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Can we have growth when population is stagnant? Testing linear growth rate formulas of non-scale endogenous growth models

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Can we have growth when population is stagnant? Testing linear growth rate formulas of non-scale endogenous growth models

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Abstract Endogenous growth theory has produced formulas for steady-state growth rates of income per capita, which are linear in the growth rate of the population. Depending on the details of the models, slopes and intercepts are positive, zero or negative. Empirical tests have taken over the assumption of exogenous population growth from the theoretical models and have mostly not distinguished steady-state results from transitional growth. In contrast, (i) we assume that there is the possibility of two-way causality as in unified growth theory, and (ii) we capture the steady-state property by a long-term relation in a series of vector-error-correction models, allowing (iii) successively for more heterogeneity. The average slope and intercepts of the growth equations are positive in this setting but less significant or even negative when allowing for heterogeneity. Intercepts are then positive for a majority of countries, zero for five or six countries, and perhaps negative for at most two countries. Results therefore favour fully- over semi-endogenous growth with and without slope homogeneity. The more frequent case is that long-run growth can remain positive if population stops growing.

JEL-codes: C33, O47. Keywords: Endogenous growth, population growth, panel times series estimation.

1 Introduction

Ever since the invention of the semi-endogenous growth model by Arrow (1962) and Phelps (1966), and its extension to micro-foundation by Judd (1985) and to spillovers by Jones (1995) a major criticism has been that it would predict to have no growth in case of the long-run absence of population growth (von Weizsäcker 1969). In contrast, Jones (1995) emphasizes that the number of engineers and scientists in R&D has increased strongly in recent years but the growth rate has not reacted and therefore semi-endogenous growth models should be favoured over fully endogenous growth models. However, more recent evaluations of fully and semi-endogenous growth models favour the fully endogenous growth models from the perspective of emphasizing the time-series dimension using unit root and cointegration analysis as well as forecasts (Ha and Howitt 2007; Madsen 2008). Ha and Howitt (2007) emphasize that R&D as a share of GDP in the USA has been constant and so have the TFP growth rates. Similarly, from the perspective of Lucas'

(1988) endogenous growth model, the education time share data of Gaessler and Ziesemer (2016) for the USA are not increasing for the period 1985-2009, and therefore growth rates are constant. Therefore, Jones' (1995) critique, based on data for engineers, would not hold when using the education data in the Lucas model or the R&D/GDP data of Ha and Howitt (2007). Even if education time-shares would increase, one would have to check for an increase of the depreciation rate for human capital during the same period in order to see the net effect on growth. Similarly, in the monopolistic competition models rates of depreciation for knowledge are missing which makes empirical work somewhat imprecise. Moreover, in the closed and the open economy versions of the Lucas model (Lucas 1988, Frenkel et al 1996; Gaessler and Ziesemer 2016) population growth and that of GDP per capita are positively related with a positive intercept in the solution, the latter implying positive growth rates in the absence of population growth. The intercept then represents institutional aspects, which ensure positive growth rates even in the absence of resource growth (Ha and Howitt 2007). In contrast, some other endogenous growth models have the opposite slope or no intercept.[1] Prettner and Prskawetz (2010) though point out that some authors favour the semi-endogenous type of models with positive slope and zero intercept more recently. This view gets some recent support from Kruse-Andersen (2017) for R&D models estimating Jones' R&D function under the assumption of one cointegrating relation for the three variables. Others doubt the positive slope though: Strulik et al. (2013) argue that 'there is little empirical support for a positive association between population growth and productivity growth'. All these stark contrasts in the views on slopes and intercepts raise two questions, (i) that of a positive, zero or even negative slope relating population growth and income growth and (ii) that of the (non-) existence of a statistically significant intercept.

2 Long-run growth formulas under monopolistic competition

Monopolistic competition models are slightly more complicated than the perfectly competitive Lucas model briefly sketched above. The semi-endogenous growth model generates the long-run growth formula $g_y = (\lambda - v)g_n/(1-\gamma)$ with $\gamma < 1$ as R&D spillover parameter, λ as percentage of non-duplication and v as the degree of

[1] An exception is Strulik (2005) where the intercept is positive and the slope can have any sign. He combines the Lucas model with that of varieties, including duplication and difficulty. Consequently, the Lucas part of the model causes the positive intercept in the growth formula. We do not deny that there are other papers fitting into the scheme, but we have to be brief here.

difficulty of R&D (see Dinopoulos and Segerström 1999). This slope coefficient can have any sign. Without duplication, $\lambda=1$, and no difficulty, $v=0$, we get the well-known case of Jones (1995) as $g_y = g_n/(1-\gamma)$.[2] These equations have a zero intercept.

In the fully endogenous growth model of Howitt (1999) there is in addition a negative intercept. The steady-state growth rate In Howitt (1999) is $g = \sigma\lambda n$, with n as productivity-adjusted R&D expenditure, σ a spillover parameter and λ a Poisson arrival rate, all related to vertical R&D. From Fig.1 in Howitt (1999) one can solve for $n = \frac{(1-\alpha+\sigma)g_{L/\psi(h^*)}}{(1-\beta)(1+\frac{\alpha\sigma}{1-\alpha})} - \frac{r}{\lambda(1+\frac{\alpha\sigma}{1-\alpha})}$, with α as elasticity of production of capital, $1-\beta$ as marginal cost of horizontal R&D expenditure, ψ as intensive-form production function of horizontal innovation, h^* the steady-state share of expenditure on research, r as the interest rate and g_L as population growth rate. Inserting the formula for n into that for g it follows that there is a negative intercept. Insertion of the standard consumption function after solving it for r and then solving for g again does not change this qualitative result of a negative intercept (calculations available upon request).

In an AK growth model, Dalgaard and Kreiner (2001) disaggregate K into a Cobb-Douglas function of two production factors, H and A, and assume a positive savings rate for the change of both. The result is a slope of g_n of minus unity in case of a non-Benthamite utility function (no N_t multiplied to the per capita utility function) and a zero slope in the Benthamite case. In both cases, they have a positive intercept. Table 1 collects these cases of hypotheses for the relation between population growth and growth of income per capita in columns 1 to 3.[3] The last column shows the country-specific results from our modelling approach; we explain them below.

[2] Note that for $\gamma<(=) 0$, steady-state growth rates should be equal or even lower than population or employment growth rates, which seems to be unrealistic for high-income OECD countries. For 1977-2011 the employment in full-time equivalents grows at 1% per year; for 2001-11 this is less than 0.5%. Since 1995 OECD population growth rates are below 0.8%. Growth rates of GDP per capita are larger than these values, not smaller.

[3] Tournemaine (2007), Bucci and Raurich (2017), Bucci et al. (2018) survey the relevant literature more broadly. In a purely technical sense, the case of a zero slope and a positive intercept is also that of the neoclassical exogenous growth model. However, there is consensus that growth is generated by human capital and R&D and the question is just 'how exactly in detail'.

Table 1 Cases of long-run growth formulas

(a) Models and country classification from regression (7)

Hypothesis	slope	intercept	Country classification from regression (7)
Lucas	positive	positive	averages from regressions (3)-(5)
Jones	positive	zero	CAN? (b), FRA,
λ=v (a)	zero	zero	AUS, GRC, SWE, USA; average regr. (6), (7)
Howitt	positive	negative	CAN? (b), NLD
AK non Bentham	negative	positive	DNK, FIN, LUX, UK; ave. regression (9)
AK Bentham .	zero	positive	ESP, DEU, IRL, ITA, PRT; ave. regression (8)

(a) Non-duplication parameter equals degree of difficulty. (b) Intercept for CAN has p=0.13.

(b) Models and country classification from regression (8)

Hypothesis	slope	intercept	Country classification from regression (8)
Lucas	positive	positive	AUS (b); FRA? (b); ave. regressions (3)-(5)
Jones	positive	zero	NLD, FRA, CAN, USA;
λ=v (a)	zero	zero	GRC average regressions (6), (7)
Howitt	positive	negative	-
AK non Bentham	negative	positive	UK, LUX, IRL, FIN, ESP; ave. regression (9)
AK Bentham	zero	positive	AUS (b), DNK, DEU, ITA, PRT, SWE; rgr. (8)

(a) Non-duplication parameter equals degree of difficulty.
(b) AUS has a positive slope with p-value 0.12; for FRA intercept has p=0.18.

We want to indicate that in principle every result for the slope or the intercept alone is possible according to the theoretical models of Table 1, provided they allow for positive growth rates.

When trying to test these hypotheses we have to take into account that the assumption of exogenous population growth in large parts of endogenous growth theory may be a simplifying one. Income and human capital have an impact on population growth in rich and poor countries, which unified growth theory takes into account (Galor and Weil 1999). This should be taken into account when evaluating non-scale models[4]. For large panels including less rich countries than our panel it is the log-level of income (with several lags though) that has an impact (Kelley and Schmidt 1995; Herzer et al 2012; Fosu et al 2016). The question here is posed for rich countries producing technical change, and therefore the income level is not an aspect of the discussion. Instead, the structure of endogenous growth models is crucial and therefore the growth rates of income, productivity and population or labour matter. This implies two-way causality between the growth rates of per capita income and the population, g_y and g_N. We do not use TFP data because the process of making them tends to impose a Cobb-Douglas function for output production, having unit elasticity of substitution, where in general, many would prefer a lower one; however, there is no agreement to a certain value below unity. Ha and Howitt (2007) use a simple error-correction model and favour the fully endogenous growth models based on analysis of unit roots, cointegration and forecasting for the USA. They do not analyse the empirics of the intercept though and they do not estimate a dynamic model allowing for only endogenous variables using lags, both of which we will do here. Moreover, the relation between the two growth rates is not only a behavioural one but rather it is based also on the labour constraint of the economic models. Therefore we do not emphasize Granger causality but rather a two-way empirical relation. Brander and Dowrick (1994) have pointed out that it is important to have a dynamic system analysis for this interaction to which we turn below.

[4] The expression 'non-scale' emphasizes the contrast with models that have the level of the population or human capital on the right-hand side of the formula for the solution of the growth rate as in Shell (1967) and others later. We do not consider this type of models. See Bloom et al. (2017) for a critique.

3 Estimation: Methods and results

3.1 *Pooled mean group estimation*

We consider the growth rates of per capita GDP (in constant 2005 US dollars) and population of 16 OECD countries for the period 1960-2014. Pooled mean group (PMG) estimators - assuming a common coefficient in the long-run relation for the two causality directions - estimated separately result in long-term relations of $g_y = -0.8g_n$ (Table 2, regression (1)) and $g_N = 0.27g_y$ (Table 2, regression (2))[5]. They are very much different from each other and indicate two-way causality with opposite signs. We demean the variables in order to have time and period fixed effects in the long-term relation before running the regressions (1)-(3) and (5).[6] The first of these equations can be seen as an estimate of the equation used as framework by Ha and Howitt (2007) with TFP as endogenous variable. In addition, the first of these equations is very similar to the cross-section results in Strulik et al. (2013) using TFP growth rates. However, cross-section analysis does not take into account that in many countries growth rates of TFP and population are both falling during the after-war period. This latter fact suggests a positive correlation which we find in the second equation above and also if we use $g_n(-20)$ in the first equation resulting in a long-run relation of $g_y = 0.67g_n(-20)$ (not shown) with a large loss of observations.[7]

[5] These regressions should neither be mixed up with those regressing population growth or fertility on (several lags of) the log of GDP per capita (see Ahituv (2001), Herzer et al (2012) and Fosu et al (2016)) nor with growth regressions which have a lagged dependent variable (Li and Zhang 2007). Both are made for out-of-steady-state purposes and growth regressions are mostly not made for endogenous growth models.

[6] The pooled mean-group estimator takes cross-section specific effects into account (Asteriou and Hall 2015). Modifying the variables by cross-section demeaning therefore does not change the results. However, demeaning for period fixed effects makes the first coefficient smaller and the second larger.

[7] Strulik et al (2013) in their Figure 2 show a positive correlation before 1920 and after 1970, and a negative correlation in between. The debates of modern growth theory focus on the phase since 1950 or 1960, because

3.2 *Panel vector-error-correction models for two-way causality*

In order to find a long-term relation with two-way causality, we use an econometric method that takes into account two-way causality. Cointegrated vector-autoregression (CVAR) or vector-error-correction models (VECM) are doing this. VECMs have also the advantage that long-term relations may reflect steady-state results (Pesaran 1997, Breitung 2005) although economies are not yet in the steady state at least in the beginning of the estimation period. Lagged impacts are used to estimate the model, which is an aspect which Ha and Howitt (2007) regret to omit. We estimate three VECMs for our sample of 16 countries allowing for successively more heterogeneity. The first is

$$\mathrm{d}(g^*_{yt}) =$$

$$\alpha_1 [g_{y\,t-1} - \beta g_{n\,t-1} - \mu - c_i - \delta_t] + \gamma_{11}\mathrm{d}(g^*_{y\,t-1}) + \gamma_{12}\mathrm{d}(g^*_{n\,t-1}) + \gamma_{13}\mathrm{d}(g^*_{y\,t-2}) + \gamma_{14}\mathrm{d}(g^*_{n\,t-2}) + \gamma_{15}\mathrm{d}(g^*_{y\,t-3}) + \gamma_{16}\mathrm{d}(g^*_{nt-3}) + \gamma_{17}\mathrm{d}(g^*_{y\,t-4}) + \gamma_{18}\mathrm{d}(g^*_{n\,t-4}) + u_{1t} \qquad t=1, \ldots, T; \qquad (1a)$$

$$\mathrm{d}(g^*_{nt}) = \alpha_2 [g_{y\,t-1} - \beta g_{n\,t-1} - \mu - c_i - \delta_t] + \gamma_{21}\mathrm{d}(g^*_{y\,t-1}) + \gamma_{22}\mathrm{d}(g^*_{n\,t-1}) + \gamma_{23}\mathrm{d}(g^*_{y\,t-2}) + \gamma_{24}\mathrm{d}(g^*_{n\,t-2}) + \gamma_{25}\mathrm{d}(g^*_{y\,t-3}) + \gamma_{26}\mathrm{d}(g^*_{n\,t-3}) + \gamma_{27}\mathrm{d}(g^*_{y\,t-4}) + \gamma_{28}\mathrm{d}(g^*_{n\,t-4}) + u_{2t}\,; \quad t=1, \ldots, T; \qquad (1b)$$

All data are pooled and the covariance matrix is $E(u_t u'_t) = \begin{bmatrix} \sigma_{11} & \sigma_{12} \\ \sigma_{21} & \sigma_{22} \end{bmatrix}$ (see Canova and Ciccarelli 2013). This 2x2 covariance matrix means that no country interaction is taken into account because the data are pooled. In order to take fixed effects for countries and periods into account in the long-term relation of vector-error-correction model (1a,b) we subtract again the country and period specific averages

before this time education and invention were limited to a small part of the population. Ziesemer (2016) uses a cubic specification for labour force growth in a growth regression for a large panel of countries producing a negative effect only if labour growth is stronger than 2.45% as it is realistic for some African countries.

of each variable from the variable itself and add the sample mean (see Greene 2012, p.404). A '*' indicates that that the variables are transformed.

The second version estimates jointly N=16 VECMs, one per country *i*:

$\mathrm{d}(g^*_{y})_{it}$ =

$\alpha_{1i} [g_{y\ it-1} - \beta g_{n\ it-1} - \mu - c_i - \delta_t] + \gamma_{11i}\mathrm{d}(g^*_{y\ it-1}) + \gamma_{12i}\mathrm{d}(g^*_{n\ it-1}) + \gamma_{13i}\mathrm{d}(g^*_{y\ it-2}) + \gamma_{14i}\mathrm{d}(g^*_{n\ it-2}) +$
$\gamma_{15i}\mathrm{d}(g^*_{y\ it-3}) + \gamma_{16i}\mathrm{d}(g^*_{n\ it-3}) + \gamma_{17i}\mathrm{d}(g^*_{y\ it-4}) + \gamma_{18}\mathrm{d}(g^*_{n\ it-4}) + u_{1it;}\ i=1,\ldots, N; t=1,\ldots,T;$ *(2a)*

$\mathrm{d}(g^*_{n})_{it}$ =

$\alpha_{2i} [g_{y\ it-1} - \beta g_{n\ it-1} - \mu - c_i - \delta_t] + \gamma_{21i}\mathrm{d}(g^*_{y\ it-1}) + \gamma_{22i}\mathrm{d}(g^*_{n\ it-1}) + \gamma_{23i}\mathrm{d}(g^*_{y\ it-2}) + \gamma_{24i}\mathrm{d}(g^*_{n\ t-2}) +$
$\gamma_{25i}\mathrm{d}(g^*_{y\ it-3}) + \gamma_{26i}\mathrm{d}(g^*_{n\ it-3}) + \gamma_{27i}\mathrm{d}(g^*_{y\ it-4}) + \gamma_{28i}\mathrm{d}(g^*_{n\ it-4}) + u_{2it;}\ i=1,\ldots, N; t=1,\ldots,T;$ *(2b)*

All coefficients are country-specific with the exception of β, which is constrained to be identical over countries and time as in the pooled mean-group (PMG) estimator. The covariance matrix then has format $Nk \times Nk = 32x32$, as there are $N = 16$ countries with $k=2$ variables and equations each (see Groen and Kleibergen 2003, eq. (6)). 'g^*' again denotes double demeaned variables, which are also used in the long-term relation in the implementation. A similar model of this type with common long-term coefficient for all countries is Breitung (2005). Our second model is a special case of this as we have at most one long-term relationship by assumption, confirmed by the Johansen-Fisher test below rejecting that the cointegration rank $r = k$; moreover, there is a constant only in the long-term relation as growth rates are assumed to be constant in the long run. This approach can take into account interaction between the residuals of the countries when using SUR or 3SLS estimators.

The third model differs from (2a, b) in that it leaves also the β_i free, except for being the same in the two equations of the VECM of each country, of course, and it adds a country-specific constant to the long-term relation.

$$\mathrm{d}(g_y)_{it} =$$

$$\alpha_{1i}\,[g_{y\,it-1} - \beta_i g_{n\,it-1} - \mu_i] + \gamma_{11i}\mathrm{d}(g_{y\,it-1}) + \gamma_{12i}\mathrm{d}(g_{n\,it-1}) + \gamma_{13i}\mathrm{d}(g_{y\,it-2}) + \gamma_{14i}\mathrm{d}(g_{n\,it-2}) + \gamma_{15i}\mathrm{d}(g_{y\,it-3}) + \gamma_{16i}\mathrm{d}(g_{n\,it-3}) + \gamma_{17i}\mathrm{d}(g_{y\,it-4}) + \gamma_{18}\mathrm{d}(g_{n\,it-4}) + u_{1it;}\ i=1,\ldots,N;\ t=1,\ldots,T; \qquad (3a)$$

$$\mathrm{d}(g_n)_{it} =$$

$$\alpha_{2i}\,[g_{y\,it-1} - \beta_i g_{n\,it-1} - \mu_i] + \gamma_{21i}\mathrm{d}(g_{y\,it-1}) + \gamma_{22i}\mathrm{d}(g_{n\,it-1}) + \gamma_{23i}\mathrm{d}(g_{y\,it-2}) + \gamma_{24i}\mathrm{d}(g_{n\,t-2}) + \gamma_{25i}\mathrm{d}(g_{y\,it-3}) + \gamma_{26i}\mathrm{d}(g_{n\,it-3}) + \gamma_{27i}\mathrm{d}(g_{y\,it-4}) + \gamma_{28i}\mathrm{d}(g_{n\,it-4}) + u_{2it;}\ i=1,\ldots,N;\ t=1,\ldots,T; \qquad (3b)$$

There are now country-specific slopes and intercepts in the long-term relation. The model has the country-specific long-term relations and the restriction of having no variables of other countries in the equations in common with the model by Larsson and Lyhagen (2007). Whereas the latter impose the assumption of identical cointegration rank for all countries, our more traditional simultaneous equation model allows for having one or no cointegrating relation for each country.[8] In all three models, the overall intercept is zero because steady states in endogenous growth theory require constant growth rates. Period fixed effects go into the residual expression of the long-term relation in equations (3a, b), or, in other words, the residual is the period fixed effect under slope and intercept heterogeneity. Therefore, no demeaning transformation of variables is needed here.

[8] Maddala and Kim (1998, ch.5) discuss the relation and differences between the Johansen-Juselius VECM approach, which we have used frequently elsewhere, and the traditional simultaneous equation approach, which has all dynamic information for the short and the long run when the number of cointegrating equations is known. The JJ approach is needed mainly to have two-stage estimation for the long and the short run when the number of cointegrating equation is not known and finding it adds valuable information.

3.3 Panel Unit roots and cointegration

The variable for population growth has a common unit root according to the IPS and Fisher tests not taking into account cross-section dependence. For the cross-sectionally augmented CADF approach of Pesaran (2007) the average t-value is *CIPS = -2.32*, just allowing to reject the unit root hypothesis at the 5 percent level (Table II(b) in Pesaran 2007 shows the critical values). On the individual level, using Table I(b) in Pesaran (2007), we reject the individual unit root hypothesis only for three countries, AUS, DEU, PRT.[9] In line with this result, the chi-square Fisher test[10] rejects the hypothesis 'a unit root for all countries' at any standard level and beyond.

The growth rate of the GDP per capita shows a unit root only for Italy and Portugal in the information on the alternative hypotheses on individual countries of the Fisher ADF test. The cross-sectionally augmented ADF test of Pesaran shows individual unit roots for FRA, DEU, NLD (and SWE if all lags are made cross-section specific).[11] The average t-value is CIPS = -4.055, rejecting the unit root hypothesis at any standard significance level. The chi-square Fisher test would reject the hypothesis that all countries have a unit root.

The variables are cointegrated according to the standard panel cointegration tests of Kao for the null of a common unit root in the residuals. In the case of the Kao test, which takes into account country fixed effects, the probability of no cointegration or a

[9] For additional lags we follow Baltagi (2013; ch.12). PRT has a unit root if all lags are cross-section specific.
[10] The Fisher test statistic (called lambda-Pearson in Canning and Pedroni 2008), which is $P = -2\sum_1^N lnp(i)$ (requiring using p-values at the highest precision in order to avoid logs of zero), follows a chi-square distribution.
[11] These results are in line with rejecting the null of a unit root too often when cross-section dependence is ignored (Gengenbach et al. 2009).

common unit root in the residuals goes from 4.5 to 13.5 percent if the variables are time-demeaned.

All of the seven tests of Pedroni, which also take into account fixed effects and use country-specific autocorrelation coefficients, show cointegration; one at the ten percent level, one at the two percent level and all others at the one percent level. The country-specific information on the heterogeneous alternative suggests no cointegration for DNK, ITA, SWE, UK, USA. The Johansen-Fisher panel cointegration test based on the Fisher statistic from the combined trace and maximum eigenvalue tests rejects the hypothesis of having no cointegration and accepts the hypothesis 'at most 1 cointegrating equation'. According to the individual tests there is no cointegration for DNK, GRC, IRL, ITA, PRT, SWE, which is similar but not identical to the previous list.

Taking into account cross-section dependence, we add the period-specific averages across the countries for both variables to the regression of g_y on g_n as in equation (42) of Smith and Fuertes (2016), which has country-specific coefficients in the correlated common effects (CCE) estimator of Pesaran (2006). Running unit root tests on the residuals we find cointegration for all countries in the Fisher PP test, and unit roots for Netherlands and Portugal in the Fisher ADF and IPS tests (at the 1 percent level also for Finland and Ireland for both tests).

Overall, the cointegration tests suggest that we should expect heterogeneity with mostly statistically significant relations between the two growth rates with a few exceptions where we found no cointegration in some of the tests. However, the standard tests have been developed for I(1) variables which we do not have throughout. What remains to be determined by our model then are the country-specific signs and the average coefficients. The reason why we have to specify our own model is that econometric cointegration procedures do not work for our purposes. First, we have a mixture of stationary and nonstationary variables for both growth rates and a way to estimate them jointly is to use ADF or VECM methods (Pesaran 1997; Maddala and Kim 1998, ch. 5) and check that residuals have no unit roots; second, we have cointegration for some countries and not for others. Some VAR-type of models, which are appealing for us because of the suggested two-way causality, have the disadvantage of assuming the same number of cointegrating equations for all countries (Groen and Kleibergen 2003; Larsson and Lyhagen 2007), whereas our preliminary cointegration analysis above would suggest that they are different, either one or none. Breitung (2005) assumes that there are the same cointegrating equations for all countries, which again cannot be the case here if we have cointegration for some countries but not for the others. Other models assume weak exogeneity (see Choi 2015), which is inadequate here because both growth rates may be endogenous. We treat cross-section dependence, which is a problem in several older models, using the SURE method (Smith and Fuertes 2016).[12]

3.4 *Estimation results for Panel VECMs*

[12] A remaining problem is the possibility of cross-unit cointegration among the income growth rates and among the population growth rates. Rivara-Batiz and Xi (1993) show that international capital movements make interest rates of countries similar to each other and thereby their growth rates. Although the correlation is spurious in the sense of depending on a third argument, interest rates, we cannot exclude the possibility that ignoring this interdependence biases our results. Our estimation strategy is not a full-system analysis but rather a combination of unit-by-unit analyses (Banerjee et al. 2004). It has the feature of a block-diagonal matrix of long-term coefficients but it does not restrict the number of relations or the coefficients to be identical across countries. This literature is still under development (see Baltagi 2013; Pesaran 2015, Choi 2015). We stick here to the assumption of endogenous growth theory versions for closed economies concerning the growth rates for income and population. Note that panel Granger causality tests have an interpretation related to business cycles, not to steady-state growth rates. Ultimately, a question going beyond the scope of this paper is whether foreign R&D spillovers are dominant (Eaton and Kortum 1997) or the closed economy models capture the essentials of growth.

The result obtained from maximum likelihood estimation of (1a, b) - a VECM with four lags (because the underlying VAR has five lags) - is a slope of 0.62 and an intercept of 1.87. Country-specific deviations from the latter are in the range of (-0.87, 1.03), leading to a range of growth rates of g_y for $g_n = 0$ in the interval from (1.0, 2.9) (see Table 2, regression (3)) implying positive growth if population growth vanishes hypothetically. Other estimation methods lead to similar results. To get an idea of the statistical significance of the intercept we use the VECM without fixed effects transformation of the data. The underlying VAR has three lags according to all criteria and the VECM yields the result $g_y = 0.63g_N + 1.81$ with t-values of 1.95 for

Table 2	**Error-correction estimates for growth rates of income and population**									
Regression		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Dependent variable(s)		d(gy)	d(gn)	d(gy), d(gn)	d(gy), d(gn)	$d(gy)_i, d(gn)_i$	$d(gy)_i, d(gn)_i$	$d(gy)_i, d(gn)_i$	$d(gy)_i, d(gn)_i$	$d(gy)_i, d(gn)_i$
long run										
dependent variable		gy	gn	gy	gy	gy	gy	gy	gy	gy
regressor	gn	-0.8	-	0.62	0.63	1.29	1.23 (i)	0.86 (i)	-0.21 (i)	-0.9
		(-3.46)	-	(1.9)	(1.95)	(3.255)	(0.64) (k)	(0.48) (k)	(-0.73) (k)	(5.47)
	gy	-	0.275	-	-	-				-
			(3.5)							
	constant	-	-	1.87+(-0.87,1.03)	1.8	1.4 +(-1.45, 1.23)	0.195 (g)	0.48 (g)	2.52 (g)	2.2 +(-0.8, 1.33)
					(-6.45)		(0.157) (k)	(0.26) (k)	(8.59) (k)	
short run										
adjustment coeff.		-0.72	-0.086	-0.47, 0.0675	-0.42, 0.035	-0.39, 0.06 (f)	0.14, -0.018 (h)	-0.534, 0.035 (h)	-0.68, 0.033 (h)	-0.67, 0.03 (f)
		(-17.5)	(-4.68)	(-8.28), (7.7)	(-10.2), (7.28)	(-2.227), (2.99) (k)	(0.12),(-0.157) (k)	(-1.27),(0.06) (k)	(-17.1),(7.9) (k)	(-16.7), (6.4) (k)
regressors										
Lags (coeff. or no)	D(gn)	0.87	2	4	2	2	2	**country specific**	country specific	2
		(-1.61)								
Lags (coeff. or no)	D(gy)	-	1	4	2	2	2	**country specific**	country specific	2
Countries		16	16	16	16	16	16	16	16	16
Period		1962-2014	1963-2014	1966-2014	1964-2014	1965-2014	1965-2014	1963-2014	1962-2014	1964-2014
Observation		828	814	764	796	1560	1560	1560	1592	1592
Method		PMG	PMG	**FIML**	FIML	**3SLS**	3SLS	3SLS	**SUR of (7)**	**SUR of (5)**
		ARDL(1,1)	ARDL(3,1)	**VECM**	VECM	VECM, **PMG**	VECM, **MG**	VECM, MG	VECM, MG	VECM, PMG
Log likelihood		-1561.246	347.6567	-1526.6, -97.38	-1833.9, -136.6	-	-	-	-	-
Fixed effects		countries	countries	countries	**none (d)**	countries	-	-	-	countries
		periods (a)	periods (b	periods (c)		periods (e)	- (l)	- (l)	- (l)	periods (e)
p (adj Q) (j)		-	-	0.16; 0.55	0.04, 0.39	0.16, 0.68	0.066, 0.32	0.14, 0.62	0.16, 0.39	0.15, 0.61

t-values in parentheses.	Bold symbols indicate new elements compared to previous regressions in the table.
(a) Fixed effects via demeaning; adjustment coefficents range between (-1.02, -0.36; highest p=0.0001);	
coefficients for d(gn) range from -2.1 to 4.77.	AIC for lag selection.
(b) Fixed effects via demeaning; AIC for lag selection.	
Adjustment coefficients range between -0.26 and 0.088 with highest p-value =0.0019	
(c) Fixed effects via demeaning; covariances are σ(1,1) = 3.185; σ(2,2) = 0.0755; σ(1,2) =σ(2,1) =- 0.24.	
Boswijk (1995) for s.e. of long run coeff. .	
Lag length choice according to lag length criteria, stability test, and LM and Portmanteau serial correlation tests.	
Intercept of 1.868 plus country-specific deviations in the range of (-0.87, 1.03)	
(d) Lag length of VAR is three for all criteria. Boswijk (1995) for s.e. of long run coeff. .	
Covariances are σ(1,1) = 5.87; σ(2,2) = 0.0825; σ(1,2) = σ(2,1) = - 0.055.	
(e) Country and period fixed effects via demeaning; lag length fixed at 2;	
long term coefficient constrained to be identical for all countries;	
adjustment coefficients averaged over equations of 16 countries; other coefficients unconstrained. Covariance matrix is 32x32.	
Portmanteau test for null of no serial correlation has p-values for adj Q-stat (see Lüthkepohl 2005) between 0.16 and 0.68.	
(f) average over first and second set of equations (2a), (2b).	
(g) average across countries with seven significantly positive, three significantly negative and six insignificant results for the intercept.	
(h) average across countries for first and second set of equations.	
(i) average over values for 16 countries.	
(j) lowest and highest p-value for 12 lags in the Portmanteau test for 'no serial correlation' hypothesis (see Lüthkepohl 2005).	
(k) the variance of a mean group estimator is obtained as the sum over all elements in the coefficient covariance matrix divided by 256.	
Taking the square root yields the standard error that can be used to divide the coefficient to get the t-value.	
See Davidson and McKinnon (2004), formula (3.68).	
(l) Under full heterogeneity time fixed effects are in the residuals.	

the slope and 6.44 for the intercept in Table 2, regression (4). The similar slope and estimate as with fixed effects indicates that the impact of fixed effects is limited although they could partly control for non-representative years or countries. In sum, slope and intercept are positive, statistically significant and economically of reasonable order of magnitude with and without fixed effects.[13] This preliminary result is in line with the Lucas type of models and not with the others listed above. By implication, if population growth goes to zero we will still have a growth rate of 1.8% as an average across the sixteen countries of our panel.

The essence of estimating systems (2a, b) and (3a, b), when the long-term coefficients are (not) common to all countries, is

(i) to estimate the equations for each country, and

(ii) to take into account heterogeneity at least in the short term relations, and

[13] Both VARs are stable. Non-linear spillover effects can in theory lead to u-shaped or hump-shaped effects of population growth rates (Diwarkar and Sorek 2017). Depending on the education policies and the value of the population growth rate itself there can be positive or negative impacts of exogenous population growth rates on income growth rates for constant policies in theoretical models (Prettner 2014).

(iii) to take into account the relation between the residuals of the different countries (Groen and Kleibergen 2003).

Moreover, the lagged dependent variables may suffer from the Nickell bias when T is small and therefore we use lags as instruments for all variables in the first instance. We use first the three-stage least squares estimator, which combines instrument variables and the seemingly-unrelated-regression (SUR) estimator dealing with contemporaneous correlation and cross-section dependence (Smith and Fuertes 2016) and later only the SUR estimation method without instruments when assuming that T is large enough.[14] The result for the estimation of (2a,b), a PMG estimator, using again the double demeaned variables (Table 2, regression (5)) is a slope of 1.29 and an overall constant of 1.4, with country fixed effects in the interval of (-1.45, 1.23). This implies for one country that the growth rate for $g_n = 0$ is about zero, but positive for all others. Regressions (3)-(5) would clearly favour the Lucas model. However, the PMG estimator of the slope may suffer from heterogeneity bias. Jusélius et al (2014) suggest separate country-by-country estimation, which has the advantage of determining the adequate lag length per country, but the interaction of growth between the countries is not taken into account. This interaction may be stronger among the OECD countries of our sample than the developing countries they consider and therefore we try to consider it when estimating equations (3a, b).

Next, we estimate the 16 VECMs of equations (3a, b) jointly, with all coefficients flexible, using lag length two for all countries in regression (6) of Table 2, and taking into account contemporaneous correlation of the residuals using 3SLS again. This yields an average slope of 1.23. We can attribute the insignificance of the slope and

[14] Using GMM-HAC leads to a 'near-singular matrix' warning.

intercept parameters either to heterogeneity or to having the case of non-duplication and degree of difficulty outweighing each other when setting coefficients to zero.[15,16]

Regression (7) in Table 2 uses country-specific lag lengths from the standard tests done country by country, after testing for stability. The average slope and intercept values are then 0.86 and 0.48, positive and between the results obtained so far. As in regression (5), these mean-group estimates are statistically insignificant.

The Nickell bias is only relevant under slope homogeneity. In case of slope heterogeneity, we are left with the standard Hurwicz bias from lagged dependent variables being pre-determined because *y(-1)* depends on *u(-1)*. As we have about 50 observations, we could assume that the bias is small and rely on the consistency of the least-squares estimator regarding the Hurwicz bias (Ramanthan 2001). Because of the contemporaneous correlation across countries, we use the SUR estimation method in regressions (8) and (9) which otherwise correspond to equations (7) and (5). In both cases, the move from 3SLS to SUR changes the sign of the slope, but it remains statistically insignificant; instruments may have done more harm than good in the previous regressions. In contrast, the intercept and the adjustment coefficients become statistically significant.

3.5 Linking panel estimation results to endogenous growth models

[15] According to Baltagi (2006) pooled estimation seems to be much more robust than allowing for heterogeneity.

[16] The slope coefficients of regressions (5) and (6) with 32x32 covariance matrix in Table 2 are twice as high as those with 2x2 covariance matrix in regression (3) and (4). Using the GMM method with heteroscedasticity and autocorrelation consistent coefficients and standard errors (HAC) or Maximum-likelihood leads to a 'near singular matrix' warning, indicating that the determinant of the inverted matrix in the estimator is close to zero. This warning is absent in the 3SLS estimates, but it may be the reason for the higher estimates. The significance of the slope parameter in regression (6) is low, indicating either that the heterogeneity is strong or we are in the curse of dimensionality because of a low number of observations. Adding common factors yields a 'near singular matrix' warning more often and so do time dummies for structural breaks.

Regressions (3)-(5) with slope homogeneity assumption and statistically significant results would favour the Lucas model, because we have a positive slope and intercept, both statistically significant. For regressions (6) and (7) the interpretation depends on the decision to look at the signs, favouring Lucas' model again, or emphasizing the insignificance. When setting slope and intercept to zero because of the insignificance, (6) and (7) would suggest a semi-endogenous growth model with non-duplication outweighed by the degree of difficulty (see Table 1, last column) predicting zero growth in the steady state. SUR regression (8) with statistically insignificant average slope and significantly positive average intercept supports the Bentham version of the AK model by Dalgaard and Kreiner (2001). Regression (9) with slope homogeneity as in (5) supports the non-Bentham version of the AK model of Dalgaard and Kreiner (2001) with significantly negative slope and positive intercept with unknown significance of implicit fixed effects.

Summing up the regression results, at best regression (6) and (7) when putting statistically insignificant coefficients to zero would support semi-endogenous growth models. If we do not put them to zero, (6) and (7) support the Lucas model. Regressions (8) and (9) support fully endogenous growth of the model by Dalgaard and Kreiner (2001). Overall, this is much support for endogenous growth and little for semi-endogenous growth.

3.6 Some properties of the preferred regression

As the SUR method with country specific lag length is the most plausible method, we explore the preferred regression (8) a bit more in Table 3 following Canning and Pedroni (2008). In columns 1, 4, 7 and 10 we present the coefficients of intercept, slope and adjustment coefficients. Columns 2, 5, 8 and 11 show the t-values and 3, 6, 9 and 12 the p-values.

The intercepts are all positive except for the USA. However, five of them are not statistically significant. The average of the t-values used is 4.21 and thereby we have a statistically significant group mean according to the Fisher (lambda-Pearson) test. The intercept is also statistically significant, again according to the Fisher (lambda-Pearson) test, because the values are so high that the chi-square distribution has a very small likelihood for the $2N=32$ degrees of freedom and we reject the corresponding null hypothesis of a zero intercept.

The slopes are negative for nine countries, of which two insignificant, and positive for seven countries, of which four insignificant. The average t-value is zero and suggests a group mean of zero, as in regression (8) in Table 2 but without using the coefficient covariances. The lambda-Pearson/Fisher test statistic is strongly positive suggesting that the slopes are not always zero.

The adjustment coefficients going to dg_y are all negative and statistically significant mostly at a lower level than one percent. The average t-value confirms this, and the lambda-Pearson test suggests that not all coefficients are zero. The adjustment coefficients going to *dgn* have positive or negative signs with a slightly positive average, with about half of them being statistically insignificant suggesting weak erogeneity of the population growth rate meaning that it does not react to disequilibrium in the long-term relations. The average t-value is just significant at the ten percent level and the lambda-Pearson statistic confirms that not all are zero. The average t-values and the lambda-Pearson are panel causality test statistics if there is cointegration; the latter suggests that none of the four coefficients is zero in the whole panel.

Table 3	**Intercepts, slopes and adjustment coefficients of regression (8)**											
	1	2	3	4	5	6	7	8	9	10	11	12
Country	*Interc*	*t-value*	*p-value*	*slope*	*t-value*	*p-value*	*adj c dg_y*	*t-value*	*p-value*	*adj c dg_n*	*t-value*	*p-value*
AUS	1.34	2.25	0.025	0.58	1.545	0.123	-0.83	-4.76	0.0000	0.175	5.111	0.000
CAN	0.86	0.99	**0.323**	1.14	1.784	0.075	-0.76	-8.76	0.0000	0.028	3.652	0.000
DNK	2.23	3.03	0.003	-0.60	**-0.387**	**0.698**	-0.56	-4.11	0.0000	**-0.001**	-0.190	**0.849**
ESP	4.76	4.47	0.000	-3.29	-2.770	0.006	-0.28	-4.03	0.0001	**-0.003**	-0.483	**0.629**
FIN	4.65	4.85	0.000	-4.45	-1.901	0.058	-0.72	-5.64	0.0000	0.010	1.897	0.058
FRA	0.72	1.32	**0.187**	2.61	3.978	0.000	-0.53	-7.72	0.0000	0.011	1.441	0.150
DEU	2.06	13.18	0.000	**-0.26**	**-0.641**	**0.522**	-1.26	-7.23	0.0000	0.199	4.111	0.000
GRC	1.42	0.94	**0.348**	**2.66**	**1.149**	**0.251**	-0.24	-2.49	0.0129	0.021	3.558	0.000
IRL	7.76	5.38	0.000	-3.49	-2.923	0.004	-0.45	-2.49	0.0010	**-0.010**	-0.980	**0.327**
ITA	1.84	2.73	0.007	0.27	**0.207**	**0.836**	-0.46	-4.76	0.0000	**-0.001**	-0.090	**0.928**
LUX	4.26	7.53	0.000	-1.34	-2.995	0.003	-0.86	-7.19	0.0000	0.023	3.241	0.001
NLD	0.57	1.02	**0.309**	2.73	4.150	0.000	-0.50	-3.99	0.0001	0.015	2.454	0.014
PRT	2.68	4.17	0.000	**-0.01**	**-0.015**	**0.988**	**-0.49**	**-4.85**	0.0000	**0.054**	**3.703**	0.000
SWE	2.30	5.93	0.000	-0.54	**-0.815**	**0.415**	-0.78	-6.79	0.0000	0.004	0.528	**0.598**
GBR	2.89	9.74	0.000	-1.42	-2.418	0.016	-0.99	-10.34	0.0000	**-0.001**	-0.303	**0.762**
USA	-0.09	-0.12	**0.907**	2.10	2.859	0.004	-1.18	-9.36	0.0000	0.010	1.455	0.146
Average	2.52	4.21		-0.21	0.050		-0.68	-5.91		0.033	1.819	
lambda-Pearson		508.0	0.000		113.5	0.000		695.81	0.0000		139.2	0.000

Last p-values in a column belong to the lambda-Pearson/Fisher test statistic.
Lambda-Pearson test statistic (below the t-values) is -2(sum from i= 1 to i=16 over lnp(i)).
P-values in the formula for the lambda-Pearson test statistic are taken with highest possible precision to avoid logs of zeros.
P- and t-values with strong statistical insignifcance are printed in bold.

3.7 *Linking individual country results to endogenous growth models*

As the statistical insignificance of some coefficients of intercepts and slopes in regressions (3)-(9) may be due to heterogeneity, we want to look also at the country-specific results. In the last column of Table 1 we attribute country results to models besides related regressions, which show a similar result. In panel (a) we do this according to regression (7) using 3SLS, and in panel (b) according to regression (8) using SUR, both having country-specific lag length. In some cases an estimate is close to the ten-percent level , which we indicate by a note presenting the p=value. Nine to twelve countries have statistically significant positive or negative intercepts in the two panels of Table 1, which is in line with the panel-cointegration result reported above and implies that they support fully-endogenous growth theory. In contrast, five or six countries support semi-endogenous growth theory. Whereas the averaging regressions (3)-(5) favour the Lucas model, actually, according to the approach of this paper, no country falls into this class unless one goes to significance levels below ten percent, and only two or none fall into the class of Howitt. Among the fully-endogenous growth cases, the Dalgaard-Kreiner models dominate in the sense that the largest number of cases has a significantly positive intercept and a zero or negative slope.[17] An implication of this is that growth can also remain positive if population growth goes to zero if intercepts are positive. In the case of a negative intercept, sufficiently strong population growth is required to get positive growth rates and has to outweigh the negative intercept constituted by interest costs or consumption growth. Finally, for one or four countries, we find slope and intercept statistically insignificant, which we interpret as semi-endogenous growth with non-duplication outweighed by the degree of difficulty.

Overall, the averaging regressions (3)-(7) support the positive intercepts and slope coefficients of population growth in line with the Lucas model with or without statistical significance. However, under full heterogeneity in regressions (7) and (8) with country-specific lag length, there is no country case belonging to the class of the Lucas model, but rather most countries have positive intercepts and zero or negative slopes as in the Dalgaard-Kreiner models. In contrast, regressions (3)-(5), imposing slope homogeneity with or without fixed effects, find statistically significant positive slopes and intercepts, but regression (9), the SUR version of (5) finds a significantly negative slope. When tests in our country panels are based on testing the slope and intercept of steady-state growth formulas for endogenous growth in VECMs, none of the growth models can be ruled out without abandoning the corresponding methods

[17] Strulik's (2005) and Bucci's (2008) synthesis of Lucas' and the variety models can be reconciled with more than one of these outcomes. Time-series studies compared to cross-country studies give less support to semi-endogenous growth (Madsen 2008). Studies without panel heterogeneity put a bit more weight to the semi-endogenous growth models (see Neves and Sequeira 2017). Our result provides also empirical support for Cozzi's (2017) hybrid model, which is based on a linear combination of the semi-endogenous and a fully endogenous growth model, leading to results of the latter when population growth is low as it is in our sample.

of handling heterogeneity and estimation. However, a negative intercept gets the least support. The preferred regression (8) supports statistically significant positive intercepts, and about equally many positive, negative or zero slopes.

3.8 Econometric endogeneity

The evaluation of regression equation (7) using 3SLS so far is based on sign and significance in the long-term relationship of economic theory only. The econometric definition of endogeneity would require that slope and adjustment coefficients are statistically significant. With this requirement, only income growth of the UK and population growth of Canada and Denmark would be endogenous in our estimate of (7). For all other countries the econometric conclusion within the 3SLS approach is that growth is weakly exogenous, when the emphasis focusses on the heterogeneity of regression (7). In contrast, in regression (8) using SUR, the income growth equations have statistically significant adjustment coefficients throughout, meaning that income growth reacts to dis-equilibrium deviations from the long-term relation. Population growth is weakly exogenous for half of all countries (DNK, ESP, FRA, IRL, ITA, SWE, UK, USA) and therefore does not react to dis-equilibrium but only to changes in both growth rates whereas for the other eight countries it does. Therefore, regression (8) fulfils the necessary condition of having at least one non-zero adjustment coefficient per country (Canning and Pedroni 2008). Standard panel unit root tests (LLC, IPS, ADF-Fisher and PP-Fisher) for the residuals of regression (8) show a probability of 0.0000 for the panel unit root hypotheses, indicating that the regression is not spurious through the mixture of I(1) and I(0) variables.

Canning and Pedroni (2008) emphasize in their appendix that the negative of the ratio of the adjustment coefficients, $-\alpha_{1i}/\alpha_{2i}$, is equal to the long-term effect of a transitory shock to population growth on income growth and its inverse for the opposite shock-effect relation under cointegration. The negative of the numerator, in column 7 of Table 3, is positive. The denominator, in column 10 of Table 3, is highly insignificant in six cases; the other ten cases have a positive value. However, in three of then ten cases (DEU, GRC, PRT) there is no cointegration because slope parameters in the long-term relation are highly insignificant. Therefore, for seven of the ten positive cases we have a positive long-term relation for the shock of population growth on income growth, and the other way around. When the coefficients in column 10 are essentially zero, the ratio is not well defined as we may not divide by zero, and the inverse is zero, implying having no impact of income growth on population growth in these six countries and also not in the three cases lacking cointegration. By implication, there is no impact in either direction in these cases. In short, a transitory shock to the residuals of changes in population growth rates has a long-run effect only in seven of sixteen countries. Heterogeneity is very strong here in both, slope coefficients and adjustment coefficients, although we are dealing only with rich countries. This result is in line with the mixed evidence reported in the introduction.

IV Conclusion

We have tested endogenous growth models, which generate a linear formula of per capita income growth and population growth. The crucial step for the empirical work is to give up the simplifying assumption of growth models that population growth is exogenous and test it. When population growth is endogenous and we allow for two-way causality, under the assumption of slope homogeneity a vector-error-correction approach shows that the relation between growth rates of income per capita and the population is positive with positive intercept. Both coefficients as well as the adjustment coefficients are statistically significant. Under the assumption of slope heterogeneity, intercepts are more frequently positive than negative or zero. Both assumptions lead us to favouring fully over semi-endogenous growth. Although we cannot exclude the cases where population growth has to be positive to continue growing, intercepts are predominantly positive and suggest that we can have endogenous growth also when population growth stops.

References

Ahituv, A. (2001). Be fruitful or multiply: On the interplay between fertility and economic development. *Journal of Population Economics*, 14, 51–71.

Arrow, Kenneth J. (1962) The Economic Implications of Learning by Doing. *The Review of Economic Studies*, Vol. 29, No. 3, pp. 155-173.

Asteriou, Dimitrios and Stephen G. Hall (2015) Applied Econometrics. Macmillan International Higher Education, 3rd edition.

Baltagi, B.H. (2013) Econometric Analysis of Panel Data, 5th edition New York: Wiley.

Baltagi, Badi H. (2006) Forecasting with panel data. Deutsche Bundesbank, Discussion Paper Series 1: Economic Studies No 25.

Bloom, Nicholas, Charles I. Jones, John Van Reenen, Michael Webb (2017), Are Ideas Getting Harder to Find? March 13, 2017 — Version 0.7.

Brander, James A. and Steve Dowrick (1994) The role of fertility and population in economic growth. Empirical results from aggregate cross-national data. *Journal of Population Economics* 7:1-25.

Breitung, Jörg (2005) A Parametric approach to the Estimation of Cointegration Vectors in Panel Data, Econometric Reviews, 24:2, 151-173, DOI: 10.1081/ETC-200067895.

Bucci, Alberto (2008) Population growth in a model of economic growth with human capital accumulation and horizontal R&D. *Journal of Macroeconomics* 30, 1124–1147.

Bucci, Alberto; Eraydın, Levent; Müller, Moritz (2018) Dilution effects, population growth and economic growth under human capital accumulation and endogenous technological change. Working Paper Series in Economics, Karlsruher Institut für Technologie (KIT), No. 113.

Bucci, A. and X. Raurich (2017) Population and Economic Growth Under Different Growth engines. *German Economic Review* 18(2): 182-211.

Canning, David and Peter Pedroni (2008). Infrastructure, long-run economic growth and causality tests for cointegrated panels. The Manchester School Vol 76 No. 5 Special Issue, 504–527.

Canova, Fabio and Matteo Ciccarelli (2013) Panel Vector Autoregressive Models: A Survey. Centre for Economic Policy Research Discussion Paper No. 9380. March.

Choi, In (2015) Panel Cointegration, 46-75, in Badi H. Baltagi (ed.), The Oxford Handbook of Panel Data. Oxford University Press, Oxford, New York.

Cozzi, Guido (2017) Endogenous growth, semi-endogenous growth... or both? A simple hybrid model. *Economics Letters* 154: 28–30.

Dalgaard, C.-J., Kreiner, C.T. (2001). "Is declining productivity inevitable?". *Journal of Economic Growth* 6: 187-203.

Dinopoulos, Elias And Paul Segerstrom (1999) A Schumpeterian Model of Protection and Relative Wages. *American Economic Review* Vol. 89, No. 3, 450-472.

Davidson, Russell, & MacKinnon, James G. (2004). *Econometric theory and methods*: Oxford University Press New York.

Diwakar, Bharat and Gilad Sorek (2017) Human-capital spillover, population and R&D-based growth. *B.E. Journal of Macroeconomics* 2017; 17(1): 1–17.

Eaton, Jonathan and Samuel Kortum (1997) Engines of growth: Domestic and foreign sources of innovation. *Japan and the World Economy* 9: 235-259.

Fosu, A., Getachew, Y., & Ziesemer, T. (2016). Optimal public investment, growth, and consumption: evidence from African countries. *Macroeconomic Dynamics*, 20(8), 1957-1986.

Frenkel, Jacob A., Razin, Assaf, Yuen, Chi-Wa, 1996. *Fiscal Policies and Growth in the World Economy*. The MIT Press, Cambridge.

Gaessler, A.E. von , T. Ziesemer (2016) Optimal Education in Times of Ageing: The Dependency Ratio in the Uzawa-Lucas growth model, *The Journal of the Economics of Ageing* 7, 125-142.

Galor, O. and d. Weil (1999) From Malthusian Stagnation to Modern Growth. *American Economic Review* 89(2), May, 150-154.

Greene, William H. (2012) *Econometric Analysis*. 7th Edition, Pearson New Jersey.

Groen, Jan J. J & Frank Kleibergen (2003) Likelihood-Based Cointegration. Analysis in Panels of Vector Error-Correction Models, *Journal of Business & Economic Statistics*, 21:2, 295-318.

Ha, Joonkyung, Peter Howitt (2007) Accounting for Trends in Productivity and R&D: A Schumpeterian Critique of Semi-Endogenous Growth Theory. *Journal of Money, Credit and Banking*, Vol. 39, No. 4, 734-774.

Herzer, Dierk, Holger Strulik, Sebastian Vollmer ((2012) The long-run determinants of fertility: one century of demographic change 1900–1999. *Journal of Economic Growth* 17:357–385.

Howitt, Peter (1999) "Steady Endogenous Growth with Population and R & D Inputs Growing," *Journal of Political Economy* 107, no. 4 (August): 715-730.

Jones, Charles I. (1995) "R & D-Based Models of Economic Growth," *Journal of Political Economy* 103, no. 4 (Aug.): 759-784.

Judd, Kenneth L. (1985), On the Performance of Patents. Econometrica, Vol. 53, No. 3 pp. 567-586.

Jusélius, Katarina, Niels Framroze Møller and Finn Tarp (2014) The Long-Run Impact of Foreign Aid in 36 African Countries: Insights from Multivariate Time Series Analysis. *Oxford Bulletin of Economics and Statistics*, 76, 2, 153-184.

Kelley, Allen C. and Robert M. Schmidt (1995) Aggregate Population and Economic Growth Correlations: The Role of the Components of Demographic Change. *Demography*, Vol. 32, No. 4 (Nov.), 543-555.

Kruse-Andersen, Peter K. (2017) Testing R&D-Based Endogenous Growth Models. Discussion Papers Department of Economics, University of Copenhagen, No. 17-05.

Larsson, R., and J. Lyhagen. (2007). “Inference in Panel Cointegration Models with Long Panels,” Journal of Business & Economic Statistics, 25, 473–483.

Li Hongbin and Junsen Zhang (2007) Do high birth rates hamper economic growth? *The Review of Economics and Statistics*, February 2007, 89(1): 110–117.

Lucas, Robert E. (1988). On the mechanics of economic development. *Journal of Monetary Economics*, 22(1), 3-42.

Maddala, G.S. and I.-M. Kim, 1998, Unit Roots, Cointegration and Structural Change, Cambridge University Press.

Madsen, Jakob B. (2008) Semi-endogenous versus Schumpeterian growth models: testing the knowledge production function using international data. *Journal of Economic Growth* 13: 1 – 26.

Neves, Pedro Cunha and Tiago Sequeira (2017) The Production of Knowledge: A Meta-Regression Analysis. CEFAGE Worrkiing Paper 2017/03.

Pesaran, M. Hashem (1997) The Role of Economic Theory in Modelling the Long Run. The Economic Journal 107 (Januar), 178-191.

Pesaran, M. Hashem (2006), Estimation and Inference in Large Heterogeneous Panels with a Multifactor Error Structure. Econometrica, Vol. 74, No. 4 967–1012.

Pesaran, M.H. (2007) A simple panel unit root test in the presence of cross section dependence, Journal of Applied Econometrics, 22(2).p265-312.

Pesaran, M. Hashem (2015) *Time Series and Panel Data Econometrics*. Oxford University Press.

Phelps ES (1966) Models of technical progress and the golden rule of research. *The Review of Economic Studies*, Vol. 33, No. 2, pp. 133-145.

Prettner, K. 2014. “The Non-monotonous Impact of Population Growth on Economic Prosperity.” *Economics Letters* 124: 93–95.

Prettner, Klaus and Alexia Prskawetz (2010) Demographic change in models of endogenous economic growth. A survey. *Central European Journal of Operations Research* 18:593–608.

Ramanathan, R. (2001) Introductory Econometrics with Applications. (Fourth Edition), Dryden and Harcourt, Orlando and Fort Worth.

Rivera-Batiz, L.A. and Danyang Xie, 1993, Integration among unequals, Regional Science and Urban Economics 23, 337-354.

Shell, K. (1967) "A Model of Inventive Activity and Capital Accumulation", 1967, in K. Shell, editor, Essays on the Theory of Optimal Economic Growth. Cambridge, Massachusetts: MIT Press, 67-85.

Smith, Ron P. and Ana-Maria Fuertes (2016) Panel Time-Series. August.

Strulik, Holger (2005) The Role of Human Capital and Population Growth in R&D-based Models of Economic Growth. *Review of International Economics*, 13(1), 129–145.

Strulik, Holger, Klaus Prettner, Alexia Prskawetz (2013) The past and future of knowledge-based growth. *Journal of Economic Growth* 18:411–437. DOI 10.1007/s10887-013-9098-9.

Tournemaine, Frederic, (2007) "Can population promote income per-capita growth? A balanced perspective." *Economics Bulletin*, Vol. 15, No. 8 pp. 1-7.

von Weizsäcker, Carl Christian (1969). Forschungsinvestitionen und Makroökonomische Modelle — Ein Wirtschaftstheoretisches Dilemma? *Kyklos* 22, Issue 3, August, Pages 454–466.

Ziesemer, Thomas (2016) Gini Coefficients of Education for 146 Countries 1950-2010, *Bulletin of Applied Economics* 3(2), 1-8.

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