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Is Growth Exogenous? Taking Mankiw, Romer, and Weil Seriously

1. *Introduction*

"This paper takes Robert Solow seriously." Thus begins one of the most influential and widely cited pieces in the empirical growth literature, a 1992 article by N. Gregory Mankiw, David Romer, and David Weil. In brief, Mankiw, Romer, and Weil (1992), henceforth MRW, performed an empirical evaluation of a "textbook" Solow (1956) growth model using the Penn World Tables, a multicountry data set constructed by Summers and Heston (1988) for the years 1960–1985. MRW found support for the Solow model's predictions that, in the long-run steady state, the level of real output per worker by country should be positively correlated with the saving rate and negatively correlated with the rate of labor-force growth. However, their estimates of the textbook Solow model also implied a capital share of factor income of about 0.60, high compared to the conventional value (based on U.S. data) of about one-third.

To address this possible inconsistency, MRW considered an *augmented* version of the Solow model, in which human capital enters as a factor of production in symmetrical fashion with physical capital and raw labor. They found that the augmented Solow model fits the data better and yields an estimated capital share more in line with conventional wisdom. They concluded (abstract, p. 407) that "an augmented Solow model that includes accumulation of human as well as physical capital provides an

We thank Alan Heston and Robert Summers for providing us with preliminary data, Peter Bondarenko for expert research assistance, and the conference discussants, Robert Solow, and Princeton colleagues for useful comments. Bernanke gratefully acknowledges the support of the National Science Foundation, and Gürkaynak the support of an SSRC Program in Applied Economics Fellowship.

excellent description of the cross-country data." Numerous authors have since used the MRW framework to study the significance of additional factors to growth (see Durlauf and Quah, 1999, for references). Islam (1995) and others have extended the MRW analysis to panel data.

That MRW's augmented Solow model fits the cross-country data well is an interesting finding (and, as they point out, the results could have been otherwise). However, as we will discuss in some detail below, it is not entirely clear to what degree the good fit of the MRW specification may be attributed to elements that are common to many models of economic growth (such as the Cobb–Douglas production structure), and how much of the fit is due to elements that are specific to the Solow formulation (such as the exogeneity of steady-state growth rates). Indeed, as we will show, MRW's basic estimation framework is broadly consistent with *any* growth model that admits a balanced growth path—a category that includes virtually all the growth models in the literature.[1] Hence, one might argue that MRW do not actually test the Solow model, in the sense of distinguishing it from possible alternative models of economic growth.

On the other hand, the fact that the MRW framework is for the most part not specific to the Solow model is also a potential strength, as it implies that their approach can in principle be used to evaluate not only that model but other candidate growth models as well. Because the policy implications of the Solow model and other growth models (especially endogenous-growth models) differ markedly, assessing the empirical relevance of alternative models is an important task.

In this paper we modestly extend the empirical framework introduced by MRW and use it to reevaluate both the Solow model and some alternatives. In particular, we re-examine the crucial prediction of the Solow model, that long-run economic growth is determined solely by exogenous technical change and is independent of variables such as the aggregate saving rate, schooling rates, and the growth rate of the labor force. To anticipate our conclusion, we find strong statistical evidence against the basic Solow prediction. In particular, we find that a country's rate of investment in physical capital is strongly correlated with its long-run growth rate of output per worker, and that rates of human-capital accumulation and population growth are also correlated, though somewhat less strongly, with the rate of economic growth.

The rest of the paper is organized as follows. Section 2 reconsiders the MRW empirical framework. We show that the assumptions underlying

1. Durlauf and Quah (1999) derive a general framework that nests a variety of alternative growth models, including alternative versions of the Solow model.

their specification can be broken into two parts: those that apply to any growth model admitting a balanced growth path (BGP), and those that are specific to the Solow model. This discussion paves the way for subsequent reanalysis of both the Solow model and some simple alternatives.

The empirics of the Solow model, under the maintained assumption of steady states, are revisited in Section 3. We first replicate and extend the MRW results, using more recent data and a longer sample period. We find that both the textbook and augmented Solow models perform slightly less well with updated data, and that parameter restrictions of the model that MRW found to be consistent with the data are now typically rejected. However, we do not consider these results to be particularly informative about the applicability of the Solow model, particularly its strong implication that long-run growth is exogenous. Instead, we propose a more powerful test of the Solow model, based on its prediction that in the steady state national growth rates should be independent of variables such as the saving rate and the rate of human-capital formation. We find a strong rejection of the joint hypothesis that the Solow model is correct and that the economies in our sample are in steady states.

Section 4 uses our version of the MRW framework to consider some simple alternative growth models: the Uzawa (1965)–Lucas (1988) two-sector model with human-capital formation, and the so-called *AK* model. Both models have some explanatory power, in the sense that rates of human-capital formation (Uzawa–Lucas) and of physical-capital accumulation (*AK*) both appear to be strongly related to output growth in the long run. However, neither model is a complete description of the cross-country data; in particular, the overidentifying restrictions imposed by each model are decisively rejected.

All the analysis through Section 4 is based on the assumption that the economies in the sample are on balanced growth paths. If all or some of the economies were in fact in transition to a balanced growth path during the sample period, our tests are invalid. MRW study the issue of non-steady-state behavior by estimating rates of convergence and relating these to the parameters of the model. We take a more direct approach: According to the Solow model, total factor productivity (TFP) growth rates should be independent of behavioral variables such as the saving rate, whether the economy is in a steady state or not. In Section 5 we construct estimates of factor shares for more than 50 countries, which allow us to infer long-run TFP growth rates. We also consider TFP growth rates for the full sample, based on a plausible assumption about factor shares. Finally, in Section 6, we verify that long-run TFP growth rates are not statistically independent of national rates of saving and other behavioral variables. We do not here take a strong position on the direction of causation between TFP growth and other country characteristics, as either suggests that a richer model than the Solow model is needed to explain long-run growth.

2. *A Generalized Mankiw–Romer–Weil Framework*

MRW provide an appealing framework for comparing the implications of the Solow model with the cross-country data. In this section we show that their framework is potentially even more fruitful than they claim, in that it can be used to evaluate essentially any growth model that admits a BGP. Indeed, as we will show, the MRW framework can be thought of as consisting of two parts: a general structure that is applicable to any model admitting a BGP, and a set of restrictions imposed on this structure by the specific growth model (such as the Solow model) being studied. Here we develop the point in some generality; in subsequent sections we apply the generalized MRW approach to study both the Solow model and some alternative models of economic growth.

Assume that in a given country at time t, the output Y_t depends on inputs of raw labor L_t and three types of accumulated factors: K_t, H_t, and Z_t. The factors K_t and H_t are accumulated through the sacrifice of current output (think of physical capital and human capital, or structures and equipment). The factor Z_t, which could be an index of technology, or of human capital acquired through learning-by-doing, is assumed to be accumulated as a byproduct of economic activity and does not require the sacrifice of current output.

The four factors of production combine to produce output according to the following standard, constant-returns-to-scale Cobb–Douglas form (note that Z_t multiplies raw labor L_t and thus may also be thought of as an index of labor productivity):

$$Y_t = K_t^{\alpha} H_t^{\beta} (Z_t L_t)^{1-\alpha-\beta}. \tag{2.1}$$

Output may either be consumed or transformed into K-type or H-type capital:

$$Y_t = C_t + \dot{K}_t + \delta_K K_t + \dot{H}_t + \delta_H H_t, \tag{2.2}$$

where C_t is consumption and the overdot indicates a time derivative. K-type and H-type capital depreciate at rates δ_K and δ_H respectively. Z-type capital does not use up output, but is accumulated according to some yet unspecified relationship that links changes in Z to the current state of the economy:

$$\dot{Z}_t = z(Z_t, K_t, \dot{K}_t, H_t, \dot{H}_t, L_t, \dot{L}_t). \tag{2.3}$$

Behavioral or technological parameters (such as the parameter that links the rate of learning-by-doing to the level of production) may be implicit in $z(\cdot)$. Finally, the labor force grows at exogenous rate n:

$$L_t = L_0 e^{nt}. \tag{2.4}$$

We consider a BGP of this economy in which constant shares of output, denoted by s_K and s_H, respectively, are devoted to gross investment in the two capital goods. For now we take these shares to be strictly exogenous. This assumption is harmless for the analysis of the Solow model, which also assumes exogenous saving rates. We examine the case of endogenous saving rates at various points below.

Using lowercase letters to denote per-worker quantities, e.g., $y_t = Y_t/L_t$, we can rewrite the production function and the capital accumulation equations in a standard way as

$$y_t = Z_t^{1-\alpha-\beta} k_t^{\alpha} h_t^{\beta}, \tag{2.5}$$

$$\dot{k}_t = s_K y_t - (\delta_K + n)k_t, \tag{2.6}$$

$$\dot{h}_t = s_H y_t - (\delta_H + n)h_t. \tag{2.7}$$

The growth rates of k and h, which are constant along the BGP, are given by

$$g_k \equiv \dot{k}_t / k_t = s_K Z_t^{1-\alpha-\beta} k_t^{\alpha-1} h_t^{\beta} - (\delta_K + n), \tag{2.8}$$

$$g_h \equiv \dot{h}_t / h_t = s_H Z_t^{1-\alpha-\beta} k_t^{\alpha} h_t^{\beta-1} - (\delta_H + n). \tag{2.9}$$

The growth rate of output per worker is

$$g_y \equiv \dot{y}_t / y_t = (1 - \alpha - \beta) g_Z + \alpha g_k + \beta g_h, \tag{2.10}$$

where $g_Z = \dot{Z}_t / Z_t$.

The first term on the right-hand side of the expression for g_k, equation (2.8), equals $s_K Y_t / K_t$. Since both g_k and $\delta_K + n$ are constant along the BGP, Y_t / K_t must also be constant. Hence Y and K grow at the same rate on the BGP (cf. Barro and Sala-i-Martin, 1999, p. 54). By similar argument, the expression for g_h, equation (2.9), implies that Y and H grow at the same rate. Hence, Y, K, and H share a common growth rate, call it $g = g_K = g_H = g_Y$. Finally, from the expression for g_y, equation (2.10), we see that Z must also grow at the same constant rate, or $g_Z = g$. The requirement that Z grow at a constant rate on the BGP rules out scale effects in the determination of Z; hence the equation for Z reduces to

$$\dot{Z}_t/Z_t = g(s_K, s_H, n, Z_0, K_0, H_0, L_0). \tag{2.11}$$

We can now solve explicitly for the BGP of output per worker. Using the equations for g_k and g_h above, and the fact that these two quantities are equal in the steady state, we find

$$\frac{h_t}{k_t} = \frac{s_H\,(n + g + \delta_K)}{s_K\,(n + g + \delta_H)} \equiv \omega. \tag{2.12}$$

To simplify the algebra a bit, and for comparability with MRW, suppose that $\delta_K = \delta_H = \delta$, so that $\omega = s_H/s_K$. Solving (2.8) and (2.9) to find the BGP values of k_t and h_t (call them k_t^* and h_t^*), we get

$$k_t^* = Z_t\left(\frac{s_K^{1-\beta}\,s_H^{\beta}}{n + g + \delta}\right)^{1/(1-\alpha-\beta)}, \tag{2.13}$$

$$h_t^* = Z_t\left(\frac{s_H^{1-\alpha}\,s_K^{\alpha}}{n + g + \delta}\right)^{1/(1-\alpha-\beta)}. \tag{2.14}$$

The output per worker along the BGP, y_t^*, is given (in logs) by

$$\ln y_t^* = \ln Z_t + \frac{\alpha}{1-\alpha-\beta}\ln s_K$$

$$+ \frac{\beta}{1-\alpha-\beta}\ln s_H - \frac{\alpha+\beta}{1-\alpha-\beta}\ln(n + g + \delta). \tag{2.15}$$

Further, the t-period difference in output per worker along the BGP is

$$\ln y_t^* - \ln y_0^* = \ln Z_t - \ln Z_0 = tg(s_K, s_H, n, Z_0, K_0, H_0, L_0). \tag{2.16}$$

To this point we have considered the BGP of a single country. Suppose now that we have a panel of countries, indexed by i. Further, suppose that $\ln Z_{it} = \bar{z}_t + \varepsilon_{it}$[2], and that $\ln y_{it} = \ln y^*_{it} + \eta_{it}$, where η_{it} is stationary and represents cyclical deviations of output from the BGP. Then equations (2.15) and (2.16) may be written in estimation form as

$$\ln y_{it} = \bar{z}_t + \frac{\alpha_i}{1-\alpha_i-\beta_i}\ln s_{Ki} + \frac{\beta_i}{1-\alpha_i-\beta_i}\ln s_{Hi} - \frac{\alpha_i+\beta_i}{1-\alpha_i-\beta_i}\ln(n_i + g_i + \delta) + \varepsilon_{it} + \eta_{it}, \quad (2.17)$$

$$\ln y_{it} - \ln y_{i0} = \ln Z_{it} - \ln Z_{i0} = tg(s_{Ki}, s_{Hi}, n_i, Z_{i0}, K_{i0}, H_{i0}, L_{i0}) + \eta_{it} - \eta_{i0}. \quad (2.18)$$

As we have stressed, our analysis thus far assumes *only* that the economy is in a BGP and does not rule out endogenous determination of TFP (identified here with Z_t). To go from this generalized MRW framework to a specific growth model, additional restrictions are required. For example, in their estimation of the augmented Solow model, MRW specialize further by assuming that α_i, β_i, and (most importantly) g_i are the same for all countries, and that actual output equals BGP output ($\eta_{it} = 0$). [MRW do not write down (2.18) explicitly, but it is implicit in their calculations, as they use average output growth to determine the value of the common growth rate g.] Their estimation of the textbook Solow model further assumes that $\beta = 0$, that is, human capital H does not enter as a separate factor of production. In Section 4 we show how this framework can accommodate other models of economic growth. First, though, we revisit the MRW estimates, using updated data.

3. *Replication and Extension of the MRW Results*

The original MRW article used cross-national data for the period 1960–1985. In this section we replicate the MRW results for 1960–1985 and extend them through 1995. We find that MRW's conclusions about the fit of the textbook Solow model and the augmented Solow model seem slightly weaker when we use revised and/or extended data, though their main results survive. We also propose a new test of the Solow model based on joint estimation of equations in the form of (2.17) and (2.18).

2. MRW assume (in our notation) that $\ln Z_{i0} = \bar{z}_0 + \varepsilon_{i0}$. Their assumption implies that $\bar{z}_t = \bar{z}_0 + \bar{g}t$ and $\varepsilon_{it} = \varepsilon_{i0} + (g_t - \bar{g})t$, where $\bar{g}$ is the mean country growth rate. Under the MRW assumption that $g_i = \bar{g}$, we have simply $\varepsilon_{it} = \varepsilon_{i0}$. We discuss the implications of this error structure further below.

Following MRW we draw our basic data from the Summers–Heston Penn World Tables (PWT), which contain information on real output, investment, and population (among many other variables) for a large number of countries. The data set used in the original MRW study was PWT version 4.0. The PWT data have been revised twice since publication of the MRW article; as of this writing, PWT version 5.6 (which extends coverage of most variables through 1992) is the latest publicly available version. Alan Heston and Robert Summers have also kindly supplied us with a preliminary version of PWT version 6.0, which extends the data through 1998 for most variables.[3] In what follows we compare results using all three PWT data sets (4.0, 5.6, and preliminary 6.0).

MRW measure n as the average growth of the working-age population (ages 15 to 64). They obtained these data from the World Bank's *World Tables* and the 1988 *World Development Report.* We use the original MRW data on working-age population in conjunction with the PWT 4.0 data set. For analyses using PWT 5.6 and PWT 6.0, we use analogous data taken from the World Bank's *World Development Indicators 2000* CD-ROM.

The saving rate relevant to physical capital, s_K, is measured as the average share of gross investment in GDP, as in MRW. In open economies, of course, investment and saving need not be equal. However, if the capacity of countries to borrow abroad is limited (for reasons well known from the literature on sovereign debt), MRW's identification of the ratio of investment to GDP with s_K seems defensible, even though technically investment is not fully financed by domestic saving. Reconciling closed-economy growth models with the existence of international capital flows is a general problem in this literature, and we do not have much to add on the issue here.[4]

MRW's estimates of the augmented Solow model (with human-capital accumulation) include a variable they call SCHOOL, analogous to our s_H, which is the average percentage of a country's working-age population in secondary school. More specifically, MRW define SCHOOL as the percentage of school-age population (12–17) attending secondary school times the percentage of the working-age population that is of secondary-school age (15–19). The age ranges in the two components of SCHOOL are incommensurate, but we are inclined to agree with MRW that the imperfect matchup is not likely to create major biases, and we use the same construct. Data on enrollment rates and on working-age popula-

3. Of course, Heston and Summers are not responsible for results obtained using these preliminary data.

4. For an open-economy extension of the augmented Solow model of MRW, see Barro, Mankiw, and Sala-i-Martin (1995).

tion and its components are from the sources noted two paragraphs above and from the UN *World Population Prospects.*

With these data we perform the following exercises. First, we replicate the MRW results for the textbook Solow model for their sample period, 1960–1985, for each of their three country samples and using all three vintages of the PWT data. Next, we use the data sets PWT 5.6 and PWT 6.0 to repeat the estimation for the periods 1960–1990 and 1960–1995, respectively. Finally, we repeat these exercises for MRW's augmented Solow model.

The replication of MRW's results for the textbook Solow model and for their 1960–1985 sample period are contained in Table 1 (compare MRW's Table I, p. 414 of their article). As in MRW, the three country samples we examine are (1) the *non-oil* sample, the set of all countries for which complete data are available, excluding oil producers (98 countries); (2) the *intermediate* sample, which is the non-oil sample excluding countries whose data receive a grade of D from Summers and Heston or whose population is less than one million (75 countries)[5]; and (3) the *OECD* sample, OECD countries with populations greater than one million (22 countries).[6] Note that, because of missing data, the sample sizes are in some cases slightly smaller than PWT 5.6 and PWT 6.0 are used for the replication.

When we repeat the MRW estimations using PWT 4.0 (see the three leftmost columns of Table 1), our results are essentially identical to theirs, as expected. In particular, in the restricted regression (which imposes cross-parameter restrictions on the regression coefficients) we find an $\bar{R}^2$ of 0.59 for both the non-oil and intermediate samples, suggesting that the model explains a significant part of the variation in real output per worker among these countries. For the OECD sample, the $\bar{R}^2$ is a much more modest 0.06, as in MRW. The single restriction imposed by the model is not rejected in any of the three samples. The primary shortcoming of the results, as identified by MRW, is that the estimated capital share α is about 0.60 in both the non-oil and intermediate samples, a value that seems too high. The estimated α for the OECD sample is a more reasonable 0.36.

We also obtained estimates for the MRW sample period, 1960–1985, using revised PWT data (see Table 1). The results are again similar to those found by MRW, with two exceptions worth noting: First, when the revised data are used, the overidentifying restriction of the model is rejected for the non-OECD country samples (the p-values are 0.02 and

5. More recent versions of the PWT data no longer include these grades.

6. Our OECD sample coincides with that of MRW throughout, that is, we do not include countries joining since 1990.

Table 1 ESTIMATION OF THE TEXTBOOK SOLOW MODEL FOR THREE ALTERNATIVE VINTAGES OF THE PWT DATASET[a]

	Value (Standard Error)								
	PWT 4.0			PWT 5.6			PWT 6.0		
Parameter	*Non-Oil*	*Intermediate*	*OECD*	*Non-Oil*	*Intermediate*	*OECD*	*Non-Oil*	*Intermediate*	*OECD*
No. of observations	98	75	22	96	75	22	90	72	21
Constant	5.62 (1.56)	5.47 (1.52)	7.99 (2.46)	4.44 (1.35)	4.74 (1.39)	8.66 (2.49)	5.06 (1.35)	5.23 (1.46)	9.10 (2.48)
$\ln(I/GDP)$	1.43 (0.14)	1.32 (0.17)	0.50 (0.43)	0.97 (0.09)	1.02 (0.13)	0.61 (0.53)	0.88 (0.09)	0.93 (0.14)	0.36 (0.37)
$\ln(n + g + \delta)$	−1.92 (0.55)	−1.97 (0.53)	−0.75 (0.83)	−2.25 (0.49)	−2.19 (0.49)	−0.66 (0.82)	−2.14 (0.49)	−2.13 (0.51)	−0.53 (0.79)
$\bar{R}^2$	0.59	0.59	0.02	0.64	0.62	0.00	0.62	0.56	0.01

Restricted Regression									
Constant	6.87	7.10	8.61	7.74	7.71	8.76	8.31	8.25	9.52
	(0.12)	(0.15)	(0.53)	(0.08)	(0.11)	(0.60)	(0.08)	(0.12)	(0.37)
$\ln(I/GDP) -$	1.49	1.43	0.56	1.07	1.16	0.63	0.98	1.09	0.40
$\ln(n + g + \delta)$	(0.12)	(0.14)	(0.36)	(0.08)	(0.11)	(0.41)	(0.09)	(0.12)	(0.26)
$\bar{R}^2$	0.59	0.59	0.06	0.63	0.60	0.06	0.60	0.54	0.06
Test of Restriction									
p-Value	0.42	0.29	0.80	0.02	0.04	0.97	0.02	0.04	0.86
Implied α	0.60	0.59	0.36	0.52	0.54	0.39	0.49	0.52	0.29
	(0.02)	(0.02)	(0.15)	(0.02)	(0.02)	(0.15)	(0.02)	(0.03)	(0.14)

[a] Dependent variable: log (GDP per working-age person) in 1985. Standard errors are reported immediately below parameter estimates. The investment and population growth rates are averaged over the period 1960–1985. $g + \delta$ is assumed to be 0.05.

Table 2 ESTIMATION OF THE TEXTBOOK SOLOW MODEL FOR MORE RECENT SAMPLE PERIODS[a]

	Value (Standard Error)					
	1960–1990 (PWT 5.6)			*1960–1995 (PWT 6.0)*		
Parameter	*Non-oil*	*Intermediate*	*OECD*	*Non-oil*	*Intermediate*	*OECD*
No. of observations	85	70	22	90	72	21
Constant	3.59 (1.37)	3.62 (1.36)	7.96 (2.20)	4.16 (1.38)	4.58 (1.44)	7.79 (2.37)
ln(*I*/GDP)	0.94 (0.10)	0.95 (0.13)	0.65 (0.47)	1.07 (0.10)	1.11 (0.14)	0.38 (0.37)
$\ln(n + g + \delta)$	−2.59 (0.49)	−2.60 (0.47)	−0.97 (0.73)	−2.66 (0.49)	−2.54 (0.50)	−1.07 (0.75)
$\bar{R}^2$	0.67	0.66	0.09	0.68	0.65	0.12
Restricted Regression						
Constant	7.84 (0.09)	7.79 (0.12)	8.72 (0.55)	8.24 (0.08)	8.19 (0.12)	9.48 (0.37)
ln(*I*/GDP– $\ln(n + g + \delta)$	1.09 (0.09)	1.19 (0.11)	0.74 (0.37)	1.22 (0.09)	1.32 (0.12)	0.57 (0.27)
$\bar{R}^2$	0.63	0.62	0.13	0.66	0.63	0.14
Test of Restriction						
p-Value	0.00	0.00	0.72	0.00	0.01	0.48
Implied α	0.52 (0.02)	0.54 (0.02)	0.43 (0.12)	0.55 (0.02)	0.57 (0.02)	0.36 (0.11)

[a]Dependent variable: log (GDP per working-age person) in 1990 (PWT 5.6) and 1995 (PWT 6.0). Standard errors are reported immediately below parameter estimates. The investment and population growth rates are averaged over the periods 1960–1990 or 1960–1995, depending on the sample. $g + \delta$ is assumed to be 0.05.

0.04 respectively for both the PWT 5.6 data and the PWT 6.0 data). This rejection contrasts with MRW's original finding for the same sample period. Second, we find somewhat lower estimates of the capital share, closer to 0.5 than 0.6.

As MRW's results go only through 1985, it is interesting to see whether their findings hold for updated data. Table 2 shows the results of estimating the MRW specification using more recent data and hence longer sample periods. The leftmost three columns of the table show estimates for the 1960–1990 sample period (using PWT 5.6), and the rightmost three columns show the results for 1960–1995 (using PWT 6.0). The end dates were chosen to minimize the effect of missing data at the end of the sample. Qualitatively the results are similar to those in Table 1; indeed, relative to the results for 1960–1985, $\bar{R}^2$ is somewhat higher for both sample periods and each group of countries. However, the overidentifying restriction proposed by MRW is now strongly rejected outside the OECD (the p-values for the non-oil and intermediate samples are respectively 0.00 and 0.00 for 1960–1990, and 0.00 and 0.01 for 1960–1995). The estimated capital shares remain between 0.5 and 0.6 for the large samples, and they rise to about 0.4 for the OECD sample.

As we have noted, the high estimated values of the capital share obtained by MRW for the textbook Solow model led them to consider a variant of the Solow model in which human capital as well as physical capital is accumulated. In terms of our exposition of Section 2, this model allows for a nonzero coefficient β on the second form of accumulated capital, while retaining the assumption that technology growth rates are the same for all countries. We also replicated and extended this set of MRW estimates. Our estimates of the augmented Solow model for the 1960–1985 sample period are reported in Table 3, and Table 4 gives the estimates for the 1960–1990 and 1960–1995 sample periods.

As MRW found, the performance of the augmented Solow model, with human capital, is generally better than that of the textbook version. The augmented model explains considerably more of the cross-country variation in output per worker; for example, for the 1960–1995 sample (using PWT 6.0), $\bar{R}^2$ equals 0.75 for the large non-oil sample, 0.77 for the intermediate sample, and 0.45 for the OECD sample. The coefficient on human capital, β, takes on reasonable values (generally between 0.3 and 0.4), and the estimates of the coefficient on physical capital, α, are correspondingly reduced. There are also some problems, however. First, the overidentifying restriction on the ordinary least-squares (OLS) coefficients is rejected at the 1% level for the broadest sample for the 1960–1990 and 1960–1995 sample periods, and at the 5% level for the 1960–1985 sample using the most recent vintage of the data (PWT 6.0). Second, the estimated capital share α is now unreasonably low in some cases: For 1960–1985, α is estimated to be 0.00 for the OECD sample when PWT 5.6 is used, and -0.03 when PWT 6.0 is used. For 1960–1990 and 1960–1995 respectively, the OECD capital share is estimated to be 0.09 and 0.04.

Table 3. ESTIMATION OF THE AUGMENTED SOLOW MODEL FOR THREE ALTERNATIVE VINTAGES OF THE PWT DATA[a]

	Value (Standard Error)								
	PWT 4.0			PWT 5.6			PWT 6.0		
Parameter	*Non-Oil*	*Intermediate*	*OECD*	*Non-Oil*	*Intermediate*	*OECD*	*Non-Oil*	*Intermediate*	*OECD*
No. of observations	98	75	22	96	75	22	90	72	21
Constant	6.98 (1.15)	7.87 (1.17)	8.67 (2.17)	6.80 (1.06)	7.94 (1.15)	10.84 (1.91)	6.71 (1.09)	8.38 (1.12)	10.29 (1.93)
$\ln(I/GDP)$	0.70 (0.13)	0.71 (0.15)	0.28 (0.39)	0.45 (0.09)	0.51 (0.12)	0.19 (0.41)	0.42 (0.10)	0.51 (0.11)	−0.01 (0.30)
$\ln(n + g + \delta)$	−1.71 (0.41)	−1.48 (0.40)	−1.06 (0.74)	−1.69 (0.38)	−1.43 (0.39)	−0.67 (0.60)	−1.82 (0.39)	−1.42 (0.38)	−0.78 (0.61)
ln SCHOOL	0.66 (0.07)	0.73 (0.10)	0.75 (0.29)	0.61 (0.07)	0.72 (0.10)	1.17 (0.28)	0.56 (0.08)	0.71 (0.09)	1.01 (0.27)
$\bar{R}^2$	0.78	0.77	0.24	0.80	0.78	0.46	0.76	0.77	0.42

Restricted Regression									
Constant	7.86 (0.14)	7.97 (0.15)	8.71 (0.47)	8.45 (0.10)	8.44 (0.13)	9.20 (0.47)	8.91 (0.10)	8.89 (0.11)	9.73 (0.29)
$\ln(I/GDP) - \ln(n+g+\delta)$	0.74 (0.12)	0.71 (0.14)	0.29 (0.33)	0.48 (0.09)	0.52 (0.12)	0.00 (0.34)	0.46 (0.10)	0.53 (0.11)	−0.06 (0.24)
$\ln(SCHOOL) - \ln(n+g+\delta)$	0.66 (0.07)	0.73 (0.09)	0.76 (0.28)	0.63 (0.07)	0.73 (0.09)	1.11 (0.28)	0.58 (0.08)	0.72 (0.08)	1.00 (0.26)
$\bar{R}^2$	0.78	0.77	0.28	0.79	0.78	0.47	0.75	0.77	0.45
Test of Restriction									
p-Value	0.45	0.93	0.98	0.12	0.66	0.39	0.05	0.65	0.77
Implied α	0.31 (0.04)	0.29 (0.05)	0.14 (0.15)	0.23 (0.04)	0.23 (0.05)	0.00 (0.16)	0.23 (0.04)	0.24 (0.04)	−0.03 (0.12)
Implied β	0.28 (0.03)	0.30 (0.04)	0.37 (0.12)	0.30 (0.03)	0.32 (0.04)	0.53 (0.13)	0.28 (0.04)	0.32 (0.04)	0.52 (0.11)

[a]Dependent variable: log (GDP per working-age person) in 1985. Standard errors are reported immediately below parameter estimates. The investment and population growth rates are averaged over the period 1960–1985. $g + \delta$ is assumed to be 0.05. SCHOOL is the average percentage of the working-age population in secondary school for the period 1960–1985.

Table 4 ESTIMATION OF THE AUGMENTED SOLOW MODEL FOR MORE RECENT SAMPLE PERIODS[a]

	Value (Standard Error)					
	1960–1990 (PWT 5.6)			*1960–1995 (PWT 6.0)*		
Parameter	*Non-Oil*	*Intermediate*	*OECD*	*Non-Oil*	*Intermediate*	*OECD*
No. of observations	85	70	22	90	72	21
Constant	5.42 (1.09)	6.50 (1.23)	10.03 (1.89)	5.81 (1.12)	7.92 (1.07)	9.48 (1.98)
$\ln(I/GDP)$	0.41 (0.10)	0.52 (0.13)	0.30 (0.39)	0.54 (0.11)	0.60 (0.12)	0.08 (0.31)
$\ln(n + g + \delta)$	−2.24 (0.38)	−1.97 (0.40)	−0.90 (0.59)	−2.35 (0.39)	−1.81 (0.36)	−1.19 (0.60)
ln SCHOOL	0.65 (0.09)	0.72 (0.13)	1.00 (0.30)	0.65 (0.09)	0.85 (0.10)	1.06 (0.32)
$\bar{R}^2$	0.80	0.77	0.40	0.80	0.83	0.43
Restricted Regression						
Constant	8.50 (0.11)	8.42 (0.13)	9.08 (0.46)	8.84 (0.10)	8.85 (0.10)	9.61 (0.30)
$\ln(I/GDP) - \ln(n + g + \delta)$	0.48 (0.11)	0.57 (0.13)	0.20 (0.34)	0.62 (0.11)	0.64 (0.11)	0.09 (0.25)
$\ln(\text{SCHOOL}) - \ln(n + g + \delta)$	0.69 (0.09)	0.79 (0.12)	0.96 (0.28)	0.68 (0.09)	0.88 (0.09)	1.06 (0.30)
$\bar{R}^2$	0.78	0.76	0.42	0.79	0.83	0.46
Test of Restriction						
p-Value	0.01	0.12	0.61	0.01	0.39	0.95
Implied α	0.22 (0.05)	0.24 (0.05)	0.09 (0.15)	0.27 (0.04)	0.25 (0.04)	0.04 (0.12)
Implied β	0.32 (0.04)	0.33 (0.05)	0.44 (0.12)	0.30 (0.04)	0.35 (0.04)	0.49 (0.11)

[a]Dependent variable: log (GDP per working-age person) in 1990 (PWT 5.6) and 1995 (PWT 6.0). Standard errors are reported immediately below parameter estimates. The investment and population growth rates are averaged over the periods 1960–1990 or 1960–1995, depending on the sample. $g + \delta$ is assumed to be 0.05. SCHOOL is the average percentage of the working-age population in secondary school for the relevant sample period.

3.1 A MORE POWERFUL TEST OF THE SOLOW MODEL

Based on the results so far, one might follow MRW and draw broadly positive conclusions about the fit of the Solow model, especially when augmented with human capital. Notably, a simple regression using only three variates (the saving rate, the schooling rate, and the population growth rate) seems to explain a remarkable share of cross-country variation in the level of output per worker. It is true that the estimates of the production-function coefficients are not always reasonable, and we have found that the overidentifying restriction implied by the Cobb–Douglas structure is often rejected, but problems with estimation of production relationships are not uncommon. Very possibly, these statistical rejections are not of great economic significance.

However, as our exposition in Section 2 suggests, the results shown so far do not constitute the strongest test of the Solow model within this framework. In our view, a better test of the Solow model involves testing the restrictions on the analogue of equation (2.18), the equation explaining long-run growth. In particular, if the hypothesis that the steady state of the Solow model describes the cross-sectional distribution of output per worker is true, then we should not be able to reject the hypothesis that factors such as the saving rate or the rate of human-capital accumulation do not enter into the determination of the long-run growth rate. Formally, equations (2.17) and (2.18), together with the assumptions that all countries share the same production function parameters and long-run growth rate, imply that

$$\ln y_t = \bar{z}_t + \frac{\alpha}{1-\alpha-\beta}\text{lns } s_{Ki} + \frac{\beta}{1-\alpha-\beta}\ln s_{Hi} - \frac{\alpha+\beta}{1-\alpha-\beta}\ln(n_i + g + \delta) + \varepsilon_i + \eta_{it}, \qquad (3.1)$$

$$\ln y_{it} - \ln y_{i0} = \ln Z_t - \ln Z_0 = tg + \eta_{it} - \eta_{i0}, \qquad (3.2)$$

where the growth rate g is constant across countries. A straightforward statistical implication of the model, easily tested in this framework, is that the coefficients on variables such as the saving rate, the schooling rate, and the growth rate of the workforce rate should be zero when they are entered on the right side of (3.2). [More precisely, we divide both sides of (3.2) by the number of periods t, so that the annual growth rate is on the right-hand side.]

Table 5 reports the results of this test. Equations (3.1) and (3.2) are estimated jointly by seemingly unrelated regression (SUR), with

Table 5 TEST OF EXOGENEITY OF GROWTH IN THE SOLOW MODEL[a]

	Value (Standard Error)							
	Textbook Solow Model				Augmented Solow Model			
Parameter	*Non-Oil*	*Intermediate*	*OECD*	*Western*	*Non-Oil*	*Intermediate*	*OECD*	*Western*
No. of observations	90	72	21	22	90	72	21	22
Constant	−0.01	0.00	0.02	0.02	−0.01	−0.01	0.02	0.02
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
I/GDP	0.14	0.14	0.06	0.06	0.12	0.12	0.07	0.05
	(0.02)	(0.02)	(0.04)	(0.04)	(0.02)	(0.02)	(0.04)	(0.04)
SCHOOL	−0.01	−0.04	−0.02	−0.08	0.07	0.05	−0.12	−0.05
	(0.05)	(0.05)	(0.10)	(0.10)	(0.05)	(0.05)	(0.10)	(0.11)
n	0.00	−0.03	−0.40	−0.36	0.03	0.03	−0.38	−0.31
	(0.15)	(0.15)	(0.28)	(0.26)	(0.15)	(0.15)	(0.28)	(0.27)
χ^2 (3)	80.41	54.57	6.84	3.48	79.68	53.13	8.03	2.90
p	0.00	0.00	0.08	0.32	0.00	0.00	0.05	0.41

[a]SUR estimation of two-equation system of the form of equations (3.1) and (3.2), with coefficients of (3.1) unconstrained. Dependent variable: change in log (GDP per working-age person), 1960–1995. The table shows the results of the estimation of equation (3.2). The final two rows report a test of the prediction of the model that variables other than the constant should be excluded from (3.2). A small value of p implies rejection of the joint hypothesis that the economies are in a steady state and growth is exogenous.

equation (3.2) being augmented by the variables I/GDP, SCHOOL, and the labor-force growth rate n.[7] The prediction of the Solow model (under the auxiliary assumption of steady states) is that the estimated coefficients of the last three variables should all be zero. Table 5 shows the parameter estimates and standard errors for the augmented equation (3.2). The chi-squared test and the associated p-value in the final two rows test the exclusion restriction implied by the model. In brief, the Solow model's implication that growth is exogenous is strongly rejected for the non-oil and intermediate samples. When equation (3.1) takes the form implied by the textbook Solow model, that is, we impose $\beta = 0$, exogeneity of growth is rejected for the OECD sample at the 10% level. When equation (3.1) allows $\beta \neq 0$, the restriction is rejected at the 5% level for the OECD. Inspection of the coefficients and standard errors in Table 5 shows that the principal reason for the rejections is the strong relationship of the saving rate (I/GDP) to the long-run growth rate.

There are at least two possible reasons for the statistical rejections found in Table 5: First, growth may not be truly exogenous, in the sense of the Solow model. Second, the maintained hypothesis that the countries in the sample are in the steady state may be wrong, i.e., we may be picking up transition dynamics.

One simple test of the second possibility is to consider only the 22 countries in our sample that are located in the Western Hemisphere. Arguably, the assumption of steady states makes more sense for Western Hemisphere countries than for the rest of the world, as the Americas have not been the scene of major wartime destruction, postcolonial transitions, or (except for Cuba, which is not in our sample) sustained nonmarket experiments during the past century. Interestingly, as Table 5 shows, the restrictions of the Solow model cannot be rejected for the countries of the Western Hemisphere as a group. Thus, it remains possible that the results of this section arise because of transition dynamics, not because the Solow model is fundamentally wrong about long-run growth. In the latter part of the paper we address this issue directly by considering the determinants of TFP growth rather than output.

3.2 ENDOGENOUS SAVINGS RATES? THE RAMSEY MODEL

Our rejection of the Solow model is based on the finding that variables such as saving rates are correlated with growth rates. One possible reason for this correlation is that saving rates are endogenous and depend on rates of growth, rather than the other way around, as in the

7. Our focus is not on equation (3.1), but the SUR approach brings efficiency gains in the estimation of that equation too.

classic formulation due to Ramsey (1928), Cass (1965), and Koopmans (1965); see, e.g., Barro and Sala-i-Martin (1999, Chapter 2), for an exposition. In the remainder of this section we briefly consider the fit of the Ramsey model to the data.

Before doing so, however, we should emphasize that the possibility that saving rates are endogenous to growth does not (in our view) invalidate our rejection of the Solow model in the previous section. In brief, there are two possibilities: Either the long-run growth rate is the same for all countries (that is, $g_i = g$ for all i), as maintained by MRW, or it is not. If the long-run growth rate is invariant, then differences in growth rates cannot account for differences in savings rates. In any case, the null that the growth rate is the same for all countries is rejected by our test reported above, under the plausible assumption that the long-run average values of I/GDP, SCHOOL, and n are not strongly correlated with the cyclical error term, $(\eta_{it} - \eta_{i0})/t$. Suppose then that the long-run growth rates differ (exogenously) across countries. This alternative assumption raises both econometric and substantive problems for the MRW analysis of the Solow model. Econometrically, if the growth rate is stochastic, the MRW equation (2.17) is no longer a valid regression, as the error term is correlated with the regressors (see footnote 2). Hence the interpretation of MRW's results favoring the Solow model is problematic. More substantively, "explaining" growth by assuming that growth rates differ exogenously across countries is not particularly helpful. Once it is allowed that long-run growth rates differ across countries, we are naturally pushed to consider explanations for these differences, as offered (for example) by endogenous growth models.

We consider the version of the Ramsey model without human capital, that is, with $\beta = 0$. The relevant equations are

$$\ln y_{it} = \bar{z}_t + \frac{\alpha}{1-\alpha}\ln s_{Ki} - \frac{\alpha}{1-\alpha}\ln(n_i + g_i + \delta) + \varepsilon_i + \eta_{it}, \tag{3.3}$$

$$\ln y_{it} - \ln y_{i0} = tg_i + \eta_{it} - \eta_{i0}, \tag{3.4}$$

$$s_{Ki} = \frac{\alpha(n_i + g_i + \delta)}{\rho + \sigma g_i + \delta} + \nu_{1i}, \tag{3.5}$$

where ρ is the discount rate (of the representative agent), σ is the coefficient of relative risk aversion, and ν_{1i} is a country-specific (but time-independent) error term. Equations (3.3) and (3.4) are the appropriately modified versions of equation (2.17) and (2.18), and equation (3.5) is the

Table 6 ESTIMATES OF THE RAMSEY MODEL[a]

Parameter	Value (Standard Error)			
	Non-Oil	*Intermediate*	*OECD*	*Western*
No. of observations	90	72	21	22
$\bar{z}$	8.54 (0.09)	8.73 (0.10)	9.56 (0.06)	8.81 (0.11)
σ	−0.17 (0.41)	0.16 (0.40)	0.08 (0.51)	0.75 (1.35)
ρ	0.13 (0.01)	0.11 (0.01)	0.07 (0.01)	0.12 (0.02)
corr(s_K, $\hat{s}_K$)	0.49	0.33	0.14	0.15

[a]SUR estimation of two-equation system (3.3) and (3.5), with $\alpha = 0.35$ assumed in both equations. The last row shows the simple correlation of actual and fitted saving rates across countries.

standard expression for the Ramsey steady-state saving rate.[8] To estimate this system, it is convenient to rewrite (3.4) as

$$g_i = \frac{1}{t}(\ln y_{it} - \ln y_{i0}) + \frac{1}{t}(\eta_{i0} - \eta_{it}). \tag{3.6}$$

Using (3.6), we substitute for g_i in (3.3) and (3.5). This substitution introduces a measurement error term, $(1/t)(\eta_{i0} - \eta_{it})$; however, this error is probably small for our sample length (35 years) and is zero asymptotically. After making this substitution, we estimate the system (3.3) and (3.5) jointly by nonlinear SUR, to take advantage of possible efficiency gains if the error terms are correlated. As noted above (see also footnote 2), when growth rates vary across countries equation (3.3) is no longer a valid regression, as the error term $\varepsilon_{it} = \varepsilon_{i0} + (g_i - \bar{g})t$ is likely to be correlated with the regressors; hence, we impose $\alpha = 0.35$ (a value justified later in the paper) and estimate only the constant term in (3.3). [Estimation of equation (3.5) alone produced similar results to those reported here.] Table 6 shows the results for the period 1960–1995 for four samples (the three MRW samples plus the Western Hemisphere).

8. This savings rate comes from the solution of the consumer optimization problem, max $\int_0^\infty e^{-\rho t}\,[(c_t^{1-\sigma} - 1)/(1 - \sigma)]\,L_t\,dt$, where c_t is per capita consumption. The same maximization problem also applies to the Uzawa–Lucas model introduced in the next section.

The results provide at best weak support for the view that saving rates are endogenous to growth rates. The link between the growth rate and the saving rate operates most directly through the risk aversion parameter (the reciprocal of the intertemporal elasticity of substitution), σ. As Table 6 shows, the estimated value of σ is much too low (negative, for the largest sample), relative to typical findings, and is poorly identified. (However, estimates of the discount rate ρ are well identified and reasonable in magnitude.) As a measure of fit, the table also reports for each sample the simple correlation of the actual saving rate and the fitted saving rate. This correlation is 0.49 for the largest (non-oil) sample (recall, though, that here the estimated σ is negative) and 0.33 for the intermediate sample. For the OECD and Western Hemisphere samples respectively, the correlations of actual and fitted saving are only 0.14 and 0.15. Further, much of the explanation for saving appears to be due to variation in the growth rate of the labor force rather than variation in the growth rate. In short, it appears that one cannot reasonably account for the observed correlation of saving and growth as reflecting the endogenous response of the former to the latter.[9,10] More evidence on this point is provided below. In the next section we consider the fit of some alternatives to the Solow model which permit growth as well as saving to be endogenous.

4. *Alternative Growth Models*

The extended MRW framework provides a means of assessing alternative growth models. In this section we consider the application of the framework to the Uzawa (1965)–Lucas (1988) two-sector growth model with human capital and to a version of the *AK* model with learning-by-doing. At this point these exercises are meant to be largely illustrative, as the models considered are quite simple.

4.1 THE UZAWA–LUCAS MODEL

In our version of the Uzawa–Lucas model, we assume that production is given by

$$Y_t = K_t^{\alpha} (Ah_tL_t)^{1-\alpha}(1 - s_H)^{1-\alpha}. \tag{4.1}$$

9. Independent evidence is provided by King and Rebelo (1993), who show that a neoclassical growth model with endogenous savings rates has strong counterfactual implications, such as real interest rates above 100% in early stages of development.
10. Preliminary estimation of the out-of-steady-state dynamics of the savings rate in the Ramsey model also resulted in unreasonable estimates of the coefficient of relative risk aversion and the discount rate.

In equation (4.1), h_t is human capital per worker at time t, and $1 - s_H$ is the share of worker time devoted to market production. The factor A is a constant (i.e., it may vary by country but not over time). Long-run growth occurs in this model only through the accumulation of human capital. The human-capital accumulation equation is

$$\dot{h}_t = Bs_H h_t \tag{4.2}$$

where B measures the productivity of educational technology and s_H (as previously defined) is the share of time devoted to education by people of working age (the SCHOOL variable of MRW). Equation (4.1) reduces to equation (2.1) when $Z_t = A(1 - s_H)h_t$ and $\beta = 0$. Since $\dot{Z}_t / Z_t = \dot{h}_t / h_t$, equation (4.2) is equivalent to equation (2.11) with $g(s_K, s_H, \ldots) = Bs_H$.

Following the steps of the analysis of Section 2, we obtain the pair of empirical equations for this model corresponding to equations (2.17) and (2.18) respectively:

$$\ln y_{it} = \bar{z}_t + \frac{\alpha}{1-\alpha} \ln s_{Ki} - \frac{\alpha}{1-\alpha} \ln(n_i + g_i + \delta) + \varepsilon_{it} + \eta_{it}, \tag{4.3}$$

$$\ln y_{it} - \ln y_{i0} = tBs_{Hi} + \eta_{it} - \eta_{i0}, \tag{4.4}$$

where $\varepsilon_{it} = \varepsilon_{i0} + (g_i - \bar{g})t = \varepsilon_{i0} + B(s_{Hi} - \bar{s}_H)t$. Thus, as expected, the product Bs_{Hi} appears in the expression for $\ln y_{it}$. Note that (4.4) has no constant term. Both equations also appear likely to exhibit heteroscedasticity; that will be taken care of by our estimation procedure.

In principle, the Uzawa–Lucas model allows the rate of human-capital information and the saving rate in the steady state to be endogenous. To accommodate this endogeneity, we append the following two equations:

$$s_{Ki} = \frac{\alpha(n_i + g_i + \delta)}{\rho + \sigma g_i + \delta} + \nu_{1i}, \tag{4.5}$$

$$s_{Hi} = \frac{1}{\sigma B}(B + n_i - \rho) + \nu_{2i}, \tag{4.6}$$

where ν_{1i} and ν_{2i} are error terms. Equation (4.5) is the same as the Ramsey expression (3.5) for the optimal saving rate, and equation (4.6) gives the optimal steady-state rate of human-capital formation. We estimate this variant of the Uzawa–Lucas model in two ways: First, we estimate only equations (4.3) and (4.4), effectively treating s_{Ki} and s_{Hi} as exogenous. Second, to allow for endogenous rates of saving and human-capital formation, we estimate the system (4.3)–(4.6) simultaneously, making the substitution (3.6) for the growth rate in equations (4.3), (4.5), and (4.6). Again we have the problem that the error term is correlated with the regressors in (4.3), and hence, for both exercises, we simply impose $\alpha = 0.35$.[11]

Table 7 shows the results of estimation for four samples of countries for the years 1960–1995. The top part of Table 7 shows the results when the savings rates for physical and human capital are treated as exogenous and given; the bottom part allows these variables to be endogenously determined by the utility maximization problem of a representative agent. We find that the parameters $\bar{z}$ and B are tightly estimated, with similar values independent of whether savings rates are treated as exogenous or endogenous. However, the estimated values of σ and ρ, shown in the bottom part of Table 7, are found to be inadmissible (σ is always estimated to be negative) or implausible. The negative estimates for σ result from the fact that human-capital investment rates and population growth rates are negatively correlated in the data, which is inconsistent with equation (4.6) unless $\sigma < 0$. Again, the representative-agent model does not seem to do very well in explaining cross-country variations in saving; future work should consider alternative models of saving, such as the life-cycle model (which focuses on demographics)

In order to assess goodness of fit, Table 7 also shows the cross-sectional correlations of the endogenous variables of the model and their fitted values. In the top half of the table, the correlations of actual and fitted growth rates treat the saving rate and the rate of human-capital formation as exogenous and given. More precisely, this correlation is just the correlation of the actual growth rate and $\hat{B}s_{Hi}$. In the bottom part of the table all three variables are treated as endogenous (the rate of population growth is thus the only exogenous source of cross-country variation). With saving rates exogenous, the correlation of actual and fitted growth under the Uzawa–Lucas model is 0.54 for the large non-oil sample and 0.43 for the intermediate sample.[12] The correlations of actual and fitted growth

11. One is tempted to put Bs_{Hi} explicitly in the expression (4.3) and assume that the term is uncorrelated with ε_{i0}, rendering the regression valid. A little reflection shows that this is unreasonable, however. If the term $g_i = Bs_{Hi}$ were uncorrelated with ε_{i0}, it would perforce by definition be correlated with every error term ε_{ij}, $j = -\infty, \ldots, -1, 1, \ldots, \infty$. But the start date of the sample is arbitrary; there is no reason to assume that the error term corresponding to the start date happens to have the unique property of being uncorrelated with the growth rate.

12. Note that these correlations are not comparable with the $\bar{R}^2$'s obtained in the MRW regressions, which take the level of output per capita rather than its growth rate as the dependent variable. By definition, the steady-state Solow model explains none of the cross-country growth variation examined here.

Table 7 ESTIMATES OF THE UZAWA–LUCAS MODEL[a]

Parameter	*Non-Oil*	*Intermediate*	*OECD*	*Western*
	Value (Standard Error)			
No. of observations	90	72	21	22
s_k, s_h exogenous				
$\bar{z}$	8.53	8.73	9.57	8.79
	(0.09)	(0.10)	(0.06)	(0.11)
B	0.21	0.23	0.25	0.15
	(0.02)	(0.02)	(0.02)	(0.02)
corr(g, $\hat{g}$)	0.54	0.43	−0.10	0.19
s_k, s_h endogenous				
$\bar{z}$	8.27	8.39	9.61	8.75
	(0.07)	(0.08)	(0.06)	(0.10)
B	0.23	0.24	0.26	0.14
	(0.01)	(0.02)	(0.02)	(0.01)
σ	−4.16	−4.57	−13.89	−5.71
	(0.40)	(0.48)	(2.60)	(1.16)
ρ	0.31	0.33	0.64	0.23
	(0.02)	(0.03)	(0.11)	(0.03)
corr(g, $\hat{g}$)	0.25	0.27	0.39	0.22
corr(s_K, $\hat{s}_K$)	−0.38	−0.42	−0.34	−0.04
corr(s_H, $\hat{s}_H$)	0.36	0.43	0.03	0.53

[a]Results are derived from SUR estimation of equations (4.3) and (4.4) in the top panel, and (4.3)–(4.6) in the bottom panel, imposing a value of 0.35 for α in all equations.

are much lower for the other two country samples (−0.10 for the OECD sample and 0.19 for the Western Hemisphere sample). For the OECD sample at least, there is probably not enough meaningful variation in measured schooling rates to explain differences in growth.

When saving and human-capital formation are allowed to be endogenous (bottom part of Table 7), the results deteriorate markedly, as expected. Conditional on fitted rather than actual schooling rates, the correlation of fitted and actual growth rates is much lower for the two bigger samples (though higher for the OECD and Western Hemisphere). The last two rows, which show the correlations of fitted and actual saving and schooling rates, make the point that (given the broad patterns in the data) the representative-agent model appears unable to fit both variables simultaneously. In particular, the correlations of fitted and actual savings rates are negative, reflecting the poor fit of $\hat{g}$ and the negative estimates of σ [see equation (4.5)].

We conclude that, conditional on rates of human-capital formation, the Uzawa–Lucas model does a reasonably good job of explaining growth for the non-oil and intermediate samples. However, an optimizing model that assumes that behavioral parameters are the same across countries does not do a good job of explaining cross-country differences in savings rates and rates of human-capital formation. This latter finding is consistent with the relatively weak explanatory power of the Ramsey model above, though at least in that case the correlations of actual and fitted values of saving rates were positive.

4.2 *THE AK MODEL*

Another standard growth model in the literature is the so-called *AK* model. One common rationalization of this model is Arrow's (1962) idea of learning-by-doing. Suppose that the production function of the economy is given by (4.1), but that worker skills are proportional to the capital–labor ratio, i.e., $h_t = k_t$. Then the per-worker production function is simply

$$y_t = \tilde{A}k_t, \tag{4.7}$$

where $\tilde{A} = A^{1-a}$ is a country-specific constant. Along the BGP the growth rate of the capital–labor ratio and hence of output per worker is $s_K\tilde{A} - (n + \delta)$. Assume that $\tilde{A}_i = \bar{A}(1 + \varepsilon_i)$ and $\ln \bar{A} = \bar{a}$, so that $\ln \tilde{A}_i = \bar{a} + \varepsilon_i$, approximately. Then the two equations describing the BGP of this model are

$$\ln y_{it} - \ln k_{it} = \bar{a} + \varepsilon_i + \eta_{it}, \tag{4.8}$$

$$\begin{aligned}\ln y_{it} - \ln y_{i0} &= t[s_{Ki}\tilde{A}_i - (n_i + \delta)] + \eta_{it} - \eta_{i0} \\ &= t[s_{Ki}\bar{A} - (n_i + \delta)] + ts_{Ki}\bar{A}\varepsilon_i + \eta_{it} - \eta_{i0}.\end{aligned} \tag{4.9}$$

We estimated (4.8) and (4.9) simultaneously by SUR and then tested the restriction that $\ln \bar{A} = \bar{a}$. Here we treat the saving rate as exogenous.

The results are shown in Table 8. As shown by the *p*-values in the penultimate row of the table, the over-identifying restriction of the model is strongly rejected.

Table 8 ESTIMATES OF THE *AK* MODEL[a]

	Value (Standard Error)			
Parameter	*Non-Oil*	*Intermediate*	*OECD*	*Western*
No. of observations	90	72	21	22
$\bar{a}$	−0.08 (0.06)	−0.20 (0.06)	−0.55 (0.06)	−0.08 (0.10)
$\bar{A}$	0.40 (0.02)	0.37 (0.02)	0.27 (0.01)	0.42 (0.03)
χ^2 (1)	376.68	341.13	393.42	115.85
p	0.00	0.00	0.00	0.00
corr(g, $\hat{g}$)	0.67	0.63	0.47	0.32

[a]Results are derived from SUR estimation of equations (4.8) and (4.9). The tested restriction is that $\ln \bar{A} = \bar{a}$.

As above, an alternative way to evaluate the *AK* model is to see how the growth rates it implies are correlated with observed growth rates. For each country we estimated $\tilde{A}_i$ as the output–capital ratio in 1995, we calculated the forecast growth rate for that country as $\hat{g}_i = s_{Ki}\tilde{A}_i - (n_i + \delta)$. The correlation of this forecast growth rate with the actual growth rate for the four country samples are shown in the last row of Table 8. Reflecting the positive relationship of saving rates and growth rates, these correlations are rather high, ranging from 0.32 for the Western Hemisphere sample to 0.67 for the large non-oil sample. We thus come to mixed conclusions about the *AK* model. On the one hand, the cross-equation restriction imposed by the model, relating the output–capital ratio and the sensitivity of growth to the saving rate, is strongly rejected by the data. On the other, the key prediction of the model that the saving rate (rate of capital accumulation) is important for explaining the *growth* as well as the *level* of per capita output seems to hold considerable validity. We find a similar result linking the saving rate and TFP growth below.

5. *Estimates of Labor's Share*

To this point we have assumed that all the economies in the sample lie on a balanced growth path. At best this can only be an approximation. First, economies are buffeted by a variety of major and minor shocks, as well as changes in institutions and policies; hence, even if our models are precisely correct, some component of observed economic growth must be accounted for by transition dynamics.[13] Second, we cannot take literally the prediction of many endogenous growth models that country growth rates may differ permanently, as that would imply counterfactually that the cross-sectional variance of real GDP per worker grows without bound. Although government policies and private-sector decisions may have highly persistent effects on growth (the prediction of endogenous growth models that we take most seriously), ultimately there must be forces (such as technology transfer from leaders to followers) that dampen the tendency toward divergence.

In the second part of their paper, MRW attempt to estimate directly the speed of convergence to the steady state and to relate their findings to the predictions of the Solow model. Although this exercise is an interesting one, measuring the speed of convergence is a difficult econometric problem, especially in the face of possible parameter heterogeneity and ongoing economic shocks. A more direct way to study the determinants of long-run growth, without having to take a stand on whether the world's economies are currently on a balanced growth path (or whether some are and some aren't), is to obtain country-by-country estimates of the growth of TFP. As is well known, if production is Cobb–Douglas[14] and factor markets are competitive,[15] then TFP growth rates can be found by standard growth accounting methods, using factor shares to estimate the elasticities of output with respect to capital and labor. In this section we build on the work of Gollin (1998) to calculate labor shares for a sample of countries. Section 6 reports the results of the associated growth accounting exercises.

Studies of labor's share have often found lower values in developing countries than in industrial countries (see, e.g., Elias, 1992). Taken at face value, this result suggests either that less-developed countries operate different technologies than industrialized countries, or perhaps that the constant-elasticity-of-substitution (CES) or other production-function form is preferable to the Cobb–Douglas. In an important paper, Gollin (1998) presents evidence against the conventional finding. Gollin's key insight is that published series on "employee compensation" may signifi-

13. Much of macroeconomics is devoted to the study of these short-run dynamics around a steady state, otherwise known as business cycles.
14. The Cobb–Douglas production function may also be viewed as a first-order approximation to more complicated production functions. Below we provide some evidence in favor of the Cobb–Douglas assumption.
15. Some endogenous growth models assume monopolistic competition and payments to factors other than capital and labor. In practice, we expect that the empirical labor share will be a reasonable measure of the Cobb–Douglas coefficients applying to an agglomerate of raw labor and human capital.

Table 9 COST COMPONENTS OF GDP

Indirect taxes, net
Indirect taxes
Less: Subsidies
Consumption of fixed capital
Compensation of employees by resident producers
Resident households
Nonresidents
Operating surplus
Corporate and quasicorporate enterprises
Private unincorporated enterprises
General government
Statistical discrepancy
Equals **Gross Domestic Product**

Source: UN *National Accounts Statistics*

cantly understate total labor compensation, particularly in developing economies, because of the large share of income flowing to workers who are self-employed or employed outside the corporate sector.[16]

To try to capture the income of the latter group of workers, Gollin employs data from the United Nations System of National Accounts (see United Nations, *National Accounts Statistics*). Our Table 9 shows the UN's method of breaking down the cost components of GDP. Income received by the self-employed and noncorporate employees is a component of the category *operating surplus, private unincorporated enterprises* (OSPUE). Gollin considers two measures of labor's share which use data on OSPUE. For the first measure, he attributes all of OSPUE to labor earnings, so that labor's share becomes (corporate) employee compensation plus OSPUE, divided by GDP net of indirect taxes. For his second measure, he assumes that the share of labor income in OSPUE is the same as its share in the corporate sector. Specifically, this measure of the share of labor income can be written

$$\text{labor share} = \frac{\text{corporate employee compensation}}{\text{GDP} - \text{indirect taxes} - \text{OSPUE}} \tag{5.1}$$

16. Gollin also examines the possibility that differences in sectoral composition might explain cross-country differences in labor share. However, he does not find this factor to be important.

We view this second measure, which allows for the existence of noncorporate capital income, as more reasonable; we will refer to it as the *OSPUE measure.*

Gollin also considers a third measure of labor's share, which uses data on the ratio of corporate employees to the total labor force less unemployed, available in various issues of the International Labor Organization's *Yearbook of Labor Statistics.* Specifically, he assumes that corporate and noncorporate workers receive the same average compensation, so that aggregate labor income can be calculated by scaling up corporate employee compensation by the ratio of the total labor force to the number of corporate employees. This measure, which we will refer to as the *labor-force correction,* is defined by

$$\text{labor share} = \frac{\text{corporate employee compensation}}{(\text{corp. share of labor force}) \times (\text{GDP} - \text{indirect taxes})}. \quad (5.2)$$

We have replicated and updated Gollin's calculations for the OSPUE measure and the labor-force correction for our sample of countries. One problem that we noted in doing so is that OSPUE is reported for only about 20 countries; the majority of countries report only the total operating surplus of corporate enterprises and private unincorporated enterprises, that is, we have only the sum of OSPUE and corporate capital income.[17] To expand the number of countries for which labor shares could be calculated, we constructed an alternative measure of labor share that combines information about the corporate share of the labor force and the aggregate operating surplus. To do so, we assume that the corporate share of total private-sector income (both capital income and labor income) is the same as the share of the labor force employed in the corporate sector. Total private-sector income is calculated as the sum of the operating surplus and corporate employee compensation. We then compute an *imputed OSPUE* as the share of noncorporate employees in the labor force times the private-sector income. Using the imputed OSPUE, we then estimate labor's share using equation (5.1), with imputed OSPUE in place of actual OSPUE.

Table 10 reports a variety of data for the 53 countries in our sample for which either (1) OSPUE is available or (2) the share of corporate employees in the labor force is at least half, or both. We impose the second

17. The operating surplus of government enterprises is also included in operating surplus. As our dataset does not include economies in which the government controls a large share of enterprises, this component can safely be ignored.

requirement because we found that, for countries with very low corporate employment shares (for some, this share is below 0.10), the calculated labor shares are often unreasonable (e.g., they may exceed one). This result is not unexpected, for two reasons: First, countries with large informal sectors are likely to have relatively poor economic statistics, all else equal. Second, our estimates which use the labor-force correction scale up corporate employee compensation by the reciprocal of the corporate employee share of the labor force. When the corporate employee share is both small and measured with error, estimates based on the reciprocal of the share will be highly unreliable. We found, on the other hand, that when the corporate employee share exceeds 0.5 or 0.6, the resulting estimated labor shares not only are reasonable in magnitude but also tend to agree closely with alternative measures. All of the analyses reported below use 0.5 as the cutoff for the corporate employee share of the labor force; results for samples based on a 0.6 cutoff are essentially identical.

In Table 10 the second column gives the share of the country's labor force employed in the corporate sector. Columns 3 through 6 give four alternative measures of labor's share for each country. Column 3, the *naive* calculation, is corporate employee compensation divided by GDP net of indirect taxes. As emphasized by Gollin, this estimate is likely to be too low, because it ignores the income of noncorporate employees. We include it for reference and comparison with other measures.

Columns 4–6 give our three primary measures of labor's share. Column 4 shows Gollin's *OSPUE measure,* column 5 our *imputed OSPUE measure,* and column 6 the measure based solely on the *labor-force correction.* Columns 2–6 are based on average data for the period 1980–1995, or for a period as close to 1980–1995 as possible. We also calculated country-by-country time series for the labor share (not shown). For comparison, columns 7–10 show estimates from previous studies, as reported in Barro and Sala-i-Martin (1999, Table 10.8, pp. 380–381). The year ranges at the head of columns 7–10 correspond to the timing of the data used by the previous studies.

We find the results of this exercise encouraging. As Table 10 shows, when alternative measures of labor's share exist, they tend to agree closely, especially when the corporate employee share is greater than 0.6 or so. Two additional findings tend to support Gollin's (1998) conclusion that the Cobb–Douglas assumption of stable income shares is a good one: First, we find no systematic tendency for country labor shares to vary with real GDP per capita or the capital–labor ratio. Indeed, most estimated labor shares lie between 0.6 and 0.8, and the average value of

Table 10 ALTERNATIVE MEASURES OF LABOR'S SHARE

Country	Corporate Employees/ LF	Est. Labor Share							
		Naive	Actual OSPUE	Imputed OSPUE	LF	1947–73 CCJ	1960–90 Dough'y	1940–80 Elias	1966–90 Young
Algeria	0.74	0.47		0.61	0.63				
Australia	0.84	0.57	0.68	0.66	0.68				
Austria	0.86	0.61		0.70	0.71				
Belgium	0.82	0.60	0.74	0.71	0.73				
Bolivia	0.55	0.37			0.67				
Botswana	0.45	0.39	0.45						
Burundi	0.06	0.22	0.75						
Canada	0.91	0.62		0.68	0.69	0.56	0.55		
Chile	0.68	0.42		0.59	0.62			0.48	
Colombia	0.68	0.45			0.65			0.37	
Congo	NA	0.38	0.47						
Costa Rica	0.72	0.54		0.73	0.74				
Denmark	0.89	0.64		0.71	0.72				
Ecuador	0.56	0.25			0.45				
Egypt	0.56	0.43			0.77				
El Salvador	0.60	0.35			0.58				
Finland	0.85	0.62	0.71	0.71	0.73				
France	0.85	0.61	0.74	0.71	0.73	0.60	0.58		
Germany, W.	0.89	0.63		0.69	0.71	0.61	0.60		
Greece	0.52	0.45		0.79	0.86				
Hong Kong	0.88	0.51			0.57				0.63
Ireland	0.77	0.58		0.73	0.75				
Israel	0.80	0.59		0.70	0.73				
Italy	0.72	0.49	0.71	0.65	0.69	0.61	0.62		
Ivory Coast	0.11	0.43	0.68						

Jamaica	0.60	0.53	0.60						
Japan	0.76	0.59	0.68	0.73	0.77	0.61	0.58		
Jordan	0.67	0.45		0.64	0.67				
Korea, Rep.	0.56	0.48	0.65						0.68
Malaysia	0.64	0.43			0.66				
Mauritius	0.85	0.48			0.57				
Mexico	0.59	0.34		0.55	0.59			0.31	
Morocco	0.63	0.36			0.58				
Netherlands	0.88	0.59	0.67	0.66	0.67	0.55			
New Zealand	0.80	0.55		0.67	0.69				
Norway	0.89	0.55		0.61	0.63				
Panama	0.65	0.50		0.73	0.76				
Paraguay	0.62	0.32		0.49	0.52				
Peru	0.53	0.31		0.56	0.59			0.34	
Philippines	0.44	0.27	0.59						
Portugal	0.71	0.52	0.72	0.71	0.73				
Singapore	0.85	0.47		0.53	0.55				0.47
S. Africa	0.94	0.59		0.62	0.63				
Spain	0.73	0.52		0.67	0.70				
Sri Lanka	0.62	0.50		0.78	0.81				
Sweden	0.91	0.68	0.77	0.74	0.75				
Switzerland	0.85	0.66		0.76	0.78				
Trin & Tobago	0.77	0.55		0.69	0.71				
Tunisia	0.66	0.41			0.62				
UK	0.89	0.65	0.75	0.72	0.74	0.62	0.61		
USA	0.91	0.65	0.74	0.71	0.71	0.60	0.59		
Uruguay	0.74	0.43		0.58	0.59				
Venezuela	0.68	0.38		0.53	0.55			0.45	
Zambia	0.62	0.48		0.72	0.78				

Sources: Authors' calculations. Studies corresponding to the final four columns are Christensen, Cummings, and Jorgenson (1980); Elias (1992); Dougherty (1991); and Young (1995).

the labor share is 0.65, similar to that observed in the United States and other industrialized countries.[18] Second, the time series of labor shares by country tend to be quite stable, with no systematic tendency to rise or fall over time.

The comparison of our calculated labor shares to previous studies suggests that the earlier studies took insufficient account of noncorporate employee income (note how close the results of several of the earlier studies are to the naive calculation of labor share, column 3). The exception is the careful work of Young (1995), who obtains numbers similar to ours for Hong Kong and Korea, but a smaller value for Singapore.

6. *The Determinants of TFP Growth*

In this section we describe our calculations of TFP growth for our sample of countries and report results of regressions of TFP growth on country characteristics. Again, the advantage of looking directly at TFP growth is that it avoids the need to take a stand on whether countries are on a balanced growth path or in transition to a BGP.

The labor shares (and by implication, the capital shares) shown in Table 6 are an important input to the calculation of TFP growth. We have output growth from the PWT 6.0 data. The two remaining required inputs to a growth accounting exercise are measures of capital-stock growth and labor-force growth.

PWT version 5.6 provides data on capital stocks for a subset of countries, but our prerelease version of PWT 6.0 does not yet have capital-stock data. We estimate capital stocks from available PWT 6.0 data by a perpetual inventory calculation. Here (in contrast to our replication of the MRW results) we assume a depreciation rate of 6%, following Hall and Jones (1999).[19] Initial capital stocks are found by the assumption that capital and output grow at the same rate. Specifically, for countries with investment data beginning in 1950 we set the initial capital stock $K_{1949} = I_{1950}/(g + \delta)$, where g is the ten-year growth rate of output (e.g., from 1950 to 1960) and δ (= 0.06) is the assumed rate of depreciation. We have investment data starting from 1950 for 50 countries, from 1955 for 14 countries, and from 1960 for 26 countries.

The calculated capital stocks include both residential and nonresidential capital. PWT 5.6 provides data on residential capital per worker

18. In the next section, we set the labor share for each country equal to the OSPUE measure, if available; to the imputed OSPUE measure, if OSPUE is unavailable; and finally to the labor-force correction measure if neither OSPUE measure is available. The average labor share derived from this procedure is precisely 0.65.

19. We get similar results if we assume 3% depreciation or if we use PWT version 5.6 instead.

as a fraction of nonresidential capital per worker for 63 countries. For these countries we use the average ratio of nonresidential capital to total capital to impute nonresidential capital stocks in the PWT 6.0 data set. For other countries we assume that residential capital is one-third of the total, about the average value for the countries on which we have data.

Labor-force growth unadjusted for quality (that is, assuming a zero return to schooling) is calculated as the rate of growth of the working-age population, as in Section 3. We also compute alternative quality-adjusted measures, as follows: We use the most recent Barro–Lee (2000) data on educational achievement to give larger weight to more-educated workers, assuming social returns to education of 7% per year (results are not sensitive to alternative assumptions). A similar method was employed by Collins and Bosworth (1996) and by Klenow and Rodriguez-Clare (1997). TFP growth rates (reported in the Appendix) are then found by the standard growth-accounting calculation. The Appendix to the working-paper version of this paper gives our estimated TFP growth rates under alternative assumptions and for different subsamples.

With average TFP growth rates by country in hand, we can ask whether these growth rates are independent of variables such as the saving rate, schooling rate, or labor-force growth rate, as the Solow model would predict. As Table 11 shows, the answer is a strong no. The top half of Table 11 shows regression results for the sample of about 50 countries for which we have calculated labor shares (see footnote 10). The bottom half uses calculated TFP growth rates under the assumption that labor's share is a fixed 0.65 in each country, an assumption which we believe to be reasonable in light of our labor-share estimates above. The advantage of this assumption is that it allows us to expand the sample to 80 countries or more. Note that in either case we are focusing on long-run averages, so that cyclical influences should be minimal.

Table 11 shows that, whether we include a human-capital correction or not, and independent of the combination of variates included in the regression, TFP growth is cross-sectionally strongly related (in both the economic and statistical senses) to the saving rate and, in most cases, to the growth rate of the labor force. TFP growth rates also tend to be related to schooling rates, but when both the saving rate and the schooling rate are included in the regression, the coefficient on the schooling rate tends to become statistically insignificant. Further, as might be expected, when the labor force is adjusted for human-capital accumulation, the effect of the schooling variable is reduced.

Table 12 repeats the analysis of Table 11 for the 1980–1995 subperiod. The data for this subperiod are probably more reliable (we don't need to worry about whether our estimated initial capital stocks are reasonable,

Table 11 DETERMINANTS OF TFP GROWTH, 1965–1995[a]

Actual Labor Shares	Value (Standard Error)													
Parameter	No Returns to Education (53 Countries)							7% Returns to Education (50 Countries)						
Constant	0.00 (0.00)	0.00 (0.00)	0.02 (0.00)	−0.01 (0.00)	0.00 (0.00)	0.01 (0.01)	0.00 (0.01)	−0.01 (0.00)	−0.01 (0.01)	0.02 (0.00)	−0.01 (0.01)	0.00 (0.00)	0.01 (0.01)	0.00 (0.01)
s_K	0.08 (0.01)			0.06 (0.02)	0.06 (0.02)		0.05 (0.02)	0.07 (0.02)			0.07 (0.02)	0.05 (0.02)		0.05 (0.02)
s_H		0.15 (0.05)		0.07 (0.05)		0.10 (0.04)	0.05 (0.04)		0.14 (0.06)		0.06 (0.06)		0.08 (0.06)	0.03 (0.05)
n			−0.44 (0.10)		−0.29 (0.10)	−0.36 (0.11)	−0.27 (0.10)			−0.45 (0.11)		−0.32 (0.10)	−0.41 (0.11)	−0.31 (0.11)
$\bar{R}^2$	0.33	0.16	0.25	0.34	0.41	0.31	0.41	0.28	0.08	0.26	0.28	0.39	0.27	0.38

Labor Share = 0.65

	No Returns to Education (90 Countries)							*7% Returns to Education (81 Countries)*						
Constant	−0.01 (0.00)	−0.01 (0.00)	0.01 (0.00)	−0.01 (0.00)	−0.01 (0.00)	−0.01 (0.00)	−0.01 (0.00)	−0.01 (0.00)	−0.01 (0.00)	0.01 (0.00)	−0.02 (0.00)	−0.01 (0.00)	0.00 (0.00)	−0.01 (0.00)
s_K	0.11 (0.01)			0.09 (0.02)	0.11 (0.01)		0.09 (0.02)	0.10 (0.01)			0.09 (0.02)	0.10 (0.01)		0.09 (0.02)
s_H		0.21 (0.03)		0.07 (0.04)		0.20 (0.03)	0.07 (0.04)		0.17 (0.03)		0.05 (0.04)		0.15 (0.04)	0.04 (0.04)
n			−0.37 (0.14)		−0.03 (0.11)	−0.10 (0.13)	0.01 (0.11)			−0.38 (0.13)		−0.10 (0.11)	−0.19 (0.13)	−0.08 (0.11)
$\bar{R}^2$	0.49	0.32	0.06	0.50	0.48	0.32	0.50	0.43	0.22	0.09	0.44	0.43	0.23	0.43

[a]Dependent variable: average growth rate of TFP, 1965–1995.

Table 12 DETERMINANTS OF TFP GROWTH, 1980–1995[a]

Actual Labor Shares	Value (Standard Error)													
	No Returns to Education (53 Countries)							7% Returns to Education (50 Countries)						
Constant	−0.01 (0.00)	−0.01 (0.01)	0.02 (0.00)	−0.02 (0.01)	0.00 (0.01)	0.01 (0.01)	0.00 (0.01)	−0.02 (0.00)	0.00 (0.01)	0.02 (0.00)	−0.02 (0.01)	0.00 (0.01)	0.01 (0.01)	0.00 (0.01)
s_K	0.10 (0.02)			0.10 (0.02)	0.07 (0.02)		0.07 (0.02)	0.10 (0.02)			0.10 (0.02)	0.07 (0.02)		0.06 (0.02)
s_H		0.14 (0.06)		0.05 (0.06)		0.10 (0.05)	0.05 (0.05)		0.06 (0.08)		0.01 (0.07)		0.05 (0.06)	0.02 (0.06)
n			−0.69 (0.13)		−0.50 (0.13)	−0.65 (0.13)	−0.50 (0.13)			−0.69 (0.13)		−0.55 (0.13)	−0.69 (0.13)	−0.55 (0.13)
$\bar{R}^2$	0.32	0.07	0.35	0.32	0.48	0.38	0.48	0.25	−0.01	0.35	0.24	0.45	0.35	0.44

Labor Share = 0.65

	No Return to Education (90 Countries)							*7% Return to Education (81 Countries)*							
Constant	−0.02 (0.00)	−0.01 (0.00)	0.01 (0.00)	−0.02 (0.00)	−0.01 (0.01)	0.00 (0.01)	−0.01 (0.01)	−0.02 (0.00)	−0.01 (0.00)	0.01 (0.00)	−0.02 (0.00)	−0.01 (0.01)	0.00 (0.01)	−0.01 (0.01)
s_K	0.13 (0.02)			0.12 (0.02)	0.11 (0.02)		0.10 (0.02)	0.11 (0.02)			0.11 (0.02)	0.10 (0.02)		0.10 (0.02)
s_H		0.17 (0.04)		0.04 (0.04)		0.14 (0.04)	0.03 (0.04)		0.13 (0.05)		0.01 (0.05)		0.09 (0.04)	0.00 (0.05)
n			−0.59 (0.16)		−0.24 (0.15)	−0.45 (0.15)	−0.24 (0.15)			−0.59 (0.15)		−0.32 (0.15)	−0.51 (0.15)	−0.32 (0.15)
$\bar{R}^2$	0.36	0.16	0.13	0.36	0.37	0.22	0.37	0.30	0.08	0.15	0.29	0.33	0.18	0.32

[a]Dependent variable: average growth rate of TFP, 1980–1995.

for example), it agrees more closely with the period for which we estimated labor shares, and in any case it is interesting to know if the results hold in shorter periods. If anything, the rejection of the Solow prediction seems stronger in the second half of the sample, with saving rates and workforce growth entering with high economic and statistical significance.

Visual inspection of the data is useful to reassure ourselves that the results are not being driven by a few outliers. Figures 1–6 show scatterplots of the bivariate relationships between TFP growth and each of the three variates: s_K, s_H, and n. To conserve space, we show results only for the larger sample in which we have imposed a fixed labor share of 0.65; the results for the smaller sample with directly estimated labor shares are quite similar, as the reader can verify from the regression results reported in Tables 11 and 12. Figures 1–3 show the results without a quality adjustment for the labor force; Figures 4–6 adjust labor-force quality by assuming a 7% return to a year of schooling. As suggested by the regression results, the weakest relationship is between TFP growth and schooling, especially when the human-capital correction is used (as expected). However, the relationship of TFP growth to both saving rates and workforce growth seems to be quite robust. It is difficult to account for these results by appealing to measurement

Figure 1 RELATION OF TFP GROWTH TO SAVING RATE

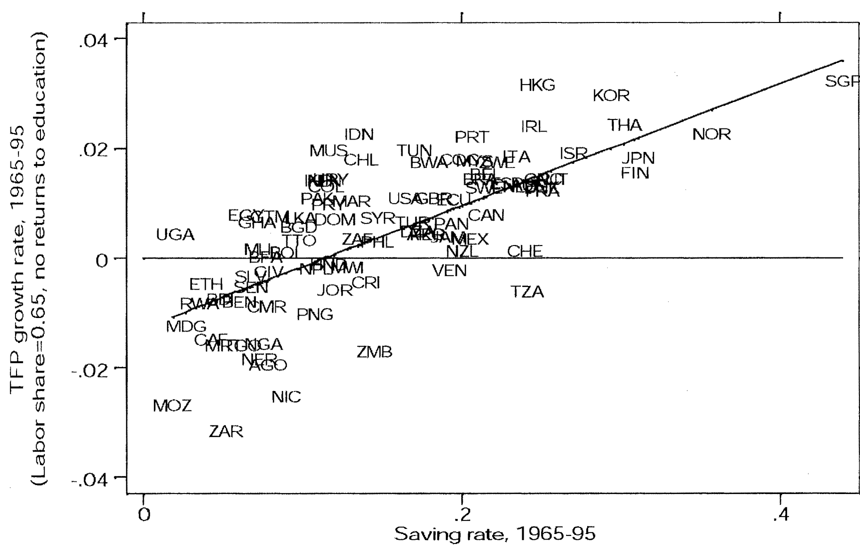


Figure 2 RELATION OF TFP GROWTH TO SCHOOLING RATE

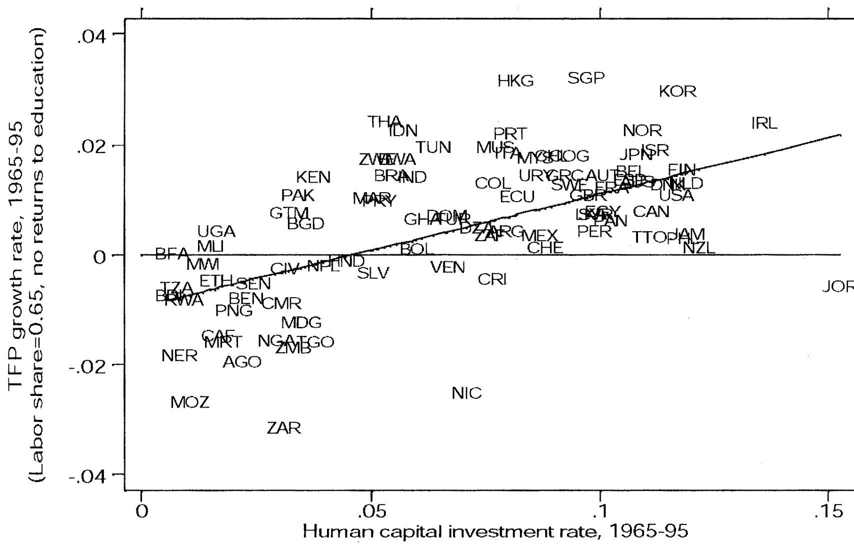


Figure 3 RELATION OF TFP GROWTH TO LABOR FORCE GROWTH RATE

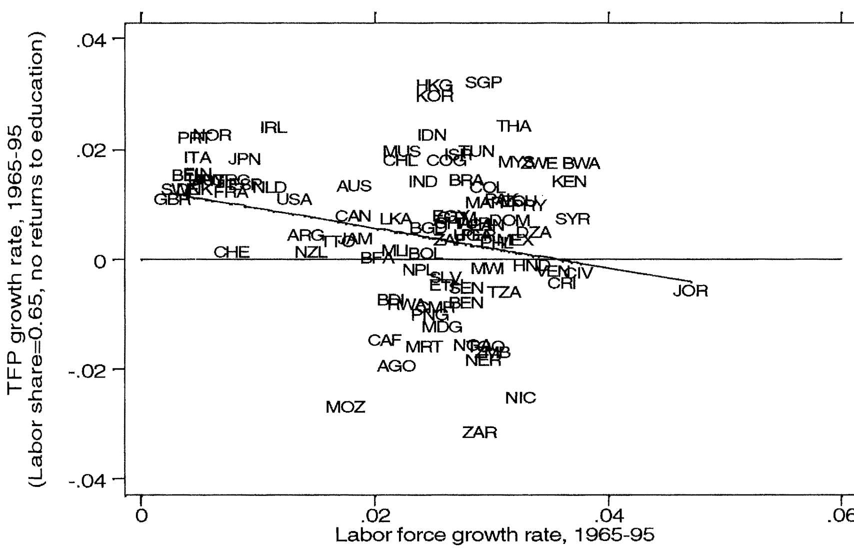


Figure 4 RELATION OF TFP GROWTH TO SAVING RATE

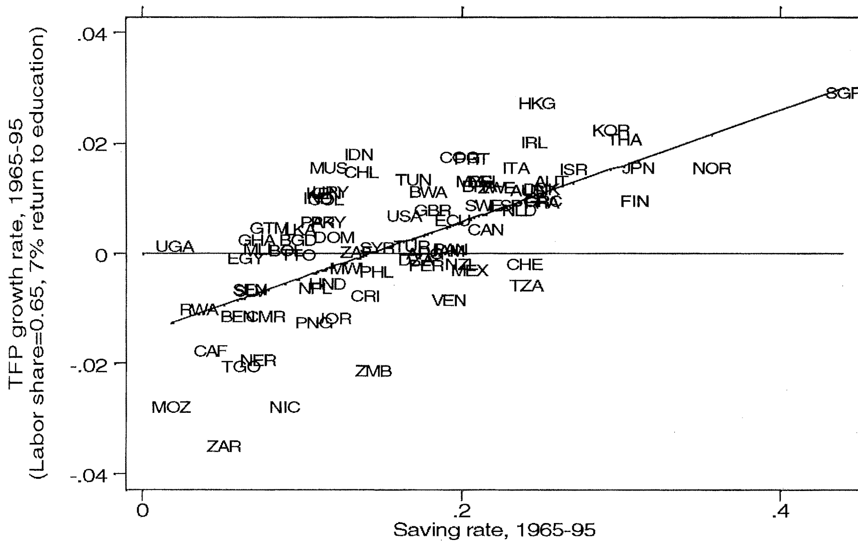


Figure 5 RELATION OF TFP GROWTH TO SCHOOLING RATE

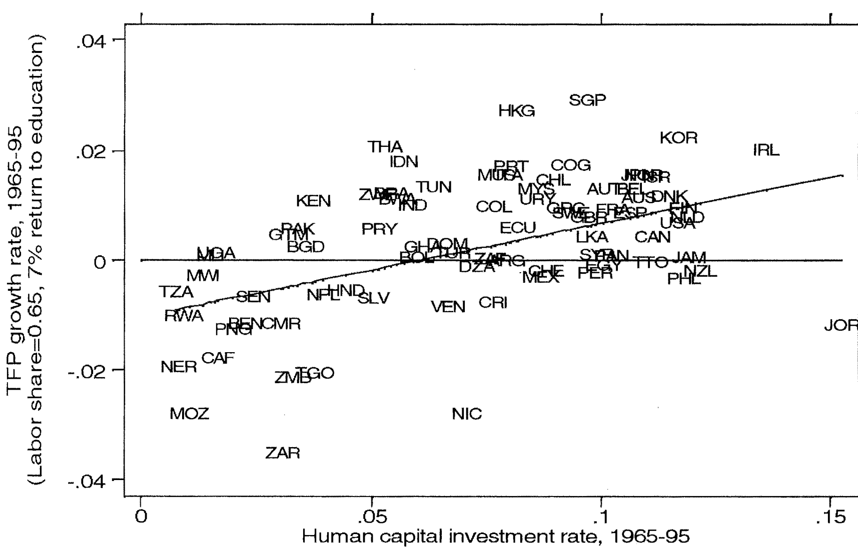
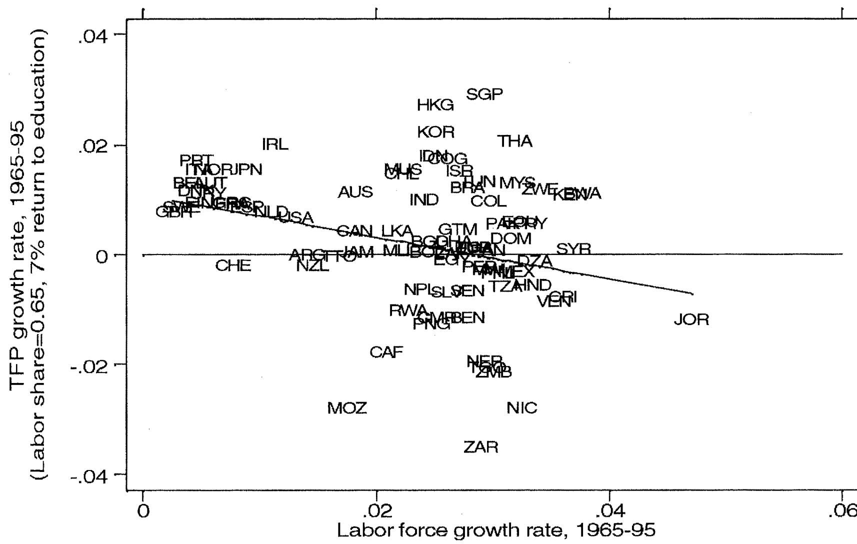


Figure 6 RELATION OF TFP GROWTH TO LABOR FORCE GROWTH RATE



error: For example, if saving rates are mismeasured, the resulting misestimation of the capital stock should tend to induce a negative relationship between TFP growth and the saving rate, rather than the positive relationship we observe.

7. *Conclusion*

We have revisited Mankiw, Romer, and Weil's classic empirical study of the Solow model of economic growth. We showed that the MRW framework applies broadly to almost any economic growth model that admits a balanced growth path, and that the restrictions specifically imposed by the Solow model tend to be rejected. In particular, we find that variables such as the saving rate seem to be strongly correlated with long-run growth rates. The correlation of variables like the saving rate with long-run output growth rates is inconsistent with the joint hypothesis that the Solow model is true and the economies being studied are in their respective steady states. The finding that the saving rate and the growth rate of the labor force are correlated with estimated TFP growth is inconsistent with the standard Solow model, even if we do not assume steady states.

We also use the MRW framework to consider some alternative models of economic growth, such as the Uzawa–Lucas model and the *AK* model. These models are rejected as literal descriptions of the data. However, the implications of these models, that country growth rates depend on behavioral variables such as the rate of human-capital formation and the saving rate, seem more consistent with the data than the Solow model's assumption that growth is exogenous. Future research should consider variants of endogenous growth models to see which, if any, provide a more complete and consistent description of the cross-country data. We believe that the generalized MRW-type framework we have developed here could prove very helpful in assessing the alternative possibilities.

Appendix. Additional Country Data

See Table 13.

Table 13 ESTIMATED TFP GROWTH RATES, 1965–1995

	Growth Rate (%/yr)			
	Actual Labor Shares		*Labor Share = 0.65*	
Country	*No Returns to Education*	*7% Return to Education*	*No Returns to Education*	*7% Return to Education*
Algeria	0.35	−0.23	0.39	−0.22
Angola	—	—	−2.05	—
Argentina	—	—	0.34	−0.11
Australia	1.30	1.10	1.24	1.06
Austria	1.52	1.41	1.33	1.22
Bangladesh	—	—	0.47	0.14
Belgium	1.67	1.41	1.43	1.20
Benin	—	—	−0.90	−1.24
Bolivia	−0.02	−0.06	0.00	−0.04
Botswana	−0.47	−0.92	1.66	1.01
Brazil	—	—	1.33	1.13
Burkina Faso	—	—	−0.07	—
Burundi	−0.37	—	−0.83	—
Cameroon	—	—	−0.98	−1.24
Canada	0.78	0.40	0.71	0.34
Central Afr. R.	—	—	−1.57	−1.88
Chile	1.66	1.37	1.70	1.39
Colombia	1.22	0.87	1.22	0.87
Congo	1.72	1.68	1.71	1.65
Costa Rica	−0.34	−0.70	−0.54	−0.87
Denmark	1.31	1.21	1.17	1.08
Dominican Rep.	—	—	0.61	0.19
Ecuador	0.81	0.48	0.97	0.49
Egypt	1.10	0.06	0.70	−0.18

Table 13 CONTINUED

	Growth Rate (%/yr)			
	Actual Labor Shares		Labor Share = 0.65	
Country	No Returns to Education	7% Return to Education	No Returns to Education	7% Return to Education
El Salvador	−0.53	−0.85	−0.43	−0.79
Ethiopa	—	—	−0.56	—
Finland	1.63	0.97	1.46	0.86
France	1.41	1.09	1.12	0.84
Ghana	—	—	0.56	0.15
Greece	1.93	1.33	1.35	0.86
Guatemala	—	—	0.67	0.36
Honduras	—	—	−0.22	−0.65
Hong Kong	2.63	2.25	3.06	2.62
India	—	—	1.31	0.91
Indonesia	—	—	2.17	1.71
Ireland	2.56	2.12	2.31	1.92
Israel	1.93	1.51	1.81	1.42
Italy	1.91	1.60	1.74	1.46
Ivory Coast	−0.34		−0.35	—
Jamaica	0.30	−0.03	0.29	−0.06
Japan	1.92	1.65	1.71	1.46
Jordan	−0.72	−1.33	−0.67	−1.29
Kenya	—	—	1.32	1.00
Korea, Rep.	2.87	2.13	2.87	2.13
Madagascar	—	—	−1.32	—
Malawi	—	—	−0.27	−0.37
Malayasia	1.73	1.27	1.66	1.21
Mali	—	—	0.07	−0.03
Mauritania	—	—	−1.69	—
Mauritius	1.73	1.36	1.87	1.46
Mexico	0.09	−0.45	0.25	−0.39
Morocco	0.80	—	0.93	—
Mozambique	—	—	−2.78	−2.89
Nepal	—	—	−0.30	−0.73
Netherlands	1.26	0.70	1.22	0.68
New Zealand	0.05	−0.29	0.02	−0.30
Nicaragua	—	—	−2.62	−2.89
Niger	—	—	−1.93	−2.04
Nigeria	—	—	−1.66	—
Norway	2.08	1.41	2.18	1.47
Pakistan	—	—	0.99	0.47
Panama	0.76	0.13	0.54	−0.02
Papua N. Guinea	—	—	−1.11	−1.35
Paraguay	0.13	−0.17	0.87	0.47

Table 13 CONTINUED

	Growth Rate (%/yr)			
	Actual Labor Shares		*Labor Share = 0.65*	
Country	*No Returns to Education*	*7% Return to Education*	*No Returns to Education*	*7% Return to Education*
Peru	0.44	−0.12	0.34	−0.32
Philippines	0.06	−0.49	0.19	−0.42
Portugal	2.44	1.91	2.10	1.62
Rwanda	—	—	−0.91	−1.12
S. Africa	0.24	−0.07	0.25	−0.07
Senegal	—	—	−0.62	−0.75
Singapore	2.09	1.85	3.12	2.82
Spain	1.34	0.83	1.25	0.76
Sri Lanka	1.27	0.91	0.64	0.34
Sweden	1.44	0.97	1.18	0.78
Switzerland	0.33	−0.08	0.05	−0.30
Syria	—	—	0.62	0.00
Tanzania	—	—	−0.70	−0.69
Thailand	—	—	2.32	1.97
Togo	—	—	−1.69	−2.15
Trinidad & Tobago	0.33	−0.03	0.22	−0.12
Tunisia	1.82	1.23	1.85	1.24
Turkey	—	—	0.55	0.03
Uganda	—	—	0.34	0.04
United Kingdom	1.28	0.93	1.00	0.70
United States	1.22	0.76	0.99	0.59
Uruguay	1.29	1.00	1.34	1.02
Venezuela	−0.22	−0.72	−0.33	−0.94
Zaire	—	—	−3.23	−3.61
Zambia	−1.97	−2.44	−1.79	−2.22
Zimbabwe	—	—	1.64	1.09

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Comment

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Paraphrasing MRW, Bernanke and Gürkaynak have titled their paper "Is Growth Exogenous? Taking Mankiw, Romer, and Weil Seriously." I can't resist the temptation to summarize my reactions to their paper by adding my own variation to the paraphrasing theme and title my discussion "Is Growth Exogenous? Taking Mankiw, Romer, and Weil a Bit Too Seriously."

As I understand it, the paper attempts to provide two contributions. The first contribution is methodological, and consists in developing a framework to use cross-country macroeconomic data to test any growth model that admits a balanced growth path. In my comment I will applaud the elegance of the idea, but will argue that, by taking the balanced-growth property too seriously, it makes it virtually inevitable that any growth model will be rejected empirically. The second contribution is to assess the empirical validity of the Solow model, using in part, but not exclusively, the methodology I just mentioned. The results are interesting, but I will argue that the authors take the Solow model a bit too seriously as a potential complete description of the data-generating process. The first two parts of my discussion develop these two points. In the final section I add some idiosyncratic notes on the status of growth empirics.

1. *The Methodology*

The methodological contribution of the paper is to propose a general strategy to test growth models within the (large) class that admits a balanced growth path (BGP). The starting point is to note that—along a BGP—economies feature constant values of a number of macroeconomic variables, such as the growth rate of GDP, the saving (investment) rate, the rate of growth of the labor force, the ratio of "idea workers" in the labor force, etc. Let me denote by x the vector of such variables that are constant in BGP. Different growth models impose different restrictions on the BGP relationship between the vector x and the level and the growth rate of per capita income. In general, such restrictions can be represented as a special case of the system

$$\begin{aligned} \ln Y_t &= f(x; t), \\ \ln Y_t - \ln Y_0 &= tg(x). \end{aligned} \qquad \text{(BGP)}$$

If countries in the international data set have been on a BGP over the period of observation, then the vector x can be estimated, for each country, by its historical average. With such estimates at hand, growth models can be tested by testing the restrictions they impose on f and g. In order to improve efficiency, Bernanke and Gürkaynak propose to estimate the two equations jointly, as a *system of unrelated regressions* (SUR).[1]

This is an elegant and sophisticated construct, which has the great merit of firmly grounding empirical work in theory. I also think it is an excellent idea to estimate the equations describing the BGP jointly, so as to achieve greater efficiency, However, I am concerned that the usefulness of this method may be severely limited by its strong reliance on the BGP property. There are three orders of considerations that make me a bit skeptical about the applicability of the method.

The first and obvious problem is clearly acknowledged by the authors, and that is of course that if the economies in the sample are observed outside their BGP, a rejection of the model based on the failure of the BGP restrictions would be spurious. When rejecting based on Bernanke and Gürkaynak's methodology, one never knows if one is rejecting the model, or just the assumption that countries are on their BGP. This is why when trying to make the case against the Solow model Bernanke and Gürkaynak are forced to resort to additional pieces of evidence, collected outside their general methodology (more on this below).

One could argue that, while a rejection is inconclusive because of the transitional-dynamic problem, applications of the method could still be informative in the case of failure to reject. A nonrejection may lead one to increase one's confidence in the joint hypotheses that the particular model that is not being rejected is correct and that the data are drawn from a sample of countries that are on a BGP. My second and third points both imply, however, that it is virtually impossible for this method to deliver a nonrejection in a cross-country sample.

Specifically, the second point is that the authors' methodology—at least as applied in the paper—seems to depend heavily on testing for exclusion restrictions. In particular, if a growth model does not predict that a variable z should be significant in an estimate of the BGP system of equations, failure of this exclusion restriction leads to a rejection of the model. The very practical problem with this is that 10 years of growth regressions have taught us that a very large number of variables tend to enter significantly into the system, and indeed many different sets of variables enter jointly significantly in growth regressions. I suspect, therefore, that for any possible growth model one can find the right z

1. In some applications there are more than two equations describing the BGP, but that is not critical for the purposes of this discussion.

that, showing up significantly in the growth regression, will lead to a rejection of the model.[2]

My third concern with the method's strong reliance on the BGP property derives from the observed behavior of the cross-country distribution of income. Because the cross-country distribution of income is neither exploding nor imploding over the typical sample period used in cross-country growth empirics, a researcher who wants to interpret the data as describing a world of countries in BGP must necessarily assume all countries to share the same BGP growth rate. But then, no cross-country variable should have explanatory power for the cross section or growth rates, a requirement that will obviously always be "rejected."

2. *Solow Empirics*

One of the contributions of the paper is to revisit and challenge Mankiw, Romer, and Weil's contention that the Solow model (in human-capital-augmented form) works well as a model for growth empirics. The BGP equations are

$$\ln Y_t = \gamma + \frac{\alpha}{1-\alpha-\beta}\ln s_k + \frac{\beta}{1-\alpha-\beta}\ln s_h - \frac{\alpha+\beta}{1-\alpha-\beta}\ln(n+g+\delta),$$

$$\ln Y_t - \ln Y_0 = tg + \gamma_0 \ln s_k + \gamma_1 \ln s_h + \gamma_2 \ln n,$$

and Bernanke and Gürkaynak reject the model (mostly) on the ground that s_k, s_h, n enter the growth equation significantly, while the Solow model predicts that the γ's should all be zero. This is striking in that the very same finding led MRW to conclude that the Solow model performs well. The reason for this apparent inconsistency is of course that MRW thought they were testing the Solow model during the transition to the BGP, where rates of accumulation are indeed expected to have explanatory power for growth rates, while Bernanke and Gürkaynak assume the world to be in steady state, where they do not.

2. What does it mean to test a model? I can think of two criteria. The first criterion is to test the basic insight of the model (e.g., "x affects y"). The second criterion is to test whether the model constitutes as exhaustive description of the data (e.g., "x, and only x, affects y). I have just argued that it is virtually impossible to fail to reject any growth model on the basis of the second criterion. But I would also argue that that criterion is overly demanding. After all, labor economists do not reject the human-capital model because variables other than education enter the Mincer regression significantly.

Since they are well aware of the transitional-dynamic difficulty, the authors also perform a completely different experiment. They argue that a key property of the Solow model is that rates of TFP growth are exogenous. Hence, they obtain cross-country estimates of TFP growth rates and regress them on s_k, s_h, and n. Since some of these variables turn out to be significant, they conclude that the data reject the Solow model.

To me this is taking Robert Solow too seriously or, to be more precise, too literally. In particular, this is turning a model's useful simplifying assumption into the model's main insight. In my view the key insight of the Solow model is that factor accumulation per se is insufficient to achieve long-run growth, and that long-run growth can only come from growth in TFP. But it is definitely not the key insight of the model that TFP is exogenous: of course growth is *not* exogenous. Indeed, an implication of the Solow model is that we need to study the determinants of TFP growth. Put differently, it is impossible for me to think of the Solow model as an attempt to fully explain the growth process, much less to be a competitor for models that endogenize TFP growth. On the contrary, the Solow model should be viewed as providing strong motivation for endogenous-growth theory.

Of course, as we explore the determinants of TFP growth, it may well be the case that we discover that the accumulation of some factors has additional indirect growth effects through this channel. This is indeed what Bernanke and Gürkaynak's regression seems to suggest, and from this perspective it may well be the most interesting result in the paper. However, the result should be interpreted with great caution, since we can't be quite sure that the accumulation variables in the TFP-growth equations are not picking up the effects of some omitted variable, a pervasive problem in cross-country growth empirics. Only an instrumental-variables approach can really tackle this issue.

3. *The Status of Cross-Country Growth Empirics*

The most dramatic feature of cross-country income data is of course the enormous dispersion of per capita income. Per capita income ratios between the richest and poorest countries in the world exceed a factor of 30. As mentioned above, as a first approximation this enormously dispersed distribution has been roughly stable over time, at least since 1960. This stability is at least in part a consequence of largely serially uncorrelated growth rates. The sheer magnitude of the inequality of income, along with the rough stability of the distribution, has recently led several researchers to de-emphasize differences in growth rates and instead to give first priority to the task of understanding differences in income *levels*.

This research agenda has already delivered some important insights. For example, it has proved useful to conceptualize per capita income Y as

$$Y = F(\text{factors, efficiency}).$$

Hence, differences in income across countries are attributed to a combination of differences in factor endowments (or accumulated stocks) and the efficiency with which these factors are used. Using data on the factors, it is then possible to decompose the cross-country variation in income into its two determinants. The emerging consensus is that variation in efficiency explains a very large fraction, indeed, a majority, of the variation in per capita income. The search is now on for the sources of such differences in efficiency levels.[3]

Comment[1]

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1. *Introduction*

I would like to start my comments by trying to set a speed record for discussant unfriendliness: I want to object to Bernanke and Gürkaynak's title. Their stated subject is, "Is Growth Exogenous?" My objection is that no one believes that growth is exogenous: growth, like everything else, has a cause. The assumption of exogenous long-run growth is a useful modeling device, not a serious hypothesis.

Fortunately, Bernanke and Gürkaynak do not actually focus on their stated subject. What they in fact investigate is the role of physical and human capital in differences in growth among countries. They take several distinct approaches to investigating this issue. First, they update a paper that Gregory Mankiw, David Weil, and I wrote concerning capital's importance in cross-country differences in economic performance. Second, they point out that Solow-style models imply that rates of investment in physical and human capital do not affect long-run growth. They

3. In developing theories featuring endogenous differences in efficiency and income levels, I think it will continue to be reasonable to write down models admitting a BGP. While certainly not literally true, the BGP property is a convenient approximation when the goal is to focus on level differences.

1. I thank Ben Bernanke and Refet Gürkaynak for providing their data.

therefore test whether investment rates are correlated with growth over the period 1965–1995. Third, they perform analogous tests concerning the correlates of long-run growth for the $Y = AK$ model and the Uzawa–Lucas model. Finally, they examine whether total factor productivity (TFP) growth from 1965 to 1995 is correlated with the investment measures.

In my comments, I want to focus on Bernanke and Gürkaynak's final approach. My reason for not spending time on their extension of MRW is simply that I felt that if I did discuss MRW I should do so thoroughly; and I did not think that would be the most interesting use of my time here. With regard to the examination of correlations between investment measures and growth, this has the problem (which Bernanke and Gürkaynak recognize) that since countries were not all on their balanced growth paths in 1965, even Solow-style models predict a correlation between investment and growth as a result of transition dynamics. Solow-style models also make this prediction if investment rates over the 1965–1995 period differed from investment rates before 1965. Thus this test does not discriminate among the competing theories. Further, it is dominated by Bernanke and Gürkaynak's final approach of looking directly at TFP growth.

The test of the $Y = AK$ and Uzawa–Lucas models suffer from the same limitations: with reasonable transition dynamics and the possibility of changes in fundamentals, these types of models do not deliver sharp predictions. More importantly, we already know that the idea that these models apply to individual countries fails fundamentally. The models imply that there are permanent differences in growth rates, and thus make the highly implausible prediction that the variance of income across countries will explode. They also imply that growth rates should have been rising rapidly over the postwar period as rates of investment in physical and human capital rose, while in fact growth rates have been essentially constant (Jones, 1995).

Because of these considerations, I will concentrate on Bernanke and Gürkaynak's examination of TFP growth. They start this part of their paper by computing TFP growth by country for the period 1965–1995. They then regress TFP growth on measures of physical-capital investment, human-capital investment, and population growth. They find positive and significant coefficients on the investment measures. As they point out, there are two possible reasons for this result. First, physical and human capital could make contributions to output beyond what is measured in the TFP calculations, which employ the standard approach of using earnings to measure marginal products. That is, there could be externalities to capital. Second, capital accumulation could merely be correlated with other influences on TFP growth.

In my comments, I want to first point out some measurement problems that may introduce important biases into Bernanke and Gürkaynak's procedure. I then want to propose a variant on their methodology that I think is cleaner and that allows one to see the limitations and implications of their approach more clearly.

2. *Measurement*

There are two potentially important measurement issues in the TFP calculations, one involving human capital and one involving physical capital. Neither issue is specific to Bernanke and Gürkaynak's paper. The issue involving human capital concerns the production function for human capital. The assumption in the MRW part of the paper is that human-capital production uses physical and human capital just as intensively as goods production. The assumption in the TFP calculations is that to measure human capital, we only need to know how much schooling workers have; this implicitly assumes that physical and human capital play no role in producing human capital. The difference between the two approaches is quantitatively important. For example, the two approaches make very different predictions about what a worker moving from a rich to a poor country will earn. More generally, the implied gap in human-capital stocks between high-saving, high-education and low-saving, low-education countries is much larger under the MRW assumption than under the schooling-only assumption. Thus differences in TFP may be smaller than what Bernanke and Gürkaynak find using their schooling-only assumption. More importantly, some of the relationship between investment and their estimates of TFP growth may actually reflect correlation between investment and measurement error in their estimates of human capital.

This problem is not specific to Bernanke and Gürkaynak: many researchers seem to choose a specification for human-capital production largely arbitrarily. But the choice often has important implications.

With regard to physical capital, Bernanke and Gürkaynak use the standard perpetual-inventory approach to construct estimates of capital stocks from investment data. But Pritchett (2000) has recently pointed out that when governments invest, we cannot be confident that one unit of resources devoted to investment produces anything close to one unit of resources' worth of capital. He makes a strong case that for countries with big, bad governments, this issue can be important. Thus differences in TFP may again be smaller than Bernanke and Gürkaynak's estimates imply. And again, some of their estimated relationship between TFP growth and investment may in fact be a relationship between measurement error and investment.

3. Methodology

Let me now turn to Bernanke and Gürkaynak's methodology. To make the issues clear, I will focus on physical capital and postpone considering human capital until I get to the results. There are two features of Bernanke and Gürkaynak's approach that seem unappealing. The first is its two-step nature. To try to detect if capital contributes more to output growth than is reflected by its private marginal product, they first subtract capital's direct private contribution from output growth and then regress what is left on investment rates. The second is that there is no clear way to interpret the magnitude of their estimates: when they find a positive correlation between TFP growth and saving rates, there is no obvious way to determine the magnitude of capital's implied additional impact on output.

Robert Solow once commented that the way Milton Friedman differs from the rest of us is that while for the rest of us, everything we see reminds us of sex, everything Friedman sees reminds him of the money supply. Well, as an empirical economist, everything I see reminds me of instrumental variables (IV). I therefore want to propose an IV variation on Bernanke and Gürkaynak's procedure.

To do this, suppose log output per worker in country i depends on log capital per worker and other factors:

$$y_i = \alpha k_i + a_i. \tag{1}$$

Bernanke and Gürkaynak's procedure would be to impose an α (derived from income data), compute the residual, and regress the residual on the saving rate. I propose instead to estimate (1) by IV, instrumenting for k with the saving rate. As you might expect, one can show that as long as the saving rate is positively correlated with k (which of course it is), Bernanke and Gürkaynak's procedure yields a positive coefficient on the saving rate if and only if the IV approach yields an estimate of α greater than the one Bernanke and Gürkaynak impose.[2] That is, the IV estimate

2. To see this, consider the more general model $Y = X\beta + \varepsilon$, with instruments W of the same dimension as X. The Bernanke–Gürkaynak procedure is to impose a β, say $\bar{\beta}$, compute the residuals $Y - X\bar{\beta}$, and then regress them on W. This yields

$$\begin{aligned}\hat{\gamma}_{BG} &= (W'W)^{-1}W'(Y - X\bar{\beta})\\ &= (W'W)^{-1}[(W'X)(W'X)^{-1}W'Y - (W'X)\bar{\beta}]\\ &= (W'W)^{-1}(W'X)(\hat{\beta}_{IV} - \bar{\beta}).\end{aligned}$$

Thus the Bernanke–Gürkaynak estimate is nonzero if and only if the IV estimate of β differs from the imposed value.

transforms Bernanke and Gürkaynak's regression coefficient onto a scale that is much easier to understand. As a result, IV provides a more direct and easily interpretable way of getting at what Bernanke and Gürkaynak are interested in.

Putting things in this IV framework makes it clear why Bernanke and Gürkaynak say that there are two possible reasons for their results. Positive correlation between the instrument and the residual causes IV to produce upward-biased estimates. Thus an IV estimate of α that exceeds capital's income share could reflect either externalities from capital or simply correlation between the saving rate and other influences on TFP. And unfortunately, positive correlation between the saving rate and the residual is very plausible. This is a simple application of what I call Xavier's law, which states, "When governments screw up, they screw up big time" (Sala-i-Martin, 1991, p. 371). That is, there tends to be positive correlation among a wide range of forces that determine economic success, such as physical-capital accumulation, human-capital accumulation, market orientation, openness to trade, macroeconomic stability, political stability, lack of corruption, cultural attitudes conducive to growth, and so on. As a result, Bernanke and Gürkaynak's procedure, or its IV cousin, is not a reliable way of testing for externalities from capital.

If we decide to go ahead and do the estimation anyway (in either its Bernanke–Gürkaynak or its IV form), we have to decide whether to consider levels or growth rates. Bernanke and Gürkaynak consider growth rates. That is, they consider not equation (1), but

$$\Delta y_i = \alpha\, \Delta k_i + \Delta a_i, \tag{1'}$$

where the changes are computed from 1965 to 1995. With the IV interpretation of what Bernanke and Gürkaynak are doing, we can describe the advantages and disadvantages of moving from levels to growth rates. The change in the capital stock has less variation than the level, and is less correlated with the saving rate; this tends to reduce the precision of the estimates. On the other hand, the change in the residual is likely to have less variation than the level; this tends to increase the estimates' precision. Similarly, the bias of the estimates can either rise or fall, depending on how the covariances of the instrument with the capital-stock variable and the residual change. Thus theory does not provide clear guidance about whether estimation in levels or in growth rates is preferable.

A final issue about the specification that needs to be addressed is the geographic extent of externalities. Externalities from capital surely do not conveniently operate uniformly within a country and then suddenly stop at borders. Given this, it is unlikely that treating each country as an independent observation, and treating all countries identically, is ideal.

4. *Results from the IV Approach*

One advantage of being a discussant is that it makes it acceptable to try things out speculatively. Thus, despite the reasons I just gave that the IV approach is likely to produce biased estimates and my uncertainty about the consequences of geographic spillovers, I decided to try the IV estimation anyway. Bernanke and Gürkaynak very kindly and helpfully provided their data. I implemented the IV procedure I just described. The only difference is that my instrument is actually the log of $s_i/(n_i + g + \delta)$, since the Solow model with Cobb–Douglas production structure implies that the log of the BGP capital stock is linear in this variable. Following Mankiw, Romer, and Weil, I set $g + \delta$ to 0.05.

Table 1 reports the results. The top panel looks at levels, and the bottom panel at growth rates. Consider levels first. As a warmup exercise, I start with OLS in the first column. Since increases in output

Table 1 ESTIMATES OF CAPITAL'S IMPACT ON OUTPUT[a]

Levels		
Estimation	OLS	IV
α	0.69 (0.02)	0.63 (0.03)
R^2	0.90	
R^2 of first-stage regression		0.82
Growth Rates		
Estimation	OLS	IV
α	0.63 (0.06)	1.55 (0.34)
R^2	0.60	
R^2 of first-stage regression		0.11

[a]Standard errors are in parentheses. All regressions include a constant. The sample size is 88.

coming from sources other than capital accumulation raise the resources available for investment, the OLS estimate is likely to be biased up. And indeed, the OLS estimate of α is quite high: 0.69 (with a standard error of 0.02). What we are mainly interested in, however, is the IV estimate. As the second column reports, it is only slightly smaller than the OLS estimate: 0.63 (0.03).[3]

There are two possible reasons for the finding that the IV estimate is so much larger than capital's income share: there could be large externalities to capital, or the instrument could be correlated with the error term. As I described, some correlation with the error seems likely. Thus we cannot have confidence in a structural interpretation of the IV estimate.

Now consider growth rates, which are what Bernanke and Gürkaynak focus on. As before, the OLS estimate of α is large and tightly estimated: 0.63 (0.06). The IV estimate, however, is now quite imprecise. Its standard error is 0.34; as a result, the two-standard-error confidence interval has a width of 1.36. The main reason is that the saving rate is a much worse instrument for the change in the capital stock than for its level: the R^2 of the first-stage regression is 0.11 here, as opposed to 0.82 with levels. The wide confidence interval means that it is essentially impossible to learn anything important about α from this regression. The point estimate is in fact huge: 1.55. Since this is not remotely plausible as an estimate of capital's importance in production, it strongly suggests correlation between the instrument and the error term.

So far I have ignored human capital. To consider it, I adopt the standard production function,

$$Y_i = A_i K_i^{\alpha}(e^{\phi S_i} L_i)^{1-\alpha}, \tag{2}$$

where S_i is years of schooling (and where I have implicitly adopted the schooling-only view of human-capital production). Dividing both sides by L_i and taking logs yields

$$y_i = \alpha k_i + (1 - \alpha)\phi S_i + a_i. \tag{3}$$

Both S_i and MRW's measure of human-capital investment are measures of time in school. Thus there is little point in instrumenting for S_i with the MRW measure. The instrument list is therefore $\ln[s_i/(n_i + g + \delta)]$ and S_i (and the constant).[4] But again there is reason to fear correlation with

3. Even though the IV and OLS estimates are similar, the Hausman test decisively rejects the null that they are equal ($t = 4.2$).

4. Bernanke and Gürkaynak's human-capital variable is in fact $H_i = \Sigma_j f_{ij} e^{0.07 S_{ij}}$, where f_{ij} is the fraction of workers in country i with j years of schooling. My S_i is therefore $(\ln H_i)/0.07$, which differs slightly from average years of schooling.

Table 2 ESTIMATES OF CAPITAL AND SCHOOLING'S IMPACTS ON OUTPUT[a]

Levels		
Estimation	OLS	IV
α	0.59	0.33
	(0.06)	(0.09)
ϕ	0.15	0.27
	(0.06)	(0.04)
R^2	0.90	
R^2 of first-stage regression		0.90
Growth Rates		
Estimation	OLS	IV
α	0.61	1.48
	(0.06)	(0.36)
ϕ	0.17	0.12
	(0.09)	(0.15)
R^2	0.65	
R^2 of first-stage regression		0.15

[a]Standard errors are in parentheses. All regressions include a constant. The sample size is 80 for the levels regressions, 77 for the growth regressions.

the residual: time in school is likely to be correlated with the same constellation of variables that may be correlated with investment in physical capital.

Table 2 reports the results of estimating (3) by OLS and IV. With both levels and growth rates, the OLS estimates of the importance of physical and human capital are quite high. The estimated α's are about 0.6, and the ϕ's about 0.15. With levels, the IV estimate of α is very much in line with capital's income share: 0.32 (0.09). The estimate of ϕ, however, is very large: 0.27 (0.04). It would be nice if these estimates could be taken as evidence of an absence of externalities from physical capital and of large externalities from human capital. Unfortunately, a more likely possibility is that the estimates largely reflect differing correlations of the instruments with the error term.

Finally, with growth rates, the estimate of α is again highly imprecise and wildly implausible. The estimate of ϕ is reasonable, but also quite imprecise.[5]

5. *Concluding Remarks*

Where do we go from here? One could try to use the IV approach to obtain more trustworthy estimates of the social returns to physical and human capital by controlling for variables that are correlated with saving rates and schooling and that affect economic performance. Unfortunately, I am skeptical that such an approach can ever produce reliable estimates. The effects of Xavier's law are sufficiently pervasive that controlling for all the relevant variables is essentially impossible. Thus, my view is that the solution will have to lie in the instruments rather than the controls. Specifically, I think the identification of the importance of externalities from capital to cross-country income differences is more likely to come not from broad measures of capital accumulation, but from smaller variations that are plausibly uncorrelated with the residual. In other words, I think we should be looking for natural experiments. I also think that any successful effort will have to tackle the issue of the geographic extent of the spillovers.

Despite my reservations about the specifics of their investigation, I want to applaud Bernanke and Gürkaynak for beginning to address the neglected issue of the role of capital externalities in cross-country differences in economic success. Capital externalities were at the heart of early new growth models, and there is plenty of statistical and anecdotal evidence for their importance at the microeconomic level. But recent work on cross-country differences has largely ignored them. By calling attention to their potential importance, Bernanke and Gürkaynak have left us with an important research agenda.

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5. Further, since the coefficient on S_i is $(1 - \alpha)\phi$, the combination of an $\hat{\alpha}$ greater than one and a positive $\hat{\phi}$ means that the estimates imply that, all else equal, an increase in S_i is associated with lower growth.

Discussion

Greg Mankiw acknowledged that Mankiw, Romer, and Weil had stacked the deck in favor of Solow by not imposing the capital share and allowing the data to choose the parameters. In contrast, authors such as Klenow and Rodriguez-Clare who imposed the capital share found that capital explained much less of cross-country differences. He went on to say that one of the big unanswered questions in the empirical growth literature is how to explain the correlation (pointed out by the authors) between TFP growth and factors that affect capital accumulation. He suggested three hypotheses that could explain this correlation: First, measurement error, as discussed by David Romer; second, externalities to physical- and human-capital accumulation; or third, some mechanism that could lead TFP to feed back into capital accumulation. For example, he noted that in work by David Weil, habit formation in consumption results in positive correlation between TFP growth and capital accumulation. Mankiw said that, in order to move forward, the literature must find instruments that distinguish econometrically among the three explanations. He also wondered whether the IV approach used by Romer in his comment might not be just another way of packaging the OLS correlations presented in MRW.

Ben Bernanke emphasized that the central result of the paper was the finding that there is a correlation between long-run growth rates, on the one hand, and saving rates and population growth on the other. The results of the paper do not distinguish among the three explanations put forward by Mankiw or a fourth possible explanation, that a common factor drives both TFP and savings. Bernanke was not convinced by Romer's IV technique, being skeptical that valid instruments for saving rates exist in country panel data sets. He suggested three ways of making progress: First, economists should try to write down simple parsimonious models that can account empirically for the broad facts about growth, in the spirit of the modern literature on modeling business cycles. Second, as David Romer said, researchers should try to identify natural experiments at the country level, such as those used by Esther Duflo in her work on the effects of schooling. Finally, timing relationships, between (say) changes in saving rates and changes in growth rates, might in some circumstances be informative. Bernanke emphasized, however, that the paper shows that the key prediction of the Solow model, that there is no long-run growth from factor accumulation, is not a good first approximation to the facts.

Bernanke, Mankiw, and Romer discussed various issues concerning how to measure human capital and how to write down the human-capital production function. Bernanke felt that while it was theoretically possible to construct a measure of the human-capital stock using the resources devoted to human-capital accumulation and the perpetual inventory method, in practice it would be very hard to collect data on inputs other than students' time. Mankiw noted that, in reality, the lack of physical capital inputs to education was a big problem in developing countries. Romer did not see the problem of measuring human-capital stocks as intractable. For example, one could follow Klenow and Rodriguez-Clare and make some simple assumptions about the fraction of total capital devoted to schooling. Alternatively, the U.S. earnings of immigrants could be compared with the earnings of U.S. natives with the same number of years of education. This gives some idea of whether students' time or physical capital is more important in accumulating human capital. The conclusion from such analyses is that both students' time and other inputs matter for human-capital accumulation, although the production function is not the same as for other types of output.

Referring to David Romer's concern about countries not being the right unit of observation, Bernanke suggested that introducing borders and distance into the empirical analysis might help to refine the estimates.