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Idle Capital and Long-Run Productivity

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Abstract

In the present paper the joint determination of long-run income per worker and capital utilization is studied. It is shown that comparatively low (optimal) rates of capital utilization may arise in poor economies in response to weak underlying structural characteristics. Moreover, the quantitative implications of variable capital utilization are also explored. It is demonstrated that adding endogenous capital utilization to the Solow model implies a rate of convergence in line with empirical estimates, and, that controlling for capital utilization leads to interesting modifications of the results stemming from oft-cited exercises in cross-country growth and levels accounting.

Keywords: Capital Utilization, Growth, Convergence, Total Factor Productivity.

JEL Classification: O41, O47.

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1 Introduction

The implications of variable capital utilization has in recent years received significant attention from macroeconomists' inquiring into the nature and sources of cyclical variation in output.¹ However, when it comes to the study of *long-run* productivity, the issue of capital utilization seems to have been somewhat neglected in the macroeconomic literature. There may be several reasons for this state of affairs. First, while it seems intuitively clear that capital utilization may undergo substantial changes in the short-run, when capital is fixed, it is less obvious that an economy persistently (i.e. on average over longer periods of time) would "under-utilize" the stock of capital. It is perhaps even less clear that such average rates of utilization should vary across countries in a systematic fashion. Second, even if capital is persistently under utilized, to a varying degree from one country to the next, one might suspect that this variation is likely to be, quantitatively, unimportant.

In addressing the first concern, the analytical framework invokes the approach developed by Taubman and Wilkinson (1970). The essential assumption is that increasing capital utilization increases the user cost of capital through an accelerated rate of capital depreciation. As a consequence of this assumption, profit maximizing behavior will imply that the rate of capital utilization is linked to the average productivity of capital. Higher capital productivity engenders higher rates of utilization. As the average product of capital, in the long-run steady state of the model, is linked to the structural

¹This renewed interest has been sparked by two discoveries. First, endogenous capital utilization appears to improve otherwise standard real business cycle models' ability to account for persistence in output fluctuations (e.g. Greenwood, Hercowitz and Huffman, 1988; Burnside and Eichenbaum, 1996). Second, the cyclical behavior of the Solow residual changes substantially, once capital utilization is taken into account. In particular, the residual becomes much less volatile, and much less highly correlated with output growth (e.g. Burnside, Eichenbaum and Rebelo, 1996).

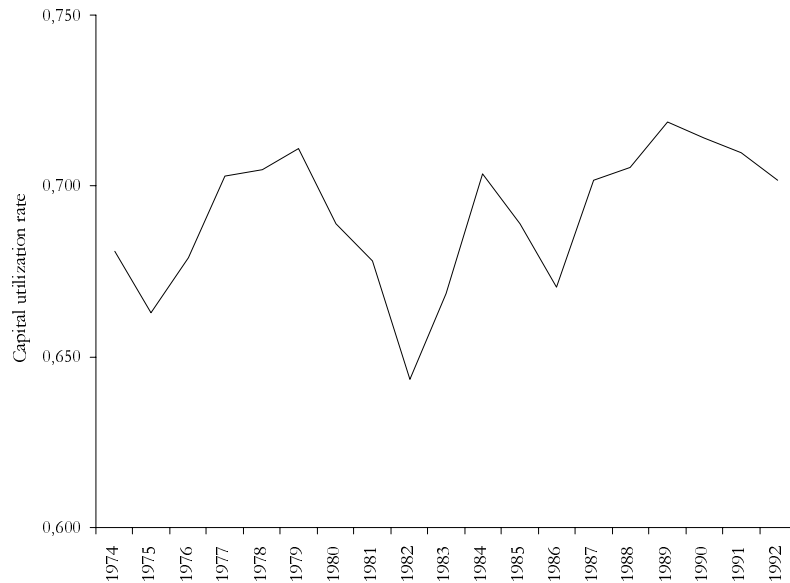


Figure 1: **Capital utilization rate for US manufacturing.** *Source:* Beaulieu and Matthey (1998). Note: The original data are from surveys by the Census Bureau. The utilization rate is computed as the fraction of hours per year where the equipment is used to the maximum number of hours per year. Maximum utilization is fixed at twenty hours per day, or, 7300 hours per year.

characteristics of the economy, rates of capital utilization should be expected to vary across countries. As argued below, cross-country variation in measured capital utilization suggest that the induced productivity differences, from this kind of variation, may be substantial. In addition, the notion of a steady state level of capital utilization seems to be broadly consistent with U.S. experience over the last couple of decades for which consistent data are available. Figure 1 shows the evolution of the rate of capital utilization within US manufacturing. As can be seen, capital is not fully utilized; on average the utilization rate is sixty nine percent. In addition, even though

the curve is rather uneven, with its peaks and valleys, the utilization rate has exhibited no clear trend over the period 1974-1992.

The formal analysis is related to that of Calvo (1975) who analysed the “desirability” of capital under-utilization within a neoclassical optimal growth model, in the absence of technical progress. However, while Calvo focused on the question of existence of a steady state with idle capital, the present paper focuses on the determinants of the long-run rate of capital utilization. Aside from investigating the sources of long-run capital idleness theoretically, the present paper also explores the quantitative implications of adding endogenous capital utilization to the analysis of long-run productivity differences.²

In particular, it is demonstrated that the rate of convergence implied by the Solow model, using plausible parameter values, is reduced to being between two and three percent, a result which conforms well with empirical estimates. The intuition behind the result that the rate of convergence declines in the presence of (this form of) endogenous capital utilization is straight forward. Suppose the economy is converging toward steady state from below. As the economy accumulates capital, the average product of capital declines. This induces firms to utilize capital less intensively, which means that the impact on aggregate capital growth, from a marginal increase in the stock of capital, is reduced. As a result, the time it takes to reach the long-run level of capital per worker is prolonged.

Another issue investigated below is the consequences of recognizing under-utilization of capital for the study of the proximate sources of long-run productivity. As is well known, over the last few years a number of studies have

²Calvo’s analysis has recently been extended by Licandro et al (2000) and Rumbos and Aurenheimer (2001) by allowing for capital adjustment costs. A few other contributions have also analyzed the role of capital utilization in a long-run context, albeit assuming an exogenous rate of utilization. See Winston (1971) for an analysis of this issue within a Harrod-Domar model, Betancourt and Clague (1981, ch. 10) for the long-run implications of capital utilization using a Solow model.

shown that differences in total factor productivity (TFP) can account for the lions share of the global variation in income per capita levels and growth rates (Hall and Jones, 1999; Klenow and Rodriguez-Clare, 1997; Easterly and Levine, 2001). As a consequence, theories emphasizing the gradual diffusion of technologies (e.g. Nelson and Phelps, 1966; Howitt, 2000) have gained momentum at the expense of models stressing the accumulation of capital. However, none of the aforementioned empirical studies take capital utilization into account, which means that variation attributed to “technology” may derive, in part at least, from variation in capital utilization. Following up on this concern, the important contributions of Klenow and Rodriguez-Clare (1997) and Hall and Jones (1999) are revisited in the light of the theoretical analysis. As shown below, correcting for capital utilization lead to interesting modifications of the original findings.

In their growth accounting study, Klenow and Rodriguez-Clare uncover a negative correlation between growth in the capital-output ratio, and calculated TFP growth rates. From a theoretical perspective this is a puzzling finding. If growth is endogenous, one might expect that countries with policies and institutions detrimental to capital accumulation also should be characterized by low rates of TFP growth. As demonstrated below, endogenous capital utilization can account, qualitatively and quantitatively, for this finding.

Another puzzling finding in the Klenow and Rodriguez-Clare study is the pervasiveness of negative TFP growth. Indeed, in roughly twenty five percent of their 98 country sample, TFP growth is recorded as negative on average over the 1960-85 period. The average rate of TFP decline for this group of countries is above one percent per year. Taking capital utilization rates into account, however, this result is substantially remedied.

The results from revisiting the Hall and Jones study also indicate that capital utilization is a factor worth including in the analysis. Indeed, if

capital utilization is controlled for, the ranking of countries by TFP levels becomes much more plausible, and, the correlation between levels of income per worker and TFP is strengthened.

The plan for the paper is as follows. Section 2 contains a brief discussion of the scope for variation in capital utilization to account for long-run productivity differences. Section 3 augment the Solow model by adding endogenous capital utilization whereupon its long-run determination is studied. Section 4 explores some quantitative implications of adding capital utilization to the analysis, and Section 5 contain concluding remarks.

2 Does Capital Utilization Matter For Long-Run Productivity?

Consider a continuous time version of the Solow model where capital utilization is parameterized. Accordingly, the economy is closed, all markets are competitive, and consumers save a constant fraction, s , of their total income; the remaining part is consumed. The work force grows at a constant rate, n , and capital depreciates at the rate δ . There are exogenous technical progress. Specifically, technology advances at the rate $\dot{A}(t)/A(t) = g$. Output, $Y(t)$, is produced combining human capital augmented labor, $hL(t)$, and capital services $\beta K(t)$. Both the level of human capital, h , and the rate of capital utilization, β , are assumed constant over time. In sum:

$$Y(t) = (\beta K(t))^\alpha (hL(t) A(t))^{1-\alpha}. \quad (1)$$

Given this set of assumptions it follows that the stock of capital per effective worker, $k(t) \equiv K(t)/A(t)L(t)$, evolves in accordance with:

$$\dot{k}(t) = s\beta^\alpha k(t)^\alpha h^{1-\alpha} - (n + \delta + g)k(t), \quad k(0) \text{ given.}$$

Solving for the steady state level of income per efficiency unit of labor, $Y(t) / [A(t) L(t)]$, leads to the following expression:

$$y^* = \left(\frac{\beta s}{n + \delta + g} \right)^{\frac{\alpha}{1-\alpha}} h.$$

As can be seen, the rate of capital utilization enters in a similar fashion to the savings (or, investment) rate. Hence, the elasticity of long-run income with respect to β is $\alpha / (1 - \alpha)$. The parameter α can, under the assumption of competitive markets, be interpreted as the (gross) share of capital compensation in total income. Based on data from the US it is common to assume that $\alpha \in (1/3, 0.4)$.³ Thus, $\alpha / (1 - \alpha)$ lies in a range from 1/2 to 2/3. In order to get a feel for the size of income differences that may be generated from variation in capital utilization, one need cross-country estimates for β . Unfortunately, capital utilization cannot be directly observed. Thus an indirect route has to be followed. At its most detailed level such an approach would have census material at its base. As comprehensive census studies on capital utilization are rare the following example will have to serve as an illustration of the likely differences in utilization rates, between developed and developing economies.

Winston (1971) report results stemming from a 1966 survey of the workweek of capital in 62 industries in Pakistan. Assuming (arbitrarily) a maximum workday for capital of twenty hours, Winston reports that capital equipment, averaging over all industries in the sample, were in use in 33 percent of the time. Foss (1981) present the results from two Census Bureau surveys of capital utilization in US industries. The surveys were conducted in 1929 and again in 1976. Averaging over all the industries in the sample reveal that capital equipment were in use roughly 78 and 98 hours per week in 1929 and 1976, respectively. Accordingly, the workweek of capital equip-

³Even in cross country data, this assumption appears to be roughly appropriate. See Gollin (forthcoming).

ment appears to have risen over the period by almost twenty five percent.⁴ Insofar as this increase took place smoothly over the period implies that the US workweek of capital in 1966 were around 93 hours, which indicate (defining a maximum workday of capital as twenty hours) that US equipment were in use roughly 66 per cent of the time during a year. Assuming the numbers obtained from the two surveys are indicative of the trend level of capital utilization in the two economies imply that differences in capital idleness can, depending on the estimate for capitals' share, account for a long-run income gap of forty one to fifty nine percent.⁵ This implies that roughly fifteen percent of the productivity gap between the two countries, in 1966, can be accounted for by differences in capital utilization alone.⁶ Hence, judged on basis of a standard neoclassical growth model plausible variation in rates of capital utilization may translate into non-negligeable long-run productivity differences. Off course, if one were to allow for endogenous growth, differences in utilization rates would translate into long-run *growth* differences, implying that even tiny differences in utilization rates entail large productivity gaps, in the long-run.

3 The Solow Model with Endogenous Capital Utilization

In what follows capital utilization will be endogenously determined in a manner originally suggested by Taubman and Wilkinson (1970). Under this approach, the rate of capital utilization is to be thought of as the intensity, or speed, at which capital is operated, per unit of time. The key assumption

⁴This trend evolution may be overstated (perhaps even non-existent) if the U.S. economy, at the time of the survey, already were sliding into the great depression.

⁵That is, $\left(\left(\frac{66}{33}\right)^{1/2} - 1\right) / 100$ and $\left(\left(\frac{66}{33}\right)^{2/3} - 1\right) / 100$, respectively.

⁶According to the revised PWT 6.0, income per worker in 1966 were 3632 and 38390 PPP corrected US\$ in Pakistan and USA, respectively.

is that increasing utilization leads to accelerated capital depreciation, and as a result, to increased user costs of capital, due to the wear and tear on equipment.^{7,8} In formal terms the rate of depreciation is given by

$$\delta(t) = d\beta(t)^\phi, \quad \phi > 1, \quad d > 0, \quad (2)$$

where $\delta(t)$ is the rate of depreciation at time t , $\beta(t)$ is the rate of utilization, while d and ϕ are parameters. This simple formulation has the advantage that empirical values can be obtained for ϕ , which will be used below in assessing the quantitative implications of utilization for the growth process.⁹

Formally, then, the problem of the representative firm is to maximize profits, i.e.

$$\max_{K,L,\beta} Y(t) - w(t)L(t) - q[r(t) + \delta(t)]K(t),$$

where $w(t)$ is the real wage, and $r(t)$ the real rate of interest. The parameter $q \geq 1$ is thought to capture distortions that enhances the costs of acquiring capital goods. The constraints associated with the problem are the production function, (1), and equation (2). The first order conditions are

$$\alpha \frac{Y(t)}{K(t)} = q[r(t) + \delta(t)] \quad (3)$$

⁷This approach can be traced back to Keynes who argued that the user cost of capital :“...constitutes one of the links between the present and the future. For in deciding his scale of production an entrepreneur has to exercise a choice between using his capital now and preserving it to be used later on ...”. Cited in Taubman and Wilkinson (1970, p. 209).

⁸For an alternative approach, which explicitly links capital utilization to the prevalence of shift-work, see Lucas (1970).

⁹Some direct evidence on this approach is available. Epstein and Denny (1980) implement an econometric model of endogenous utilization and depreciation on aggregate US manufacturing data. They find that the standard assumption of constant depreciation can be rejected in favor of their model. Although they do not identify the parameters in (2), this finding does suggest that the considered mechanism is empirically relevant. Estimates for ϕ derive from RBC studies where general equilibrium models are taken to the data (see below).

$$(1 - \alpha) \frac{Y(t)}{L(t)} = w(t) \quad (4)$$

$$\alpha \frac{Y(t)}{\beta(t)} = q\phi d\beta(t)^{\phi-1} K(t). \quad (5)$$

Of these, only equation (5) is non-standard. The condition states, that the marginal gain, in profits, from increasing utilization has to equal the marginal costs, deriving from accelerated depreciation. Note that (5) can be solved for the optimal capital utilization rate, at time t , as a function of the average productivity of capital

$$\beta(t) = \left(\frac{\alpha}{\phi d q} \frac{Y(t)}{K(t)} \right)^{\frac{1}{\phi}}. \quad (6)$$

The simplest way to proceed involves substituting for β in the production function, equation (1). After some rearrangements, production per effective unit of labor input, $y(t) \equiv Y(t)/A(t)L(t)$, can be written

$$y(t) = Ek(t)^\mu h^{1-\mu}, \quad (7)$$

where $E \equiv (\alpha/(\phi dq))^{\alpha/(\phi-\alpha)}$, $k(t) \equiv K(t)/A(t)L(t)$ and $\mu \equiv \alpha \frac{\phi-1}{\phi-\alpha} < 1$.¹⁰ Note that the elasticity of capital with respect to output no longer equals α , but $\mu < \alpha$. The elasticity is smaller because increasing capital input, ceteris paribus, leads to a lower average productivity of capital, which the firm responds to by cutting the utilization rate.

Since the remaining part of the model is as described in Section 2, the capital stock in efficiency units evolves in accordance with

$$\dot{k}(t) = sy(t) - (n + \delta(t) + g)k(t), \quad k(0) \text{ given.} \quad (8)$$

Next, using equation (6) in equation (2) it follows that depreciation, at time t , is given by $\delta(t) = [\alpha/(\phi q)] [y(t)/k(t)]$. Using this along with equation

¹⁰See Appendix A for derivations.

(7) in equation (8) implies that

$$\dot{k}(t) = \tilde{s}Ek(t)^\mu h^{1-\mu} - (n+g)k(t), \quad (9)$$

where $\tilde{s} \equiv s - \alpha/(\phi q)$ is to be interpreted as the net investment rate. If $\tilde{s} \leq 0$ the dynamical system will be characterized by global contraction. Accordingly, in what follows attention is restricted to the more interesting scenario where $\tilde{s} > 0$. In this case the model behaves exactly as a standard Solow model. The economy gradually approaches its unique (non-trivial) steady state, along which

$$\left(\frac{y}{k}\right)^* = \frac{n+g}{\tilde{s}}, \quad (10)$$

and where the steady state level of utilization is given by

$$\beta^* = \left(\frac{\alpha}{\phi dq} \frac{n+g}{s - \alpha/(\phi q)}\right)^{\frac{1}{\phi}}. \quad (11)$$

Thus, insofar as different economies are equipped with different structural characteristics, the long-run utilization rate will vary from one country to the next. Differences in labor force growth, the rate of technical progress, the (net) investment rate, and country specific distortions (captured by q), will lead to permanent differences in β^* . Notice that q affects the steady state rate of utilization through two channels, both of which works to reduce long-run utilization. The effect running through the first term in the parenthesis, $\alpha/\phi dq$, is a direct effect on firm behavior. A high effective (relative) “price” on capital implies that a marginal increase in the depreciation rate, induced by higher utilization, entail a larger marginal reduction in profits. Consequently, firms will tend to lower the rate of utilization in order to reduce the depreciation rate, and, as a result, the user cost of capital. This reduction in capital depreciation will, in addition, entail a higher net investment rate. This indirect effect, associated with the term $s - \alpha/(\phi q)$, induces a lower

average product of capital in the long run, and, as a result enhances the original decline in utilization. Hence, the analysis implies that more distorted economies, in the sense of a “high” q , should be expected to have lower rates of capital utilization. The remaining parameters, n, g and s , all affect β^* through their impact on long-run average productivity of capital.¹¹

3.1 Capital Utilization and the Level of Economic Activity

In the light of the discussion above it is of interest to inquire whether utilization is likely to be higher in economies with high levels of income per worker. As it turns out, this question does not allow for a clear-cut answer. On the one hand, countries with high savings rates will, *ceteris paribus*, obtain high levels of income per worker, and, as seen above, relatively low steady state utilization rates. On the other hand, highly distorted economies (that is, countries with high values for q) will tend to have both low levels of income, and rates of utilization.¹² Slight extensions of the model above further underline the potential complexity of the relationship between capital utilization and the stage of development.¹³

¹¹The analysis of growth with endogenous capital utilization can easily be extended to allow for optimizing behavior on the part of households. Appendix B solves the social planners problem in the Ramsey-Cass-Koopmans model and derives the long-run savings rate, and rate of capital utilization. In this model long-run differences in utilization rates are also related to the preferences of the representative household.

¹²Actually, the relationship between steady state income and q is not unambiguous. On the one hand, higher costs of investment will lower steady state utilization, and thereby contribute to lower long-run productivity. On the other hand, lower utilization entail less depreciation, which works to increase capital, and thus income, per worker. It can be shown that the former effect will dominate the latter if and only if $s > \alpha/q$. Thus, if either s or q is sufficiently large, higher investment costs will always lower long-run productivity. Jones (1994) find that a higher relative price of investment goods tend to depress long-run productivity.

¹³This ambiguity is in contrast to the theoretical contribution of Kim and Winston (1974), who argue, based on a model of a representative firm, that the optimal utilization rate should be expected to be lower in richer economies.

In a recent paper, Mayer and Howitt (2001) hypothesize that the long-run growth potential of an economy crucially depends on its capability to imitate during early phases of development. This capability, in turn, is determined by the human capital stock. In particular, if an economy is sufficiently human capital poor it might never be able to imitate, and, as a result, will be stuck in a no-growth equilibrium. The flavor of this idea can be captured by assuming that

$$g = \begin{cases} \bar{g} > 0 & \text{if } h \geq \tilde{h} \\ 0 & \text{otherwise} \end{cases},$$

where \tilde{h} is a critical human capital stock required to imitate. Since average productivity of capital is increasing in the long-run growth rate of the economy, “poor” economies will tend to have lower rates of capital utilization than fast-growing countries.

Another possibility is to hypothesize, as Azariadis and Drazen (1990), that the level of production (for convenience proxied by the capital stock) matters for the efficiency at which capital and labor are converted into output. A simple way to express this idea in formal terms is to assume that

$$y(t) = A(k(t)) E k(t)^\mu h^{1-\mu},$$

where $A'(k) > 0$. More specifically, suppose the economy can benefit from a more efficient technology, if the stock of physical capital reaches a sufficiently high level:

$$A(k) = \begin{cases} A_H & \text{if } k(t) \geq \bar{k} \\ A_L & \text{if } k(t) < \bar{k} \end{cases}.$$

The dynamics of the economy is now characterized by

$$\dot{k}(t) = \begin{cases} \tilde{s}A_H E k(t)^\mu h^{1-\mu} - (n+g)k(t) & \text{if } k(t) \geq \bar{k} \\ \tilde{s}A_L E k(t)^\mu h^{1-\mu} - (n+g)k(t) & \text{if } k(t) < \bar{k} \end{cases}.$$

Now, consider the capital-output ratios in the two steady states (assuming the A 's and the \bar{k} is chosen so that there exists two):

$$\left(\frac{k}{y}\right)_H^* = \frac{\left(\frac{\tilde{s}A_H}{n+g}\right)^{\frac{1}{1-\mu}}}{A_H \left(\frac{\tilde{s}A_H}{n+\delta}\right)^{\frac{\mu}{1-\mu}}} = \frac{\tilde{s}}{n+\delta} = \frac{\left(\frac{\tilde{s}A_L}{n+g}\right)^{\frac{1}{1-\mu}}}{A_L \left(\frac{\tilde{s}A_L}{n+\delta}\right)^{\frac{\mu}{1-\mu}}} = \left(\frac{k}{y}\right)_L^*.$$

Thus, in the presence of this form of threshold effects it follows that even if long-run income levels differ substantially, the average productivity of capital, and therefore, the rates of capital utilization, may not.

In sum, the relationship between long-run capital unemployment, and the level of development, is theoretically ambiguous. So far, only very few comparative studies of capital utilization exist, and the general message emerging from this empirical literature seems to mirror the theoretical ambiguity.¹⁴ As a result, whether utilization is higher or lower in richer places is an empirical issue to be settled.

4 Quantitative Implications

In this section the analytical framework developed above is confronted with data. Using estimates for the elasticity of the depreciation rate with respect to utilization, the outcomes from recent growth and levels-accounting exercises are reassessed. Moreover, it is also demonstrated that the rate of convergence implied by the augmented Solow model lies in an interval between two and three percent, in accord with available evidence.

¹⁴Kim and Winston (1974) argue, based on data for Pakistan, South Korea and the United States, that utilization seems to be higher in richer economies. Their measure of utilization is defined in terms of the relationship between electricity consumption and the rate capacity of electric motors over the year. Betancourt and Clague (1981), on the other hand, reports data from a survey undertaken in four countries: India, Japan, Israel and France. Here, utilization is defined as the prevalence of shift work. That is, utilization is higher the larger the share of firms in the economy where shift work is used. Their conclusion is that there appears to be very little systematic relationship between utilization and the stage of development.

4.1 Cross-Country Growth Accounting Revisited

In the important contribution by Klenow and Rodriguez-Clare (1997) (KR), the authors goes through a series of accounting exercises. Specifically, TFP is calculated as the residual, A , in the following equation

$$\frac{Y(t)}{L(t)} = A(t) h(t) \left(\frac{K(t)}{Y(t)} \right)^{\frac{\alpha}{1-\alpha}}, \quad (12)$$

where $\alpha = 1/3$ is used, and $h(t)$ is calculated primarily on the basis of information on years of schooling, and Mincerian returns on education. The authors' calculate TFP growth rates as

$$g_y - g_h - \frac{\alpha}{1-\alpha} g_\kappa = g_A,$$

where $y \equiv Y/L$ and $\kappa \equiv K/Y$. The variance decomposition, using $(g_y, g_h, g_\kappa, g_A)$, reveal that TFP by-and-large can account for the observed growth differences. Indeed, more than ninety per cent of the variation in growth in income per worker can be accounted for by variation in TFP growth.

However, their empirical investigation also unravels a couple of puzzles. First, In a cross section of countries, the growth rates of TFP and κ are *negatively* correlated. From a theoretical perspective this finding, which is reproduced in Figure 2, is concentering. If growth is endogenous, one might expect that countries with policies and institutions detrimental to capital accumulation should also be characterized by low rates of TFP growth, as a consequence of, say, low rates of technological adoption. Second, as can be seen from Figure 2; a rather large number of countries appear to have undergone “technical regress” over the period 1960-85. Specifically, this is the case for twenty four countries. The average rate of decline in TFP, for this group of countries, is 1.13 percent per year.

Now, suppose capital utilization is added to the analysis. Then the accounting exercise has the following equation as point of departure

$$y(t) = A(t) h(t) \beta(t)^{\frac{\alpha}{1-\alpha}} \kappa(t)^{\frac{\alpha}{1-\alpha}}. \quad (13)$$

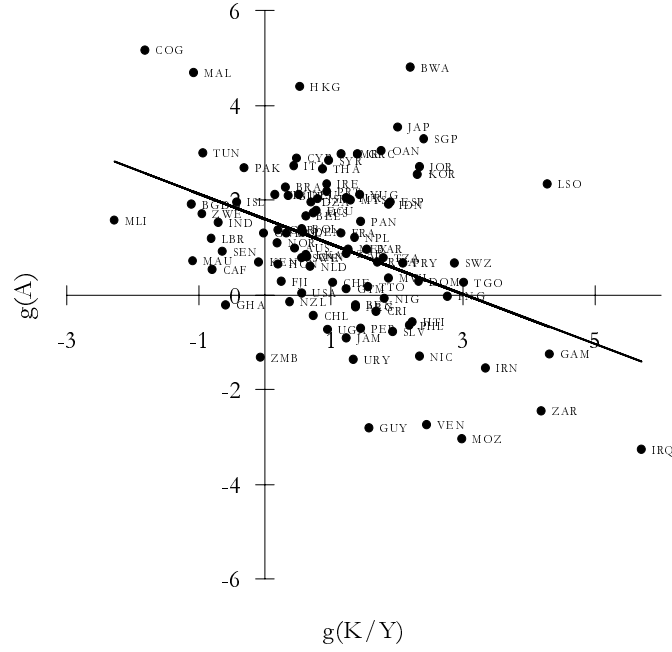


Figure 2: **TFP growth vs. growth in the capital - output ratio.** *Data source:* Klenow and Rodriguez-Clare (1997). Note: The solid line is estimated by least squares.

Consequently, TFP growth is recovered as

$$g_y - g_h - \frac{\alpha}{1 - \alpha} g_\kappa - \frac{\alpha}{1 - \alpha} \frac{\dot{\beta}(t)}{\beta(t)} = \frac{\dot{A}(t)}{A(t)}.$$

Thus, failure to take utilization into account introduces a systematic bias into the TFP estimate. Specifically, the calculated rates of KR are related to the “true” TFP growth, $\left[\dot{A}(t)/A(t)\right]^T$, in the following way

$$\frac{\dot{A}(t)}{A(t)} = \left[\frac{\dot{A}(t)}{A(t)}\right]^T + \frac{\alpha}{1 - \alpha} \frac{\dot{\beta}(t)}{\beta(t)}. \quad (14)$$

In order to push this issue a little further, note that the model developed in Section 3 imply that changes in utilization rates are related to changes in

the capital-output ratio, $\dot{\kappa}(t)/\kappa(t)$ (cf. equation (6)):

$$\frac{\dot{\beta}(t)}{\beta(t)} = -\frac{1}{\phi} \frac{\dot{\kappa}(t)}{\kappa(t)}.$$

Substituting this expression back into equation (14) yields

$$\frac{\dot{A}(t)}{A(t)} = \left[\frac{\dot{A}(t)}{A(t)} \right]^T - \frac{\alpha}{\phi(1-\alpha)} \frac{\dot{\kappa}(t)}{\kappa(t)}. \quad (15)$$

Hence, a possible explanation for the puzzling negative correlation between growth in the capital-output ratio and “TFP”, is that capital utilization tends to decline when the capital-output ratio rises. Moreover, if capital utilization declines, TFP growth is underestimated by the KR method. Accordingly, time-varying capital utilization rates may also be responsible for the seemingly negative TFP growth rates discussed above. The real test of these explanations, however, is whether they make sense quantitatively.

A simple way to approach the first issue of the negative correlation between factor accumulation and TFP growth, is to estimate the following equation, using KR’s data set:

$$\frac{\dot{A}(t)}{A(t)} = b_0 + b_1 \frac{\dot{\kappa}(t)}{\kappa(t)} + \varepsilon. \quad (16)$$

If the utilization story makes sense then the estimate of b_1 should take on the value implied by $\alpha/[\phi(1-\alpha)]$. In a recent study, Burnside and Eichenbaum (1996) take a general equilibrium RBC model to U.S. data. In the process they estimate ϕ to be around 1.56. Allowing the estimate to move two standard deviations to either side implies that it could take on a value between 1.45 and 1.65.¹⁵ Invoking these empirical results, along with standard estimates for capitals’ share, implies that the estimate of b_1 should lie in the region $[0.3, 0.46]$ (cf. Table 1).

¹⁵Thus their empirical estimates are in accord the independent study by Finn (1995), who calibrate a (somewhat different) RBC model (also to US data) and obtain a value for ϕ of approximately 1.45.

$\phi \backslash \alpha$	1/3	0.4
1.45	.35	.46
1.56	.32	.43
1.65	.30	40

Estimating equation (16) by least squares yields the following result (robust standard errors in parentheses):

$$g_A = \underset{(0.19)}{1.6} - \underset{(0.14)}{0.53} \cdot \frac{\dot{\kappa}(t)}{\kappa(t)}, \quad R^2 = 0.17. \quad (17)$$

The estimate for b_1 is highly significant, and in the ball park of what was expected. Indeed, taking the standard deviation into account places the estimate comfortably in line with the values shown in Table 1. As a matter of robustness, equation (16) is modified slightly to include growth in human capital, which is also available in the KR data set. This augmentation could be thought to capture the likely interrelationship between human capital accumulation and technological progress, as implied, for example, by the model developed in Dalgaard and Kreiner (2001). The result is

$$g_A = \underset{(0.37)}{1.2} - \underset{(0.17)}{0.42} \cdot \frac{\dot{\kappa}(t)}{\kappa(t)} + \underset{(0.37)}{0.52} \cdot \frac{\dot{h}(t)}{h(t)}, \quad R^2 = 0.2.$$

The interesting finding is that upon inclusion of human capital, the point estimate associated with growth in the capital-output ratio rises to a value which conforms very well with the values predicted in Table 1. Thus it seems that endogenous capital utilization represents a reasonable explanation for the observed negative correlation between TFP growth, and growth in the capital-output ratio.

The results from the first regression are also useful in addressing the second puzzle: the disturbing pervasiveness of negative TFP growth. First of all, note that the estimate for b_0 in equation (16) represents the (“true”)

average TFP growth rate in the sample (cf. equation (15)). The result, 1.6 percent per year, is considerably higher than what is implied by the calculations of KR, i.e. roughly one percent per year. Next, adding the residuals from the regression to the average TFP growth rate yield individual country TFP growth, corrected for capital utilization. Figure 3 shows a cross-plot of the TFP growth rates obtained by KR and the outcome when capital utilization has been controlled for (“CU corrected”).

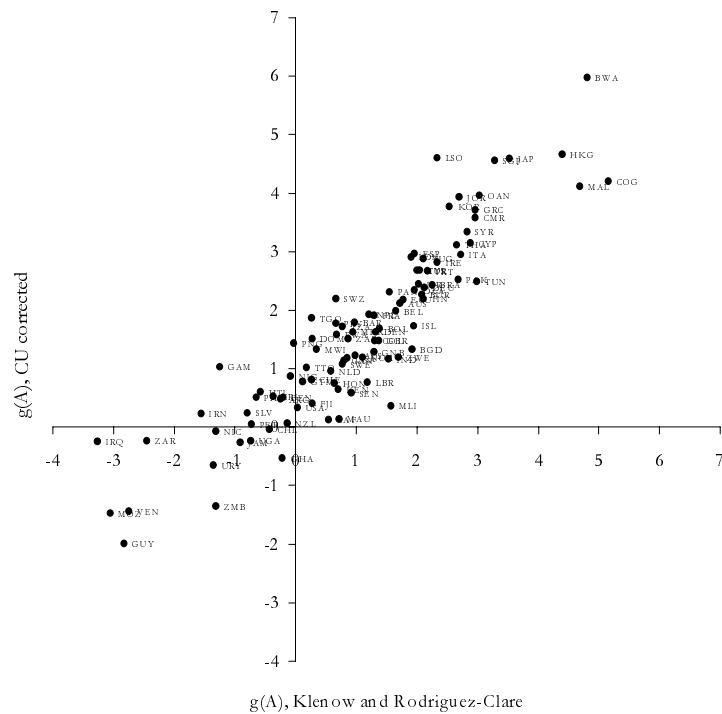


Figure 3: Average TFP growth rates 1960-85, with and without corrections for capital utilization.

Overall the correlation between the two series is obviously high, at 0.91. Nonetheless, allowing for time varying capital utilization does lead to the interesting finding that the number of countries with negative TFP growth falls

significantly. Indeed, TFP growth is now negative in only twelve countries. Moreover, the average rate of TFP decline shrinks to 0.7 percent per annum. This would seem to indicate that many – notably the poorer economies – have witnessed declining rates of capital utilization over the period in question. Although capital utilization appears not to be the full story it seems to go a some way in reconciling the TFP estimates with a prior belief that “technology may stagnate by never shrink”.¹⁶

4.2 Levels-Accounting Revisited

Another much cited contribution in the literature on long-run productivity differences is that of Hall and Jones (1999) (HJ). The key result obtained by the authors is that differences in broad institutions (by the authors’ labeled “social infrastructure”) seems to be a major contributor to long-run differences in income per worker. Moreover, the authors investigate the impact of social infrastructure on the proximate sources of income differences, i.e. capital (physical and human) and TFP. The result is that institutions seem to work primarily through TFP. However, as the authors use the same accounting procedure as KR, one could be concerned that this result is modified once capital utilization is added to the analysis.

This turns out not to be the case. Figure 4 documents a very high correlation with the original HJ TFP estimates.¹⁷ Moreover, the pure correlation

¹⁶Recently, Pritchett (2000) has argued that capital stock estimates, particular in less developed economies, may be very misleading as they are derived on the basis of reported investments, which are unlikely to reflect the amount of actual capital accumulation undertaken. As a result, capital accumulation tends to be overestimated, and therefore, TFP growth becomes underestimated. He shows that if TFP at least can be believed to be constant in the countries with seemingly negative TFP growth, then the capital stock numbers are overestimated by as much as fifty percent. Accordingly, this argument is complementary to the one pursued here, where the idea is that TFP estimates becomes misleading since they are derived under the assumption that capital services rises with the capital stock. If utilization declines, they may not.

¹⁷Relative levels of capital utilization are calculated as $\beta^i/\beta^j = (\kappa^i/\kappa^j)^{1/\phi}$. Using this in

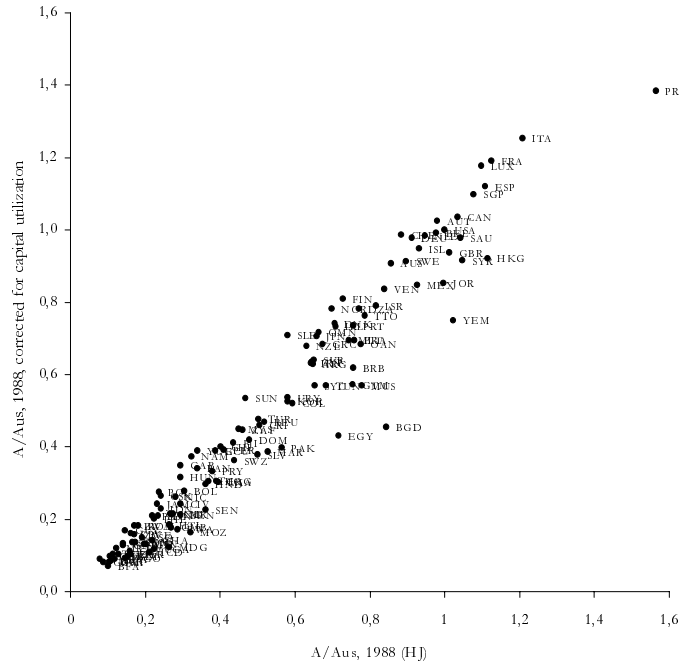


Figure 4: **Relative levels of total factor productivity in 1988, with and without corrections for capital utilization, US =1.** Data source: Hall and Jones (1999).

between TFP and income per worker rises, when moving from the HJ TFP estimates to the corrected figures, from 0.85 to 0.92.

Although the results are similar in terms of pure correlations, the correction does have interesting implications for the *ranking* of countries by TFP levels. Table 2 shows the top twenty ranking implied by the HJ calculations. As can be seen, a number of countries that one does not usually associate

equation (13) allows for the calculation of utilization corrected relative TFP levels. Thus, for this exercise, one important assumption is that the parameters, (d, ϕ) are identical across countries. Moreover, there is a subtlety here as the data on capital stocks builds on the assumption of a common depreciation rate, which is inconsistent with the theoretical model developed in Section 3. Still, the hope is that making some correction for utilization is better than making no adjustment at all.

with “high productivity” are present. These are countries such as Syria (8), Saudi Arabia (9), Yemen (11), Jordan (14) and Mexico (19). However, as the row labeled “CU corrected” indicate, all of these countries’ position is lowered once capital utilization is taken into account. In fact, Jordan, Mexico and Yemen exits top twenty altogether. These three countries are replaced by Sweden (enters at 19th), Switzerland (enters at 11th) and Australia (enters as 20th). Another interesting result is that the position of Hong Kong changes from being the 4th most productive country in the world, to a position as number seventeen. This could be taken to imply that part of the reason for the spectacular performance of this East-Asian tiger is associated with a high level of capital utilization in addition to high investment rates.

Table 2: The Changing Distribution of TFP

Rank HJ	Country	CU corrected	Rank HJ	Country	CU corrected
1	PRI	1	11	YEM	29
2	ITA	2	12	GBR	16
3	FRA	3	13	USA	9
4	HKG	17	14	JOR	21
5	ESP	5	15	AUT	8
6	LUX	4	16	BEL	10
7	SGP	6	17	NLD	12
8	SYR	18	18	ISL	15
9	SAU	14	19	MEX	22
10	CAN	7	20	DEU	13

4.3 The Rate of Convergence

As a point of departure it is useful to briefly review the implications of a standard Solow model, as described in Section 2. In this model it can be shown, that the rate of convergence, λ , is given by:

$$\lambda = (1 - \alpha)(n + \delta + g).$$

As benchmark values for the parameters, the following are usually invoked by appealing to US data: $\alpha = 1/3$ or 0.4, $n = 0.01$, $\delta = 0.05$ and $g = 0.02$.

Together these imply a rate of convergence around five percent, which is two to three percentage points above the value obtained through empirical tests of a structural Solow model.¹⁸

Next consider the model developed in Section 3. It is straight forward to show that the rate of convergence is given by

$$\lambda = (1 - \mu)(n + g).$$

In order to proceed, a reasonable value for μ needs to be chosen.¹⁹ Table 3 shows the values that μ can undertake, allowing for different assumptions regarding capital's (gross) share in total income and ϕ .²⁰

$\phi \backslash \alpha$	1/3	0.4
1.45	0.13	0.17
1.56	0.15	0.19
1.65	0.17	0.21

Using the same values for g and n as above, Table 4 gives the implied rates of convergence for varying values of μ .

¹⁸Structural estimation of the Solow model was pioneered by Mankiw, Romer and Weil (1992) (MRW). Their original convergence estimate of 2-3 percent have subsequently been confirmed in several studies using cross-section data. However, structural estimations of the model, using panel-data and the GMM estimation technique (e.g. Caselli, Esquivel and Lefort, 1996), has led to significantly higher estimates for the rate of convergence, casting some doubt on the MRW finding. A possible reconciliation of the MRW estimate, and the Caselli, Esquivel and Lefort study, has recently been put forward by Bond, Hoeffler and Temple (2001). Essentially, the authors argue, following Arellano (1989), that the standard panel-data GMM estimator may be poorly behaved when time series are persistent. The authors suggest a more efficient GMM estimator, and goes on to show that this brings the rate of convergence back to roughly 2 percent.

¹⁹Recall that $\mu \equiv \alpha(\phi - 1) / (\phi - \alpha)$.

²⁰In a recent study, Dowrick and Rogers (2001) estimate an aggregate (Cobb-Douglas) production function on a panel of 51 countries covering the 1970-90 period. Their estimate for the elasticity of capital w.r.t. output lies in the range (0.17 : 0.23), depending on the exact specification and choice of instruments, which is very well in accord with the numbers reported in Table 3.

$\phi \backslash \alpha$	1/3	0.4
1.45	.0 261	.0 249
1.56	.0 255	.0 243
1.65	.0 249	.0 237

Note: n=0.01,g=0.02

As can be seen, λ lies in a range which is consistent with the empirical evidence on rates of convergence. The intuition for the result that the rate of convergence declines in the presence of endogenous capital utilization is simple. If the economy is converging towards steady state from below, the average product of capital declines in the process. This induces firms to utilize capital less intensively, which means that the impact on aggregate capital growth, from a marginal increase in the stock of capital, is reduced. As a result, the time it takes to reach the long-run level of capital per worker is prolonged.²¹

5 Concluding Remarks

The main message of the present paper is that capital utilization is of importance to economic activity, even from a long-run perspective. As argued above, variation in structural characteristics may lead to varying levels of (long-run) capital utilization rates. The theoretical discussion also demonstrates that the *a priori* relationship between levels of income per worker,

²¹It should be noted, however, that this result is modified if the savings rate is endogenous. Under reasonable parameter values the savings rate will be decreasing in transition to the steady state. As a result the convergence rate implied by a Ramsey - Cass - Koopmans model with endogenous utilization, will be higher than what is implied by a Solow model. This is shown in Appendix B. However, if one were to consider a open-economy Ramsey - Cass - Koopmans model, featuring convex costs of installation, the rate of convergence to the steady state may plausibly be brought back to the level implied by Table 4. See Rumbos and Auernheimer (2001) for details.

and rates of capital utilization, may not be as clear-cut as previous contributions have suggested (e.g. Kim and Winston, 1974). In particular, “poor” countries may very well end up with lower (optimal) rates of capital utilization, than their richer counterparts. This would be the case, for example, if the reason for underdevelopment lies in failing technological progress. Moreover, the theoretical framework can also be implemented empirically, which, as shown above, may be useful in terms of aggregate growth - and levels accounting, and, in reconciling the predictions of the standard neoclassical growth model with available evidence.

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A The Production Function on Intensive Form

Rewriting equation (1) in efficiency units yields

$$y(t) = \beta(t)^\alpha k(t)^\alpha h^{1-\alpha},$$

where $z \equiv Z/AL$, $Z = K, Y$. Next, insert the first order condition for capital utilization, equation (6):

$$\begin{aligned} y(t) &= \left(\frac{\alpha y(t)}{\phi q d k(t)} \right)^{\frac{\alpha}{\phi}} k(t)^\alpha h^{1-\alpha} \\ &\Downarrow \\ y(t)^{\frac{\phi-\alpha}{\phi}} &= \left(\frac{\alpha}{\phi q d} \right)^{\frac{\alpha}{\phi}} k(t)^{\alpha \frac{\phi-1}{\phi}} h^{1-\alpha} \\ &\Downarrow \\ y(t) &= \left(\frac{\alpha}{\phi q d} \right)^{\frac{\alpha}{\phi-\alpha}} k(t)^{\alpha \frac{\phi-1}{\phi-\alpha}} h^{\phi \frac{1-\alpha}{\phi-\alpha}}, \end{aligned}$$

where $\alpha \frac{\phi-1}{\phi-\alpha}$ clearly is less than one. Next, define

$$\mu \equiv \alpha \frac{\phi-1}{\phi-\alpha} \text{ and } E \equiv \left(\frac{\alpha}{\phi q d} \right)^{\frac{\alpha}{\phi-\alpha}}$$

Note that $1 - \mu = 1 - \alpha \frac{\phi-1}{\phi-\alpha} = \phi \frac{1-\alpha}{\phi-\alpha}$. Hence the reduced form production function is:

$$y(t) = E k(t)^\mu h^{1-\mu}.$$

B The Ramsey-Cass-Koopmans model with Endogenous Capital Utilization

Consider the social planners problem, where human capital and q , for ease of exposition, are ignored: $q = h = 1$.

$$\underset{\{c(t), \beta(t)\}_{t=0}^{\infty}}{MAX} \int_0^{\infty} \frac{c(t)^{1-\theta}}{1-\theta} e^{-(\rho-n-(1-\theta)g)t} dt$$

$$\dot{k} = \beta(t)^\alpha k(t)^\alpha - c(t) - (n + g + \delta(t)) k(t), \quad k(0) \text{ given} \quad (18)$$

$$\delta(t) = d\beta(t)^\phi, \quad \phi > 1. \quad (19)$$

$$k(t) \geq 0.$$

All variables are in efficiency units of labor. The Hamiltonian is:

$$H(c_t, \beta_t, k_t, \lambda_t) = \frac{c(t)^{1-\theta}}{1-\theta} + \lambda(t) \left[\beta(t)^\alpha k(t)^\alpha - c(t) - (n + g + d\beta(t)^\phi) k(t) \right].$$

The first order conditions are

$$H_c : c(t)^{-\theta} = \lambda(t) \quad (20)$$

$$\begin{aligned} H_\beta & : \quad \lambda(t) \left(\alpha \beta(t)^{\alpha-1} k(t)^\alpha - d\phi \beta(t)^{\phi-1} k(t) \right) = 0 \\ & \quad \Downarrow \\ \beta(t) & = \left(\frac{\alpha y(t)}{d\phi k(t)} \right)^{1/\phi} \end{aligned} \quad (21)$$

$$H_k : \left(\alpha \frac{y(t)}{k(t)} - d\beta(t)^\phi - n - g \right) \lambda(t) = -\dot{\lambda}(t) + (\rho - n - (1 - \theta)g) \lambda(t). \quad (22)$$

Thus using equations (19) - (21) and (22) leads to:

$$\frac{\dot{c}(t)}{c(t)} = \frac{1}{\theta} \left(\alpha \frac{y(t)}{k(t)} - \left(\frac{\alpha}{\phi} \right) \frac{y(t)}{k(t)} - \rho - \theta g \right) = \frac{1}{\theta} \left(\left(\alpha - \frac{\alpha}{\phi} \right) \frac{y(t)}{k(t)} - \rho - \theta g \right). \quad (23)$$

While equation (18) along with equations (19) and (21) yield:

$$\dot{k}(t) = \left(1 - \frac{\alpha}{\phi} \right) y(t) - c(t) - (n + g) k(t). \quad (24)$$

Output per worker is, using the same steps as in Appendix A:

$$y(t) = Ek(t)^\mu$$

where $\alpha \frac{\phi-1}{\phi-\alpha} \equiv \mu$, $E \equiv \left(\frac{d\phi}{\alpha}\right)^{\frac{\alpha}{\alpha-\phi}}$. Using this in equation (23) and (24) allows one to write the dynamical system of the model as:

$$\begin{aligned}\dot{k}(t) &= \left(\frac{\phi-\alpha}{\phi}\right) Ek(t)^\mu - c(t) - (n+g)k(t). \\ \frac{\dot{c}(t)}{c(t)} &= \frac{1}{\theta} \left(\frac{\alpha(\phi-1)}{\phi} Ek(t)^{\mu-1} - \rho - \theta g\right).\end{aligned}$$

As can be seen, the model with endogenous capital utilization is, in its ultimate form, close to identical to the standard Ramsey-Cass-Koopmans model. As a result, the modified model have the same formal properties as the standard model, i.e. uniqueness of steady state, saddle point stability etc. It is straight forward to solve for the steady state level of capital per efficiency units of labor, and the long-run rate of capital utilization. The latter is given by:

$$\beta^* = \left(\frac{\rho + \theta g}{d(\phi-1)}\right)^{1/\phi}.$$

B.1 Dynamics of the Savings Rate and the Rate of Convergence

Define

$$z(t) \equiv \frac{c(t)}{f(k(t))}$$

next, the evolution in the consumption rate:

$$\begin{aligned}\frac{\dot{z}(t)}{z(t)} &= - \left(\frac{f'(k(t))k(t)}{f(k(t))}\right) \frac{\dot{k}(t)}{k(t)} + \frac{\dot{c}(t)}{c(t)} \\ &= -\mu \frac{\dot{k}(t)}{k(t)} + \frac{\dot{c}(t)}{c(t)}\end{aligned}$$

using the laws of motion for capital and consumption

$$\frac{\dot{z}(t)}{z(t)} = -\mu \left(\frac{\phi - \alpha}{\phi} \right) Ek(t)^{\mu-1} + \mu \frac{c(t)}{k(t)} + \mu(n + g) + \frac{1}{\theta} \frac{\alpha(\phi - 1)}{\phi} Ek(t)^{\mu-1} - \frac{\rho + \theta g}{\theta}$$

rearrangements yield:

$$\frac{\dot{z}(t)}{z(t)} = \mu \left(\frac{\phi - \alpha}{\phi} \right) Ek(t)^{\mu-1} \left[z - \frac{\theta - 1}{\theta} \right] + (\rho + \theta g) \left(s^* - \frac{1}{\theta} \right),$$

where $s^* \equiv \mu \left(\frac{n+g}{\rho+\theta g} \right)$.

Now if

$$\mu \left(\frac{n + g}{\rho + \theta g} \right) = \frac{1}{\theta},$$

the savings rate will be constant in transition to steady state. As a result, the rate of convergence, will, parametrically, be the same as the one implied by the Solow model. (See Barro and Sala-i-Martin (1995, ch. 2) for details on the relationship between the time path of the savings rate and the rate of convergence.) But this condition is not likely to be met, under the parameter values considered in the text. Suppose $r^* = 0.05 = \rho + \theta g$; empirical values for the parameters that generate this long-run real rate of interest could be $\theta = 4$, $\rho = 0.01$ and $g = 0.01$. Next, assume $\mu = 0.2$. Then the *required* n , in order for the savings rate to be constant over time, is

$$n = \frac{0.05}{4 \cdot 0.2} - 0.01 \approx .05.$$

This is too high a rate of growth of the labor force to be realistic, at least for the US economy. From 1950-90 labor force growth in the US were around two per cent per annum. Accordingly, under reasonable parameter values, the savings rate will be *decreasing* toward steady state. As a result, the implied rate of convergence will be higher than that predicted by the Solow model.

It can be shown that the rate of convergence rate of the model is given by

$$\lambda = \frac{1}{2} \left(\varepsilon - \sqrt{\varepsilon^2 + \frac{4}{\theta} \frac{1-\mu}{\mu} (r^*)^2 (1-s^*)} \right)$$

where

$$\begin{aligned} s^* &= \mu \left(\frac{n+g}{\rho+\theta g} \right) \\ r^* &= \frac{\alpha(\phi-1)}{\phi} E(k^*)^{\mu-1} = \rho + \theta g \\ \varepsilon &\equiv \rho - n - g(1-\theta). \end{aligned}$$

Now assuming $r^* = 0.05$ ($\theta = 4$, $\rho = 0.01$ and $g = 0.01$), $\mu = 0.2$ and that $n = 0.02$, it follows that

$$\varepsilon = 0.01 - 0.02 - 0.01(1-4) = .02$$

$$s^* = 0.2 \left(\frac{0.02 + 0.01}{0.05} \right) = 0.12$$

Thus

$$\lambda = \frac{1}{2} \left(.02 - \sqrt{(.02)^2 + \frac{1-0.2}{0.2} (0.05)^2 (1-0.12)} \right) \approx 0.038,$$

which is lower than what a standard Ramsey-Cass-Koopmans model predicts (i.e, in excess of 5 percent), but higher than empirical estimates.

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