear least-squares (NLS) estimate of b, 0.022 (*t-ratio*=9.84). This estimate corresponds closely to the estimates reported by BS (1992). Column 2 presents the estimation results for the unrestricted model in equation (10). The results indicate a hump-shaped partial relation between the initial age distribution and the subsequent growth rate of income per capita. Even though all estimated age group coefficients have insignificant t-ratios, the hypothesis that all age group coefficients simultaneously are equal to zero is strongly rejected. (A LR test of this joint hypothesis gives a p-value of 0.001.) Insignificant t-ratios together with joint significance is a signal of multicollinearity. This is supported by Table 1 where the age groups are shown to be highly correlated among each other. (If, hypothetically, the age groups in the column 2 regression were expressed in levels instead of in log-levels, perfect collinearity would be present.) To mitigate the degree of multicollinearity, the restriction of CRS is imposed. Provided that this restriction is correct, estimation of the restricted model should generate more reliable estimates. In contrast, other empirical growth studies that include age structure variables tackle the problem of multicollinearity by omitting some age groups (see McMillan and Baesel, 1990; Fair and Dominguez, 1994; Lindh and Malmberg, 1999) and/or by imposing a second-degree polynomial restriction on the coefficients of the age group variables (Sarel, 1995; Fair and Dominguez, 1994). An obvious problem with the approach of omitting age groups is an omitted variable bias. Unless the growth effects of the omitted variables are zero, the coefficient estimates of the age groups included in the regression are likely to be biased due to a likely correlation between the omitted and the included age groups.

TABLE 2: Dependent variable: $(\ln y_{i,t} - \ln y_{i,t-10})/10$, where y is income per capita.

Variable/Parameter	1 NLS	2 NLS	3 NLS	4 FE	5 NLS	6 NLS	7 FE	8 FE	9 IV	10 IV
Period	1930-2000				1940-2000					
b	0.022	0.034	0.034	0.075	0.044	0.058	0.144	0.182	0.029	0.061
	(9.84)	(6.83)	(6.86)	(6.42)	(8.27)	(6.71)	(6.32)	(5.31)	(6.40)	(7.11)
$\overline{k} \cdot (1-a-l) \cdot g_{0-14} /(1-a)$		-0.013	-0.006	0.000	-0.006	-0.022	-0.009	-0.017		-0.030
		(0.73)								
$\overline{k} \cdot (1-a-l) \cdot g_{15-24} /(1-a)$		-0.007	-0.002	-0.003	-0.002	-0.001	0.016	0.011		-0.009
		(0.61)	(0.25)	(0.37)	(0.27)	(0.18)	(1.76)	(1.31)		(1.22)
$\overline{k} \cdot (1-a-l) \cdot g_{25-44} /(1-a)$		0.017	0.025	0.027	0.029	0.032	0.028	0.017		0.046
		(1.02)	(2.62)	(2.56)	(2.87)	(3.17)	(2.57)	(1.51)		(4.24)
$\overline{k} \cdot (1-a-l) \cdot g_{45-64} /(1-a)$		0.013	0.019	0.033	0.022	0.015	0.053	0.030		0.016
		(1.00)	(1.95)	(3.05)	(2.13)	(1.54)	(5.01)	(2.63)		(1.60)
$\overline{k} \cdot (1-a-l) \cdot g_{65+} /(1-a)$		-0.009	-0.007	-0.004	-0.007	-0.011	-0.012	-0.014		-0.009
		(1.42)	(1.69)	(0.52)	(1.66)	(2.58)	(1.87)	(2.19)		(1.87)
$\overline{k} \cdot l /(1-a)$						0.031		0.057	0.012	0.031
						(3.35)		(3.60)	(1.33)	(3.38)
$Ln(\tilde{n} + 0.07)$									0.008	0.038
									(0.73)	(1.94)
MR									-0.002	-0.020
									(0.41)	(3.03)
R^2	.652	.673	.673	.748	.715	.728	.846	.858	.695	.740
Adj. R^2	.645	.661	.661	.695	.705	.717	.808	.822	.685	.728
CRS-assumption	no	no	yes	yes	yes	Yes	yes	yes	no	yes
P-value for CRS			0.570	0.432	0.122	0.037	0.006	0.001		0.012

Notes: Time effects (not reported) in all regressions. Absolute values of *t*-ratios in parentheses. Standard errors are adjusted according to White (1980). In the nonlinear IV estimations the variables that are dated at time *t-10* enter as their own instruments. The instruments for $\tilde{n}$, and MR (that are measured between time *t-10* and time *t*) are the log of initial real income per capita, age structure variables (dated at time *t-10*), and the lagged value of respective variable. Thus, the first-stage regression equation for e.g. MR is:

$$MR_{i,t-10,t} = a_t + b_t \cdot \ln y_{i,t-10} + c_t \cdot \ln h_{0-14\,i,t-10} + \ldots + d_t \cdot \ln h_{65+,i\,t-10} + e_t \cdot MR_{i,t-20,t-10} + v_{it}\ .$$

where $MR_{i,t-10,t}$ is the net migration rate for state *i* between years *t-10* and *t*.

Column 3 reports estimation results for the restricted model in equation (11). It shows positive coefficients on the age groups 25-44 and 45-64 years, 0.025 (2.62) and 0.019 (1.95), respectively, and a negative coefficient, -0.007 (-1.69), on the age group over 65 years. The estimated coefficient on the age group 15-24 years is -0.002 (-0.25). These column 3 estimates imply an estimate of $\bar{k} \cdot (1 - a - l) \cdot g_{0-14} /(1 - a)$, which is negative: -0.006.[10] Thus, also the estimation results for the restricted version of the model yield a hump-shaped partial relation between the initial age structure and the subsequent growth rate of income per capita. The restriction of CRS is not statistically rejected. A LR test of the null hypothesis of CRS gives a p-value of 0.570. (The LR statistic is, under the null hypothesis, asymptotically chi-squared distributed with one degree of freedom.)

The column 4 regression allows for state-specific fixed effects (FE), and is based on the nonlinear least-squares dummy-variable technique. The regression provides empirical evidence of fixed effects, and produces an estimated partial relation between the initial age structure and the subsequent growth rate of income per capita that remains hump-shaped.[11]

Quantitatively, the estimated coefficients of the age structure variables are of importance. The point estimates in column 3 (and in column 4) mean that a one-standard-deviation decrease of each of the age groups 0-14 and 65+ (expressed as ratios to total population) and also assuming that each of the three remaining age groups increase proportionally to their size and jointly so that total population stays constant, then this alteration of the age distribution is associated with an increase of the annual growth rate by about 0.4 percentage points over a subsequent 10-year period. (The

[10] The implied estimated coefficient on the age group 0-14 years is given by:

$$\left(\bar{k} \cdot (1 - a - \hat{l}) \cdot g_{0-14} /(1 - a)\right) = (1 - e^{-\hat{b} \cdot 10})/10 - \left((\bar{k} \cdot \hat{l} / 1 - a)\right) - \left((\bar{k} \cdot (1 - a - \hat{l}) \cdot g_{15-24} /(1 - a))\right)$$
$$- \left((\bar{k} \cdot (1 - a - \hat{l}) \cdot g_{25-44} /(1 - a))\right) - \left((\bar{k} \cdot (1 - a - \hat{l}) \cdot g_{45-64} /(1 - a))\right) - \left((\bar{k} \cdot (1 - a - \hat{l}) \cdot g_{65+} /(1 - a))\right)$$

For the period 1930-2000 $\left((\bar{k} \cdot \hat{l} / 1 - a)\right) = 0$ as data on educational attainment are missing.

[11] As the LSDV estimator is a biased and inconsistent estimator when individual effects exist in a dynamic panel, some studies (e.g., Caselli et al., 1996) use theoretically consistent IV estimators. The (nonlinear) LSDV estimator is here preferred because the number of time periods is not very small relative to the number of cross-sectional units, and because IV techniques may lead to poor finite sample efficiency (see Baltagi, 2001; Kiviet, 1995). It turns out, however, that the LSDV estimates of coefficients and of their standard errors are very similar to the estimates generated by a GMM estimator (see Persson, 1999).

values used for this calculation refer to 1960, which is selected as it is in the middle of the sample period.[12])

The estimation results in columns 5-8 are based on the period 1940-2000. They show that the estimated partial relation between the initial age structure and the subsequent growth rate of income per capita continues to be hump-shaped and quantitatively important also when the sample period is shortened by ten years and educational attainment is controlled for. Moreover, columns 6 and 8 report positive and statistically significant estimates of $\overline{k} \cdot l /(1-a)$, the coefficient on the educational attainment variables in equations (8)-(11), which thus is consistent with the model.

The Standard MRW Model

This section investigates whether coefficient estimates of standard explanatory variables in growth regressions (see MRW; Islam, 1995) are biased if the age distribution is not accounted for in the case of the U.S. states. A bias is expected as the analysis in section 2 indicates that the age distribution is highly correlated with income per capita, educational attainment, and with the components of the population growth rate.

Column 9 reports results from nonlinear IV estimation (see notes to Table 2) of the standard MRW model, which is described by equation (8) provided the term $k \cdot \ln q /(1-a)$ is omitted.[13] [14] This model is here tested in terms of per capita, which means that it is assumed that $L = N$. As a result, n in the expression $\ln(n+g+d)$ is measured by the contemporaneous population growth rate, which by equation (8) is predicted to have a negative (transitory) effect on the growth rate of income per capita. The contemporaneous population growth rate is in column 9 decomposed into its components: the natural population growth rate ($\tilde{n}$) and the net in-migration rate (MR). $g+d$ is assumed to equal 0.07 (see BS, 1995, p. 37). The coefficient estimates of $ln(\tilde{n}+0.07)$ and of MR in column 9 are statistically insignificant.

[12] The standard deviation (and the mean) of the age groups 0-14 and 65+ in 1960 are 0.023 (0.320) and 0.016 (0.092), respectively (see Table A1 in Persson, 1999).

[13] Following BS (1995, Ch. 12), this paper uses lagged values as instruments. This approach may be satisfactory if the correlation of the error terms between adjacent periods is not substantial, which is the case here. The correlation coefficients of the residuals (from the column 3 regression) between the seven adjacent 10-year periods are: -0.22, 0.15, -0.11, -0.25, 0.16, and 0.11.

[14] It turns out that the results from nonlinear IV estimation in columns 9-10 are qualitatively similar to the results obtained from NLS estimation. However, NLS generate a statistically insignificant coefficient estimate of MR for the column 10 specification. These regression results are available upon request.

Moreover, column 9 reports a statistically insignificant estimate of $\bar{k} \cdot l/(1-a)$, the coefficient of the educational attainment variables in equations (8)-(11). Thus, the standard MRW model is inconsistent with the U.S. states data not only with respect to coefficient estimates of variables measuring the population growth rate but also with respect to estimates of $\bar{k} \cdot l/(1-a)$. These results correspond to some previous country evidence.[15] In contrast, estimates of $\bar{k} \cdot l/(1-a)$ in the age-structure-augmented MRW model are (as already noted) positive and statistically significant, which thus is model consistent. In other words, the estimated growth impact of educational attainment turn from statistically insignificant to positive and statistically significant when the age structure is accounted for.

Table 2 shows that estimates of b are higher when the age structure is accounted for. For example, the b estimate of the standard MRW model in column 9 is 0.029, whereas the b estimate of the age-structure-augmented MRW model in column 6 is twice as high, 0.058. Thus, using the equation, $b = (1 - a - l) \cdot (n + g + d)$ to structurally interpret these estimates, the estimated implied capital share of physical and educational human capital ($a + l$) decreases (for a given positive value of $n + g + d$) when the age structure is held constant.[16]

Column 10 shows estimation results for the age-structure-augmented MRW model expanded with the variables that measures the contemporaneous population growth rate (which thus far have been suppressed). While the estimated hump-shaped partial relation between the initial age structure and the subsequent growth rate of income per capita remains, the coefficient estimates of the contemporaneous natural population growth rate and of the contemporaneous net in-migration rate substantially change compared to the case when the age structure variables are omitted (i.e., in the case of the standard MRW model).[17] These empirical results thus provide additional support for the hypothesis that the age structure affects the subsequent growth rate of income per capita as well as

[15] The surveys of Fagerberg (1994) and Durlauf and Quah (1999) report inconclusive country evidence regarding the impact of population growth on the rate of economic growth. Moreover, Temple (1999) and Islam (1995) point out that country panel data studies often fail to find a positive growth effect from educational attainment. In addition, the study on the U.S. states by BS (1992, footnote 13) report that “educational differences aside from college attainment were not important”.

[16] Table 2 also reports that estimates of b increase even further when fixed effects are allowed for. This result is consistent with country evidence reported by e.g. Islam (1995), and Caselli et al. (1996).

[17] The qualitative results on demographics and economic growth reported in columns 9-10 are unchanged if the sample period instead is 1930-2000 (which then means that data on educational attainment are missing). A qualitative difference occurs with respect to the statistical validity of the CRS assumption, which is not rejected for the 1930-2000 period. These regression results are available on request.

indicate that coefficient estimates of the components of the contemporaneous population growth rate are substantially biased if the age structure is ignored. We note, e.g., that the estimated growth impact of the net-migration rate turns from statistically insignificant to negative and statistically significant when the age structure is accounted for.

Sensitivity Analysis: Income per Working-Age Person

Several neoclassical growth studies (see e.g. MRW) use the working-age population as the empirical measure of aggregate labor (i.e. they assume $L = N_{15-64}$). To relate to these studies the model is in this section tested in terms of per working-age person. This means that N in equations (3) and (4) is replaced by N_{15-64}. The variables in the regression equations (10) and (11) are now defined by:

$$y_{i,t} = \frac{Y_{i,t}}{N_{15-64\,i,t}},\ h_{j,i,t} = \frac{N_{j,i,t}}{N_{15-64\,i,t}},\ \frac{h_{15-24\,i,t}}{h_{0-14\,i,t}} = \frac{N_{15-24\,i,t}}{N_{0-14\,i,t}},\ \frac{y_{i,t}}{h_{0-14\,i,t}} = \frac{Y_{i,t}}{N_{0-14\,i,t}}.$$

The regressors of the CRS-model in equation (11) are, except for the educational attainment variable[18], identical to previously, and the correlation between the growth rate of income per capita and the growth rate of income per working-age person is high: 0.91 for the period 1930-2000.[19] [20] Table 3 reports the estimation results. Not surprisingly, as both the dependent variable and the regressors do not change much, the regression results are strikingly similar to the results reported in Table 2. The estimated partial relation between the initial age distribution and the subsequent rate of economic growth remains hump-shaped.

Column 4 shows that the standard MRW model (also when it is tested in terms of per working-age person) is inconsistent with data in the sense that the coefficient estimate of *ln(n+0.07*)

[18] The educational attainment variables differ as average years of schooling per labor force person (aged 25-65) is assumed to measure both H/N and H/N_{15-64}. Thus, in the CRS-regressions of Table 2 the educational attainment variable is ln(average years of schooling per adult labor force person/ N_{0-14}/N) whereas it is ln(average years of schooling per adult labor force person/ N_{0-14}/N_{15-64}) in Table 3.

[19] In the model, the growth rate of income per capita equals the growth rate of income per working-age person by the assumption that all age groups grow at the same (constant) rate.

[20] This high correlation is of course due to a small variation in the population share of the working-age population as the growth rate of income per capita equals the growth rate of income per working-age person plus the growth rate of the population share of the working-age population.

is statistically insignificant. n is here measured by the average annual growth rate of the working-age population as the working-age population here is assumed to measure aggregate labor. As this measure includes some of the migration flows, MR is not included as a separate explanatory variable and instrumental variables are used in the estimation.[21] A difference relative to the case when this model is tested in terms of per capita is that the estimate of $\bar{k} \cdot l /(1-a)$ now is positive and statistically significant, 0.022 (2.36), which thus is consistent with this model. The estimate of $\bar{k} \cdot l /(1-a)$ continues, however, to be higher if the age structure is accounted for (see column 6).

TABLE 3: Dependent variable: $(\ln y_{i,t} - \ln y_{i,t-10})/10$, where y is income per working-age person.

Variable/Parameter	1 NLS	2 NLS	3 FE	4 IV	5 NLS	6 NLS	7 FE	8 FE
Period		1930-2000				1940-2000		
b	0.023	0.035	0.082	0.034	0.043	0.058	0.151	0.187
	(9.09)	(7.14)	(6.78)	(6.45)	(7.87)	(6.63)	(6.26)	(5.28)
$\bar{k} \cdot (1-a-l) \cdot g_{0-14} /(1-a)$		-0.011	-0.011		-0.011	-0.019	-0.022	-0.016
$\bar{k} \cdot (1-a-l) \cdot g_{15-24} /(1-a)$		-0.001	0.003		-0.001	-0.002	0.022	0.016
		(0.16)	(0.26)		(0.08)	(0.24)	(2.39)	(1.72)
$\bar{k} \cdot (1-a-l) \cdot g_{25-44} /(1-a)$		0.024	0.027		0.027	0.023	0.032	0.011
		(2.44)	(2.58)		(2.53)	(2.28)	(2.90)	(0.87)
$\bar{k} \cdot (1-a-l) \cdot g_{45-64} /(1-a)$		0.028	0.041		0.030	0.018	0.057	0.027
		(2.85)	(3.78)		(2.87)	(1.77)	(5.15)	(2.05)
$\bar{k} \cdot (1-a-l) \cdot g_{65+} /(1-a)$		-0.010	-0.004		-0.010	-0.011	-0.011	-0.008
		(2.23)	(0.50)		(2.08)	(2.43)	(1.58)	(1.12)
$\bar{k} \cdot l /(1-a)$				0.022		0.035		0.055
				(2.36)		(3.68)		(3.48)
Ln(n+0.07)				-0.034				
				(0.70)				
R^2	.760	.775	.831	.789	.798	.809	.891	.899
Adjusted R^2	.755	.767	.796	.783	.791	.801	.864	.873
CRS-assumption	no	yes	yes	no	yes	yes	yes	yes
P-value for CRS		0.036	0.970		0.003	0.000	0.008	0.001

Notes: See Table 2. n is here the average annual growth rate of the working

5. CONCLUDING REMARKS

To improve measurement of aggregate labor and aggregate human capital, this paper augments the Mankiw, Romer, and Weil (1992) model by allowing the different age cohorts to impact aggregate

[21] The NLS estimate of the coefficient of ln(n+0.07) is 0.069 (1.75).

labor differently. Thereby, this paper studies the impact on the rate of economic growth of an obvious but largely ignored variable, the age distribution. In the empirical analysis, the *whole* age distribution is taken into account, which is important in order to avoid biased estimated coefficients on included (age-group and other) explanatory variables. The problem of multicollinearity is tackled by the restriction of constant-returns-to-scale.

The estimation results, which are consistent with this model, yield an estimated partial relation between the initial age structure and the subsequent growth rate of income per capita over the next ten years that is hump-shaped, of quantitative importance, and robust for the U.S. states for the period 1930-2000. A hump-shaped partial relation between the initial age structure and the subsequent rate of economic growth is obtained also when the model is tested in terms of per working-age person. As the estimation results are consistent with the model, they are consistent with an explanation that the age structure affects aggregate income through aggregate labor and experience-based aggregate human capital. A hypothesis that an increased share of dependents diverts labor away from production is consistent with reported negative estimated effects of the age groups 0-14 years and over 65 years.

This paper finds that coefficient estimates of standard explanatory variables in growth regressions -- the initial level of income, educational attainment, and variables measuring the contemporaneous population growth rate -- are substantially biased if the age distribution is not controlled for in the case of the U.S. states 1930-2000. It is found that the coefficient estimate of educational attainment turn from statistically insignificant to positive and statistically significant, that conditional estimates of the rate of convergence substantially increase, and that the estimated growth impact of the net-migration rate turns from statistically insignificant to negative and statistically significant when the age structure is accounted for.

Appendix: Data Sources

Data on income for the period 1930-2000 are from the US Commerce Department (Bureau of Economic Analysis). Data for 1880, 1900, and 1920 (for Figure 2) are from Easterlin (1960). (For years up to 1960 the overall index from the US Commerce Department (1975), series E135 is used to compute real income, whereas figures from the Statistical Abstract of the US for all items is the source after 1960.)

Data on the population age distribution for the period 1880-1970 are from the US Department of Commerce (1975), which determines the division of age groups. Data on educational attainment are from Mulligan and Sala-i-Martin (1997, Table 8), who base their computation on the population censuses. Data on migration are from the US Department of Commerce (1975). (Data from the survival rate method is used from 1910 to 1940. After 1940, data from the components of change method is used.) The data sources for net migration (after 1970) and for the birth and death rates are various issues of the Statistical Abstract of the U.S.

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