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LONG-RUN GROWTH DIFFERENCES AND THE NEOCLASSICAL GROWTH MODEL

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This paper shows that allowing factor income share differences across countries in a modified Solow model can imply differences in output growth rates across countries. Using cross-sectional data for 52 countries, an empirical illustration shows that the parameters of the modified model are intuitively plausible, jointly significant, and possess modest explanatory power (R^2 around 0.25). The paper emphasizes the methodological importance of simplifying assumptions on applied theory.

JEL Codes: E13, E25, O41

Keywords: factor income shares, growth differences, production function

1. Introduction

The message of this paper is a simple one: the assumptions we make in economic theory are almost never trivial. Consider one of the simplest theoretical models in macroeconomics: Robert Solow's early version of the neoclassical growth model (NGM). One of the key implications of the NGM is that the underlying growth rate of output per worker is constant across all countries. This view of long-run growth is articulated by Mankiw *et al*. (1992): "We assume that [steady-state growth rate] *g* [is] constant across countries. *g* reflects primarily the advancement of knowledge, which is not country-specific." This implication has been the source of criticism of the NGM from work by Easterly and Levine (2001) and Grier and Grier (2007), among others. This paper follows work such as McQuinn and Whelan (2007a) by highlighting the sensitivity of this criticism to the particular choice of assumptions.[1]

I demonstrate that this weakness of the model can be attributed to the assumptions that (1) aggregate production is constant returns to scale (CRS) in physical and human capital, and (2) factor income shares are identical across countries—assumptions implemented more for mathematical convenience than

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[1]It also follows in the spirit of Gómez and De Cos (2008) and Pastor and Serrano (2008), who show that income inequality across countries is affected by population age and life expectancy. Here, persistent income inequality across countries would be an implication of divergent growth rates associated with variation in factor income shares.

economic realism.[2] Relaxing these assumptions produces a model which implies cross-country variation in growth rates. I then provide a cross-sectional empirical illustration that even these easily implemented changes in assumptions can provide intuitively plausible growth parameters and improve the predictiveness of the NGM.

2. Theory

Recall that in the most basic version of the Solow model, the production function is $Y(t) = K(t)^{\alpha}(A(t)L(t))^{1-\alpha}$. Since physical capital is reproducible, in the steady state it must grow at the same rate as output, implying that per capita output growth only depends on growth in $A(t)$. Even if we follow the common practice of replacing raw labor with human capital, per capita output growth still only depends on growth in $A(t)$ and education. If labor-augmenting technology is not country specific, then all countries should have the same underlying growth rate.

As an alternative, consider a model with a more general production process.[3] The Cobb–Douglas production function is $Y(t) = A(t)K(t)^{\alpha}H(t)^{\beta}N(t)^{\gamma}$, where K, H, and N denote, respectively, reproducible physical capital, human capital, and non-reproducible natural capital (including land and natural resources such as oil reserves). For now, I assume human capital is simply average education level times the number of workers, or $H(t) = e(t)L(t)$. I also assume output elasticities α, β, and γ are all non-negative and sum to one. The Hicks-neutral productivity term $A(t)$ can be decomposed into components augmenting each input to production: $A(t) = A_K(t)^{\alpha}A_H(t)^{\beta}A_N(t)^{\gamma}$.[4]

In the absence of ongoing changes to national borders, no country can expand its productive land. To reflect this fact, I assume the growth rate of land is zero, $g_N = 0$. In the steady state labor force growth and population growth must be equal, and I employ the conventional simplification that $\dot{L}(t) = nL(t)$ and a comparable definition for growth in average education, $\dot{e}(t) = g_e e(t)$.[5]

Similarly, using the conventional equation of motion for physical capital implies that capital and total output must grow at the same rate in the steady state, so the steady-state growth rate of output per worker is

$$g_y = g_{AK}\frac{\alpha}{1-\alpha} + g_{AH}\frac{\beta}{1-\alpha} + g_{AN}\frac{\gamma}{1-\alpha} - n\frac{\gamma}{1-\alpha} + g_e\frac{\beta}{1-\alpha}, \tag{1}$$

[2]Although Chirinko (2008) presents evidence against the use of the Cobb–Douglas production function, Aiyar and Dalgaard (2009) argue that the Cobb–Douglas function still provides a reasonable approximation for some applications. The results presented here show that some of the weaknesses of the standard Cobb–Douglas production function are related to other modeling assumptions.

[3]The following builds on Nordhaus (1992) and Romer (2006).

[4]This assumption for productivity allows me to estimate coefficients related to each factor income share, but is not necessary to produce cross-country variation in growth rates.

[5]Strictly speaking, since average years of education is bounded, in the very long run this growth rate would equal zero, so the theoretical structure could still hold even if we see no effect of average education growth on per capita output growth. This is only strictly true in the very long run, though, and we need not expect this to hold in a finite sample. For this reason, I use the growth rate of average education in the empirical application.

where g_{AX} is the (constant) growth rate of technology augmenting input x. The presence of the fixed factor $N(t)$ results in a growth rate which is a function of population growth, education growth, technology growth, and factor income shares.

This result differs from the most basic NGM result, in which the long-run growth rate of output per worker is simply the growth rate of human capital-augmenting technology plus the growth rate in education, $g_{AH} + g_e$. If knowledge is a pure public good, then all countries should converge to the same long-run growth rate. Essentially, the standard NGM can account for zero variation in long-run growth rates. Here, however, the introduction of land to the production function means the long-run growth rate of output per worker also depends on factor income shares, growth in average education, and population growth. The long-run growth rate also depends on multiple technology growth rates, not just labor-augmenting technology, due to the general multiplicative technology used.

3. An Empirical Illustration

Although the theoretical implications are straightforward, it is worth asking how empirically relevant they are. To answer this question, I use a simple cross-sectional regression to determine the statistical significance and explanatory power of the variables in equation (1). This is hardly a robust test of the model, and empirical results supporting the model could also be consistent with many others. The exercise here is meant to illustrate how changing commonly accepted simplifying assumptions matters for applied theory.

3.1. *Methods*

Empirical tests of the NGM typically treat growth rates in population and technology as data, while the estimated parameters are functions of output elasticities. This implies that factor income shares (which equal output elasticities under competitive factor markets) are identical across countries, despite previous research indicating that pooling output elasticities across countries is not supported by the data (see Grier and Tullock, 1989; Durlauf and Johnson, 1995).[6] I reverse the usual paradigm by using data on factor shares to estimate factor-specific technology growth rates, which should be pooled across countries according to the NGM.

The version of equation (1) that I estimate is

$$g_{yi} = g_{AK}\frac{\alpha_i}{1-\alpha_i} + g_{AH}\frac{\beta_i}{1-\alpha_i} + g_{AN}\frac{\gamma_i}{1-\alpha_i} - b_1\frac{n_i\gamma_i}{1-\alpha_i} + b_2\frac{g_{ei}\beta_i}{1-\alpha_i} + \varepsilon_i, \tag{2}$$

[6]Owen *et al.* (2009) estimate the number of growth regimes (implicitly determining the number of distinct αs and βs) in a neoclassical structure using a finite mixture model. They primarily focus on the evidence that there are multiple components to the mixture rather than on implications for the NGM.

where subscript i indicates country. The country specific error term ε_i is mean-zero and i.i.d. Normal; the technology growth rates, b_1 and b_2 are regression parameters; and all other variables are defined as in Section 2. This cross-sectional regression can be estimated using OLS.[7]

The theoretical model implies the regression parameters b_1 and b_2 should equal −1 and 1, respectively. Practically speaking, it is difficult to think of growth in natural capital-augmenting technology that would not be correlated with growth in physical capital-augmenting technology, suggesting that g_{AN} may be small and possibly statistically insignificant. These implied restrictions, combined with inspection of the estimated technology growth rates, provide a useful check of how plausible the theoretical model is in an empirical setting.

3.2. *Data*

I use factor income share data for 52 countries from Caselli and Feyrer (2007), who expand on the work of Gollin (2002) and Bernanke and Gurkaynak (2002) by distinguishing the factor share of reproducible capital (RC) from total capital (TC). I use RC as physical capital shares, TC minus RC as natural capital shares, and the residual as human capital share so that all factor shares sum to unity. Izyumov and Vahaly (2013) have criticized this data, arguing that its treatment of labor income from unincorporated enterprises obscures systematic differences in factor shares between rich and poor countries. I use this data both because it is standard in the literature and because it highlights the impact of modeling assumptions even if the data implies that factor share differences are small.

Data on output per capita and population come from the Penn World Table 6.3 of Heston *et al*. (2009).[8] In order to capture the long-run trend in income and population growth, I use 35-year growth rates of both variables (1973–2007) by taking the difference between the natural logs of the first and last period and divide by the number of periods.[9] Since most of the factor income share data is from around 1990, I also run the regressions using 18-year growth rates beginning in 1990–2007 to reduce concerns about reverse causality. Recent evidence by McQuinn and Whelan (2007b) suggests that convergence speeds are substantially higher than earlier estimates indicate, and thus the 18-year sample should still give a relatively accurate picture of long-run growth.

In order to capture as large a fraction of the labor force as possible, I use the measure of average education for the full population over the age of 15 from Barro

[7]Although factor shares do vary between countries, I assume that they are relatively constant over time within countries, which is consistent with the claims of Gollin (2002). This insures that analysis along the balanced growth path is valid. This assumption has been criticized (see Sturgill, 2012). Such arguments are in keeping with this paper's concerns about simplifying assumptions, although criticism of constant factors over time is beyond the scope of this paper, which highlights weaknesses of the model even if factor income shares do not vary over time.

[8]The output variables are chain-weighted real per capita GDP (rgdpch) and real GDP per worker (rgdpwok).

[9]The calculated growth rates are nearly identical for a simple linear regression on time over the sample period.

TABLE 1
Descriptive Statistics

	N = 52	Mean	S.D.	Max	Min
α		0.185	0.071	0.380	0.030
β		0.654	0.088	0.790	0.450
γ		0.161	0.090	0.470	0.060
g_e	(1973–2007)	0.017	0.010	0.042	0.003
	(1990–2007)	0.012	0.007	0.032	0.001
n	(1973–2007)	0.016	0.012	0.071	0.002
	(1990–2007)	0.013	0.008	0.034	–0.001
g_y	rgdpch				
	(1973–2007)	0.019	0.014	0.055	–0.008
	(1990–2007)	0.019	0.015	0.056	–0.023
	rgdpwok				
	(1973–2007)	0.012	0.014	0.043	–0.015
	(1990–2007)	0.013	0.015	0.038	–0.023

Note: The output variables are chain-weighted real per capita GDP (rgdpch) and real GDP per worker (rgdpwok).

TABLE 2
Variable Correlations

	α	β	γ	g_e ('70)	g_e ('90)	n ('73)	n ('90)	rgdpch ('73)	rgdpwok ('73)	rgdpch ('90)	rgdpwok ('90)
α	1	**–0.37**	**–0.43**	–0.09	–0.09	–0.16	–0.11	0.41	0.39	0.23	0.28
β		1	**–0.69**	–0.30	–0.16	–0.24	–0.45	0.03	0.11	0.13	0.28
γ			1	0.36	0.22	0.36	0.52	–0.35	–0.41	–0.30	–0.48
g_e ('70)				1	**0.84**	0.35	0.54	–0.13	–0.15	–0.27	–0.39
g_e ('90)					1	0.29	0.42	–0.18	–0.20	–0.24	–0.32
n ('73)						1	**0.61**	–0.19	–0.22	–0.22	–0.28
n ('90)							1	–0.32	–0.34	–0.37	–0.47
rgdpch ('73)								1	**0.96**	**0.79**	**0.77**
rgdpwok ('73)									1	**0.70**	**0.76**
rgdpch ('90)										1	**0.92**
rgdpwok ('90)											1

Note: Correlations among factor shares and between alternative measures of education, population, and output growth are bolded.

and Lee (2013).[10] Since this data is available at five-year intervals, with the most complete data (not requiring estimation) only every decade, I use the difference between the natural log of average education in 2010 and 1970 for the 35-year regression and beginning in 1990 for the 18-year regression.

Descriptive statistics for all variables are shown in Table 1, with the correlations between variables shown in Table 2. It is clear from these tables that the empirical growth rates of output per capita vary substantially, ranging from –2.3 percent up to +5.6 percent, and alternative measures are highly correlated with each other. It is also worth pointing out that by construction α, β, and γ sum to one, so that the variables $\beta/1 - \alpha$ and $\gamma/1 - \alpha$ used in the regression also sum to 1.

[10]Although this age grouping will include many non-workers in some countries, the results presented below are almost identical to those using population over the age of 25.

TABLE 3

Regressions Results

	1973–2007		1990–2007	
	rgdpch	rgdpwok	rgdpch	rgdpwok
g_{AK}	0.045**	0.041*	0.029	0.028
	(0.020)	(0.021)	(0.019)	(0.019)
g_{AH}	0.011	0.008	0.012*	0.014**
	(0.007)	(0.007)	(0.007)	(0.007)
g_{AN}	0.017	–0.005	0.097***	0.052*
	(0.026)	(0.026)	(0.031)	(0.028)
b_1	–1.245	–0.866	–4.984***	–4.118***
	(0.894)	(0.867)	(1.276)	(1.070)
b_2	0.051	0.026	–0.139	–0.277
	(0.255)	(0.261)	(0.335)	(0.287)
R^2	0.242	0.250	0.354	0.431
$Adj - R^2$	0.178	0.186	0.299	0.382
$F(4, 47)$	3.75	3.91	6.45	8.89
N	52	52	52	52

Notes: Heteroskedasticity-robust standard errors are in parentheses.

***Significant at the 1% level; **at the 5% level; *at the 10% level.

These variables do not represent independent information; rather, they indicate how the $1 - \alpha$ share of income is split between human and natural capital.

3.3. *Results and Discussion*

The estimation results of equation (2) are presented in Table 3. The columns indicate the different measures of output, using per capita and per worker constant-price GDP (adjusted for purchasing power parity). For the 35-year growth estimates, the estimated growth rates on technology are relatively intuitive. The parameter representing (physical) capital-augmenting technology growth is the largest and most significant with more than 4 percent annual growth. Labor-augmenting technology is barely insignificant in the first regression, with roughly 1 percent growth for both. Land-augmenting technology is insignificant and switches signs between regressions. Although the estimate is not significant, it is also worth noting that the theoretical prediction of $b_1 = -1$ is quite close to the actual estimates produced.

Further statistical support for the model is provided by F-tests of the following restrictions on the parameters: (1) restricting the three growth parameters to zero; (2) restricting g_{AK} to zero and the other growth parameters to be identical (essentially replacing the growth parameters with an intercept term); and (3) restricting all regressors to zero except for an intercept. In almost all cases, we reject the restrictions at the 5 percent level, providing evidence that the variables suggested by the model have a joint impact on long-run growth rates.[11] In terms of

[11]The only exception is replacing the growth parameters with an intercept for the rgdpwok 1990–2007 output measure (p = 0.136).

goodness-of-fit, the estimates explain roughly a quarter of the variation in per capita GDP growth rates across countries. This last point stands in stark contrast to the conventional Solow model's implication that long-run growth rates should be nearly identical, which by definition would imply an R^2 of zero.

The goodness-of-fit and statistical significance of the individual estimates both increase if we look at the shorter time span beginning in 1990. Labor-augmenting technology again grows at roughly 1 percent, while capital-augmenting technology is nearly 3 percent. However, using this data the growth rate of land-augmenting technology is between 5 and 10 percent, which is markedly higher than the results from the longer time span. The coefficient on population growth, b_1, is also far larger than the theory would suggest, with values around –4 and −5 (and highly statistically significant). This closer relationship between population growth and output growth over the shorter time-frame is likely the main source of the improved goodness-of-fit, and may suggest an out-of-steady-state relationship in this sample which had little effect on the 35-year growth rates.

While b_2 is not close to the value suggested by the theory, this implication is dependent on the assumption that education enters human capital linearly, which Krueger and Lindahl (2001) and Trostel (2004) suggest may not be an accurate representation of the contribution of education to output. Hall and Jones (1999) use $H(t) = exp\{\varphi(e(t))\}L(t)$, where $\varphi(e(t))$ is a piecewise linear function. This implies the following modified version of the regression:

$$g_{yi} = g_{AK}\frac{\alpha_i}{1-\alpha_i} + g_{AH}\frac{\beta_i}{1-\alpha_i} + g_{AN}\frac{\gamma_i}{1-\alpha_i} - b_1\frac{n_i\gamma_i}{1-\alpha_i} + b_2\frac{g_{ei}\beta_i}{1-\alpha_i}e_i\varphi_i' + \varepsilon_i, \tag{3}$$

where e_i is the level of education and φ_i' is the return to education. I use the rates of return to education from Psacharopoulos and Patrinos (2004).[12] I re-estimate using this equation, with results presented in Table 4. The results are quite similar to the previous estimates, with only the b_2 parameter changing substantially.

A further check allows for an even more general human capital term, $H(t) = h(e(t))L(t)$, which implies the regression as follows:

$$g_{yi} = g_{AK}\frac{\alpha_i}{1-\alpha_i} + g_{AH}\frac{\beta_i}{1-\alpha_i} + g_{AN}\frac{\gamma_i}{1-\alpha_i} - b_1\frac{n_i\gamma_i}{1-\alpha_i} + f(e_i)\frac{g_{ei}\beta_i}{1-\alpha_i}e_i + \varepsilon_i, \tag{4}$$

where $f(e_i) = b_2h'(e(t))/h(e(t))$, which may be highly non-linear. However, estimates of g_{AK}, g_{AH}, g_{AN}, and b_1 can still be found by multiplying the regression through by $(1 - \alpha_i)/g_{ei}\beta_ie_i$ and using semi-parametric estimation to factor out the function $f(e_i)$. The results of this estimation are presented in Table 5.[13] The estimates of g_{AH} are now closer to zero, but are otherwise broadly similar to the previous results.

[12] I use the average level of education and the average return to education over the sample period. The results do not substantially change if I use the initial level of education and initial return to education.

[13] For non-parametric estimation I use the locally weighted scatterplot smoothing (lowess) estimator with a tricube weighting function and a bandwidth of 0.8.

TABLE 4

Regressions Results (Piecewise Linear Returns to Education)

	1973–2007		1990–2007	
	rgdpch	rgdpwok	rgdpch	rgdpwok
g_{AK}	0.042**	0.039*	0.027	0.029
	(0.020)	(0.020)	(0.020)	(0.020)
g_{AH}	0.008	0.006	0.008	0.011
	(0.007)	(0.007)	(0.008)	(0.007)
g_{AN}	0.017	–0.005	0.098***	0.054*
	(0.028)	(0.027)	(0.031)	(0.028)
b_1	–1.423	–0.997	–5.225***	–4.363***
	(0.936)	(0.879)	(1.295)	(1.112)
b_2	0.569	0.383	0.379	–0.073
	(0.532)	(0.574)	(0.516)	(0.537)
R^2	0.259	0.257	0.357	0.420
$Adj - R^2$	0.196	0.194	0.303	0.371
$F(4, 47)$	4.10	4.08	6.53	8.51
N	52	52	52	52

Notes: Heteroskedasticity-robust standard errors are in parentheses.

***Significant at the 1% level; **at the 5% level; *at the 10% level.

TABLE 5

Regressions Results (Non-Linear Returns to Education)

	1973–2007		1990–2007	
	rgdpch	rgdpwok	rgdpch	rgdpwok
g_{AK}	0.044**	0.042**	–0.010	0.009
	(0.022)	(0.021)	(0.027)	(0.024)
g_{AH}	–0.003	–0.006	0.003	–0.001
	(0.007)	(0.006)	(0.007)	(0.007)
g_{AN}	0.024	0.009	0.100***	0.062***
	(0.021)	(0.018)	(0.027)	(0.023)
b_1	–0.973	–0.941	–4.202***	–3.366***
	(0.800)	(0.641)	(1.004)	(0.820)
R^2	0.226	0.192	0.404	0.422
$Adj - R^2$	0.160	0.124	0.354	0.372
$F(4, 47)$	3.42	2.80	7.98	8.56
N	52	52	52	52

Notes: Heteroskedasticity-robust standard errors are in parentheses. Non-parametric estimation uses the locally weighted scatterplot smoothing (lowess) estimator with a tricube weighting function and a bandwidth of 0.8.

***Significant at the 1% level; **at the 5% level; *at the 10% level.

These results may suggest the combined importance of both allowing factor income shares to differ across countries and allowing the production function to have decreasing returns to scale in physical and human capital, but the interpretation of such a simple illustration must be tentative. A plausible alternative might be that capital-augmenting technology (which might be capturing quality improvements in capital goods) diffuses slowly across borders compared to either labor- or land-augmenting technology, leading to a higher degree of variation. For example, insect-resistant crops may only provide benefits in the specific land and climate where they are developed. Overall, the goodness-of-fit, plausibility of estimated growth rates, and near-unity of b_1 in the 35-year growth rate regressions should be viewed as suggestive of the importance of simplifying assumptions for applied theory.[14]

4. Conclusion

This paper points out that the neoclassical implication that all countries grow at the same rate, an implication starkly at odds with the evidence of Grier and Grier (2007), is related to the assumptions of common cross-country factor income shares and CRS in physical and human capital. Researchers conducting cross-country growth comparisons should be particularly careful about using these assumptions. Although the empirical evidence for this particular model is modest, it is methodologically important if we wish to link empirical studies to economic theory.

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[14]An additional point on interpretation is that the regressions only include those variables which the theoretical model suggests are important. These results would not be meaningful outside the context of the model presented, since a model suggesting additional variables would likely imply an omitted variable bias in the results presented here.

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