Contributions to Macroeconomics

Volume 3, *Issue* 1 2003 *Article* 6

Idle Capital and Long-Run Productivity

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Abstract

This paper examines the joint determination of long-run income per worker and capital utilization. Comparatively low (optimal) rates of capital utilization may arise in poor economies in response to weak underlying structural characteristics. 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 has important consequences for the results stemming from cross-country growth and levels accounting.

KEYWORDS: Capital Utilization, Growth, Convergence, Total Factor Productivity

1 Introduction

The implications of variable capital utilization have 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 would persistently (i.e. on average over longer periods of time) "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 marginal product of capital. Higher capital productivity engenders higher rates of utilization. Since the marginal product of capital in the long-run steady state of the model is linked to the structural 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 suggests 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

[1] This renewed interest has been sparked by two discoveries. First, endogenous capital utilization appears to improve the ability of otherwise standard real business cycle models 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 Mattey (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.

average the utilization rate is 69 percent. While there is substantial year-to-year variation, the utilization rate has exhibited no clear trend over the period 1974-1992.

The formal analysis is related to that of Calvo (1975) who analyzed the "desirability" of capital under-utilization within a neoclassical optimal growth model, in the absence of technological progress.[2] However, while

[2] Calvo'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.

Calvo focused on the question of the 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.

The first quantitative exercise conducted below consists of exploring 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 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 variations attributed to "technology" may derive, in part at least, from variations in capital utilization. Following up on this concern, important cross-country growth and levels-accounting studies are revisited. As demonstrated below, correcting for capital utilization lead to interesting modifications of the original findings.

In their growth accounting study, Klenow and Rodriguez-Clare (1997) uncover a negative correlation between growth in the capital-output ratio, and calculated total factor productivity (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 should also 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 25 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. When capital utilization is taken into account, this result is substantially remedied.

The results from revisiting the Hall and Jones (1999) study also indicate that capital utilization is a factor worth including in the analysis, albeit the size of the original sample is dramatically reduced in order to include comparable data on capital utilization rates. Roughly 14 percent of the variation in levels of income per worker can be attributed to variation in capital utilization rates. This result is somewhat surprising in that the group of countries for which comparable data on rates of capital utilization are available are all relatively rich member states of the European Community. Still, even by this extension, TFP continues to be the single most important factor in accounting for productivity differences.

Finally, 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 that conforms well with empirical estimates. The result is noteworthy in that it arises even though the tendency for diminishing returns is *strengthened* in the model of endogenous capital utilization, as compared with a standard Solow model. Hence, the implied low rate of convergence to steady state is consistent with the emerging consensus among growth researchers that technology, rather than capital accumulation, is at the heart of observed income differences.

This paper proceeds as follows. Section 2 gives a brief discussion of the scope for variations in capital utilization to account for long-run productivity differences. Section 3 augments the Solow model by adding endogenous capital utilization whereupon its long-run determination is examined. Section 4 explores some quantitative implications of adding capital utilization to the analysis, and Section 5 concludes.

2 The Solow Model with Exogenous Capital Utilization

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. 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 to be constant over time. In sum:

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

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:

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

Solving for the steady state level of income per efficiency unit of labor, $y(t) \equiv Y(t)/[A(t)L(t)]$, 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 variations in capital utilization, one needs cross-country estimates for β.

Unfortunately comparable data on capital utilization rates are scarce. Consequently the following example will have to serve as an illustration of the likely differences in utilization rates, between developed and developing economies.[4] Winston (1971) reports results stemming from a 1966 survey of the work week 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, was in use 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

[3] Even in cross country data, this assumption appears to be roughly appropriate. See Gollin (2002).

[4] In the empirical part of the paper a further attempt at gauging the importance of capital utilization for differences in productivity differences, by way of levels-accounting, is presented. However, due to a lack of data, only countries usually considered "developed" are encompassed in the levels-accounting analysis.

in 1929 and again in 1976. Averaging over all the industries in the sample reveal that capital equipment was in use roughly 78 and 98 hours per week in 1929 and 1976, respectively. Accordingly, the work week of capital equipment appears to have risen over the period by almost 25 percent.[5] Assuming this increase took place smoothly over the period implies that the US work week of capital in 1966 was around 93 hours, which indicates (defining a maximum work day of capital as 20 hours) that US equipment was 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 implies that differences in capital idleness can, depending on the estimate of capitals' share, account for a long-run income gap of 41 to 59 percent.[6] This implies that roughly 15 percent of the productivity gap between the two countries in 1966 can be accounted for by differences in capital utilization alone.[7] Hence, judged on the basis of a standard neoclassical growth model, plausible variations in rates of capital utilization may translate into non-negligible long-run productivity differences. Still, the model presupposes that the rate of utilization is exogenous, making it incapable of explaining the cross-country variations in utilization rates that the data just cited indicate exists. Hence, the next section extends the model by allowing capital utilization to be endogenously determined.

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 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

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

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

[7] According to the revised Penn World Tables 6.0, income per worker in 1966 was 3632 and 38,390 PPP corrected US$ in Pakistan and the USA, respectively.

equipment.[8] There is some direct evidence that this mechanism is empirically relevant. Epstein and Denny (1980) implement an econometric model of endogenous utilization and depreciation on aggregate US manufacturing data. They strongly reject the standard assumption of constant depreciation in favor of their model which allows for variable depreciation. Following Burnside and Eichenbaum (1996), this idea is formalized by assuming that the rate of depreciation is given by

$$\delta(t) = d\beta(t)^{\phi}, \;\; \phi > 1, \;\; d > 0, \tag{2}$$

where $\delta(t)$ is the rate of depreciation at time t, $\beta(t)$ is the rate of capital utilization, while d and ϕ are parameters. Evidence discussed below strongly suggests that $\phi > 1$ is an empirically plausible assumption.

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 $q \geq 1$ captures distortions that increases 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

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

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

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

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 arising from accelerated depreciation. Note that (5) can be solved for the optimal capital utilization rate, at time t, as a function of the marginal

[8] This approach can apparently 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).

product of capital, or equivalently, since the present analysis invokes a Cobb-Douglas production function, the *average* product of capital:

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

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

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

where $E \equiv (\alpha/(\phi dq))^{\alpha/(\phi-\alpha)}$, $k(t) \equiv K(t)/A(t)L(t)$ and $\mu \equiv \alpha\frac{\phi-1}{\phi-\alpha} < 1$.[9] 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. Hence, once capital utilization is endogenous, diminishing returns to capital accumulation will set in more quickly for any $\phi > 1$.

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

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

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 (7) in equation (8) implies that

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

where $\tilde{s} \equiv s - \alpha/(\phi q)$ is to be interpreted as the net investment rate. If $\tilde{s} \leq 0$, the dynamic system will be characterized by global contraction. This possibility comes from making depreciation endogenous and ultimately proportional to the average product of capital. In the standard Solow model net investments, $k \cdot (s(y/k) - \delta)$, are always positive when the capital stock is sufficiently small. Essentially this is ensured by assuming a constant depreciation rate along with the (lower) Inada-condition, which states that the marginal (and average) product of capital is infinitely large for a capital stock

[9] See Appendix A for derivations.

near zero. In the present case, however, depreciation is linked to the average product as well. Consequently, the depreciation rate rises explosively when k tends to zero, which implies that net savings may never be positive. In what follows attention is restricted to the more interesting scenario where $\tilde{s} > 0$.[10]

In this case the model behaves exactly as a standard Solow model. The economy gradually approaches its unique (non-trivial) steady state, along which

$$\left(\frac{Y}{L}\right)^{*} = E^{\frac{1}{1-\mu}} \left(\frac{\tilde{s}}{n+g}\right)^{\frac{\mu}{1-\mu}} hA(0)\, e^{gt}, \;\; E \equiv \left(\frac{\alpha}{\phi dq}\right)^{\frac{\alpha}{\phi-\alpha}}, \tilde{s} \equiv s - \frac{\alpha}{\phi q}, \quad (10)$$

while capital utilization remains constant at the level

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

Consider first the expression for long run productivity, $(Y/L)^{*}$. As can be seen from equation (10), the relationship between income per worker on the one hand, and s, n and d (depreciation when capital is fully utilized) on the other, are as in a standard Solow model. But the relationship between long-run productivity and the distortion parameter, q, is less clear cut. Mechanically, $(Y/L)^{*}$ and q are related through the term E, and through net savings, $\tilde{s}$. When q increases, E declines, while $\tilde{s}$ rises. Thus, the net effect is, in general, ambiguous. However, as demonstrated in Appendix B, $(Y/L)^{*}$ is *decreasing* in q, iff

$$s > \frac{\alpha}{q}\frac{\mu + \frac{\alpha}{\phi q}}{\mu + \frac{\alpha}{q}} < 1,$$

that is, if the savings rate is sufficiently large. In the opposite case, where $s < \frac{\alpha}{q}\frac{\mu+\frac{\alpha}{\phi q}}{\mu+\frac{\alpha}{q}}$ (while still being large enough to avoid global contraction), income per worker is actually *increasing* in the distortion parameter. The intuition for this somewhat surprising result is as follows. Suppose q increases, implying an intensification of domestic distortions. This will induce firms' to cut capital utilization as the value of depreciated capital, and thus the costs of utilizing capital intensively, rises. If capital is utilized less intensively then the level

[10] It should be noted that a similar possibility does not arise in a model with Ramsey consumers. Appendix C solves the social planners problem in the Ramsey-Cass-Koopmans model and derives the long-run savings rate, and rate of capital utilization. A more general version of this model can be found in Calvo (1975).

of activity in the economy will decline at all points in time, ceteris paribus. This is the effect running through the term "E", in equation (10). However, lower capital utilization also implies a higher rate of *net* savings, $\tilde{s}$, since capital depreciation declines. This is the effect represented by the term $\alpha/\phi q$ in equation (10). The size of the latter effect will depend on the savings rate, as it determines the steady state level of capital per worker. Intuitively, if the savings rate is low (implying a low steady state stock of capital per worker), then the marginal product of capital is "high", which implies that an increase in (net) savings will have a "large" impact on long-run income per worker. This is why the latter effect tends to dominate when s is sufficiently small, creating the somewhat surprising implication: $\partial y^*/\partial q > 0$. But insofar as the investment rate is beyond the threshold stated above, $\partial y^*/\partial q$ becomes negative.

Based on the condition stated above, it is not entirely obvious which scenario is the more likely one, from an empirical perspective. However, as is also shown in Appendix B, if the economy is equipped with a savings rate close (or equal) to the one corresponding to the golden rule of capital accumulation, then long-run productivity is unambiguously declining in the distortion parameter.[11]

Next, as for capital utilization, it should be clear that 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 savings/investment rate, and country specific distortions (captured by q), will lead to permanent differences in β^*. Note that q affects the steady state rate of utilization through two channels, both of which work 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" of capital implies that a marginal increase in the depreciation rate, induced by higher utilization, entails 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

[11] Jones (1994) find a significant negative association between the relative price of investment and the average growth rate of income per capita. If the relative price of investment is a reasonable proxy for q, then this would indicate that the latter scenario is the empirically relevant one.

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 the long-run average productivity of capital.[12]

3.1 Capital Utilization and the Level of Economic Activity

In 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. In contrast to, e.g., Kim and Winston (1974), who argue that (optimal) capital utilization should be unambiguously higher in "poor" places, the present analysis does not give rise to a clear-cut answer to this question. 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 low levels of both income per worker and rates of utilization. Moreover, slight extensions of the model above further underline the potential complexity of the relationship between capital utilization and the stage of development.

In a recent paper, Howitt and Mayer (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 the 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.

[12] In a Ramsey-Cass-Koopmans model, long-run differences in utilization rates are also related to the preferences of the representative household. See Appendix C for details.

Another possibility is to hypothesize, as Azariadiz 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

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

where $A'(k) > 0$. More specifically, suppose the economy can benefit from 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 are now characterized by

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

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 these forms 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 summary, the relationship between long-run capital utilization and the level of development is theoretically ambiguous.

As for empirical evidence on capital utilization, only a few studies, allowing for cross-country comparisons, seem to exist. Kim and Winston (1974) conclude, based on data for Pakistan, South Korea and the United States, that utilization displays a tendency to rise with income per worker. Their measure of utilization is an indirect one, defined in terms of the relationship between electricity consumption and the rate capacity of electric motors over the year. Betancourt and Clargue (1981), on the other hand, report 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. Finally, the most recent cross-country study (as far as I am aware) on capital utilization was produced by the European Commission in 1991. This study is based on a survey covering 24,000 companies in 10 European countries. In the questionnaire each firm was asked to report its average operating hours per week, a number which ought to track the number of hours per week that capital is used. The results from this study are summarized in Mayshar and Halevy (1997), the source of the data used below. Figure 2 shows the correlation between log income per worker in 1988 and the (average) rate of capital utilization in various countries for 1989. As is visually obvious, the

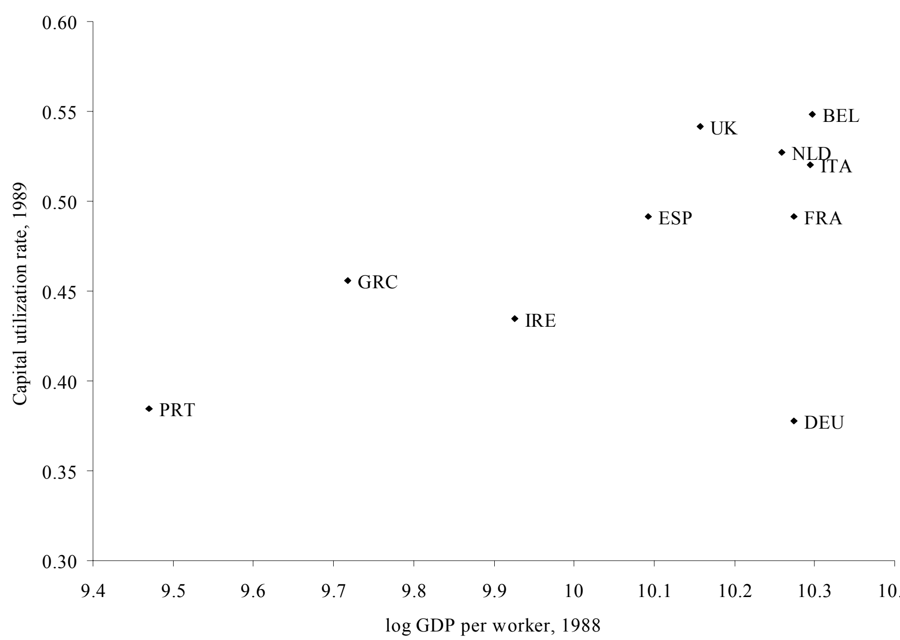

Figure 2: **Capital utilization vs. Income per worker in 10 European countries.** *Data Sources*: Capital utilization is from Mayshar and Halevy (1997), Table 1 "Average weekly hours of plant operation", and refer to averages for the respective economies. Income per worker is from Penn World Tables 5.6. Note: The utilization rates are calculated by assuming that 7300 is the maximum number of operating hours per year.

correlation is positive and quite high, at 0.57. While this (together with the findings of Kim and Winston) does provide some evidence of higher capital utilization in more economically developed regions, it seems fair to say that the relationship between utilization and development is still open to debate. Certainly more data is needed, across countries and time, in order to make more definite statements about what the facts really are. Nevertheless, the model discussed above is consistent with Figure 2, as long as differences in productivity growth, and/or economy-wide distortions, are important determinants of differences in income per worker across countries.

4 Quantitative Implications

In this section the qualitative implications of the analytical framework are explored. In order to do so, however, two questions need to be confronted right away. First, what is an empirically plausible estimate of the elasticity of the depreciation rate with respect to utilization (i.e. "ϕ")? Second, and equally important, what is the empirical relationship between capital utilization and its main determinants (i.e. K/Y and "q") as implied by the model?

4.1 The Model and the Data

In order to pin down a reasonable range of values for the elasticity of the depreciation rate with respect to utilization, three types of data are drawn upon: First, high frequency data that underlie empirical studies of the business cycle; second, low frequency data related to long-run averages for real rates of interest, depreciation rates and shares of capital in national income; and third, cross-country data, which also allows one to ask whether capital-output ratios are related to measures of capital utilization in the manner predicted by the model.

4.1.1 Estimates of ϕ from the Real Business Cycle literature

The most direct way of parameterizing the model is to use existing empirical studies, that attempt to identify ϕ. In a recent study, Burnside and Eichenbaum (1996) apply a general equilibrium RBC model to U.S. aggregate data, which allows them to estimate ϕ. Their point estimate is 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. These results are roughly consistent with independent studies by Greenwood, Hercowitz and Huffman (1988) and Finn (1995). Calibrating (somewhat different) RBC models (also using US data) they obtain a value for ϕ of approximately 1.4. Over-all these studies suggest that ϕ roughly fall in an interval from 1.4 to 1.7.

There are, however, a couple of drawbacks in relying entirely on these estimates, from the perspective of the present analysis. First, they are all based on high frequency information – quarterly data. It is not obvious that using lower frequency data, which arguably are more relevant in a growth context, would yield similar results. Second, the estimates only refer to the US. In what follows data on lower frequencies, and for various countries, will be drawn upon.

4.1.2 Calibrating ϕ

The first calibration exercise uses a unique implication of the model with endogenous capital utilization. Specifically, it can be shown that the first order conditions of the firm imply that[13]

$$r(t) = \delta(t)(\phi - 1),$$

i.e. there is a narrow connection between the instantaneous real rate of return on capital, r, and the instantaneous depreciation rate, δ. To obtain an alternative estimate of ϕ, using lower frequency information, one can calibrate ϕ by applying long-run averages of r and δ. According to Mehra and Prescott (1985) the average long-run return on stocks in the US is about seven percent, which seems to be a reasonable proxy for r. The depreciation rate is more difficult to obtain, but careful studies that attempt to estimate rates of depreciation do exist. A much cited paper due to Hulten and Wykoff (1981) find depreciation rates on capital equipment which averages around 13 percent per annum. A concern, however, is that their methodology assumes a constant rate of depreciation, which is inconsistent with the model above. However, the work of Epstein and Denny (1980) makes no such assumption. Interestingly, their estimate of the depreciation rate on equipment is also

[13] Equation (5) can be restated to yield $\alpha\frac{Y(t)}{K(t)} = q\phi d\beta(t)^{\phi} = q\phi\delta$. Next use equation (3) to substitute for the marginal product of capital. A simple rearrangement then yields the stated result.

about 13 percent on average for US manufacturing 1947-71. Applying these estimates implies that

$$\phi = 1 + \frac{0.07}{0.13} \approx 1.54,$$

which is almost exactly the point estimate obtained by Burnside and Eichenbaum. It is easy to assess the implications for ϕ of varying the assumptions regarding real rates of return and depreciation. For example, Barro and Sala-i-Martin (1995) use five percent as their bench mark value of capital depreciation, taking structures into account. Using this broader concept of capital, it is not entirely obvious that $r = 0.07$ is still a reasonable proxy for the return on capital, since it seems likely that the return on structures is somewhat lower than on stock market investments. Presumably the latter contains a (larger) risk premium. Still, if $r = 0.07$ is maintained, the implied ϕ is about 2.6, or, put another way, in order to obtain $\phi = 1.56$, the return on structures and equipment taken together would need to be around three percent, which is low but not outlandish.

An alternative approach is to invoke national accounts data. The model developed in Section 3 contains the familiar implication that capital's gross share of GDP is a constant, α, by virtue of the Cobb-Douglas production function and competitive markets. But the model also holds predictions for capital's *net* share of output, which theoretically is given by[14]

$$\frac{rK}{Y} = \frac{\left(\alpha \frac{Y}{K} - \delta\right) K}{Y} = \alpha - \delta \frac{K}{Y}.$$

In models where the depreciation rate is exogenous, the net capital share would change over time as the economy builds up capital. Hence, the Cobb-Douglas assumption only ensures that the gross share of capital in output remain constant over time. However, if capital utilization is linked to depreciation and optimally chosen by competitive firms, then $\delta(t) = d\beta(t)^{\phi} = \frac{d\alpha}{\phi d} \frac{Y(t)}{K(t)}$, which implies that capital's net share is given by the constant

$$\frac{rK}{Y} = \alpha \left(\frac{\phi - 1}{\phi} \right).$$

As long as $\phi > 1$, capital's net share of output is positive, and strictly below α. Clearly the size of ϕ can then be inferred from the ratio of capital's gross

[14] Here q is normalized to one, for ease of exposition only.

share to the net share, since according to the above considerations

$$\phi = \frac{1}{1 - \left(\frac{\text{Net capital share}}{\text{Gross capital share}}\right)}.$$

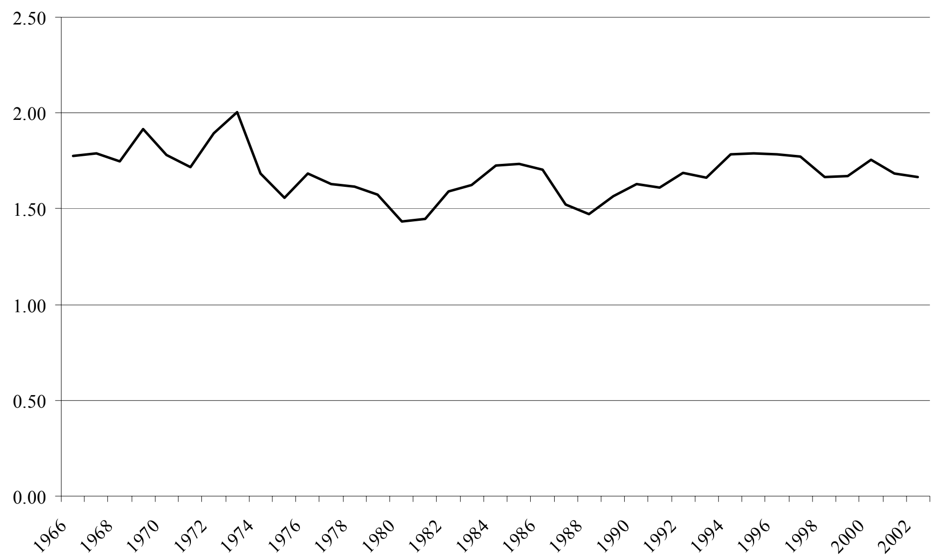

Figure 3: **The graph shows the implied ϕ for Denmark, 1966-2002.** Data source: See Appendix D.

Figure 3 shows the evolution of "ϕ" for the Danish economy from 1966 to 2002, calculated in this manner.[15] As can be seen, it is remarkably stable over the period.[16] The average value for ϕ is 1.69, which is reasonably well in accord with the calibration involving real rates of returns and depreciation rates.

Implicitly Figure 3 also reflects the relative stability of capital's gross *and* net share of total income in the Danish economy.[17] Over the period in

[15] See Appendix D for exact data sources, details of the calculations involved and the series for gross and net capital shares.

[16] Using a likelihood ratio test (Johansen, 1996, Ch. 6) for unit roots reveals that the series for ϕ is indeed mean stationary .

[17] The data series for the net share of capital is also mean stationary judged from the likelihood ratio test (Cf. footnote 16).

question the gross share averaged roughly 30 percent, while the net share averaged 11 percent. Interestingly, the constancy of the net capital share is also found in US data. According to calculations performed by Evans (2000), the net capital share in the US economy hovered around 0.18 from 1947 to 1999, and displayed no statistically significant trend over the post WWII period.[18] This relative constancy of net shares of capital in Denmark and the US provides some additional evidence in favour of the model. As noted above, in standard growth models with exogenous depreciation such constancy is not obtained, even when a Cobb-Douglas production function is adopted.

4.1.3 Some Suggestive Cross-Country Evidence

Based on the theoretical analysis, one should expect a log-linear relationship between capital utilization on the one hand, and the capital-output ratio and country specific distortions on the other (cf. equation (6)). Using the utilization rates displayed in Figure 2, this hypothesized association can be tested using data on capital-output ratios along with an appropriate measure of domestic distortions. Capital-output ratios relate to 1988, and come from Hall and Jones (1999). The distortion parameter, q, is proxied by the relative investment/consumption price in 1988, taken from Penn World Tables 5.6. Accordingly, it is assumed that

$$\ln q^i = \pi \ln \left(\frac{P_I^i}{P_C^i} \right),$$

where π is an unknown factor of proportionality. Hence, the equation that is estimated is

$$\ln \beta^i = \gamma_0 + \gamma_1 \ln \left(\frac{K^i}{Y^i} \right) + \gamma_2 \ln \left(\frac{P_I}{P_C} \right),$$

where $\gamma_0 = \ln \left(\frac{\alpha}{d\phi} \right)$, $\gamma_1 = -\frac{1}{\phi}$, $\gamma_2 = \pi\gamma_1$. In light of the fact that the data on β^i refer to averages over a subset of industries in the ten EC member states,

[18] The level difference in the two estimates of the net share might be attributable to the fact that I subtract the wage income of the self-employed from capital income, as suggeted by Gollin (2002), when calculating capitals share in total output. Without this adjustment the average net share of capital in Denmark is 0.2, which is close to Evans' estimate for the US economy.

it seems unlikely that reverse causality is a major issue. To be sure lagged values for K/Y and P_I/P_C are used (capital utilization is measured in 1989). Estimating the above equation using OLS yields (robust standard errors in parenthesis):

$$\ln \beta^i = \underset{(0.26)}{-0.20} - \underset{(0.30)}{0.58} \ln \left(\frac{K}{Y}\right)^i - \underset{(0.18)}{0.38} \ln \left(\frac{P_I}{P_C}\right), \; R^2 = 0.33.$$

The prediction of a negative association between capital utilization and aggregate capital-output ratios is borne out in the data. The point estimate is borderline significant at the five percent level. Moreover, taking the estimate for γ_1 at face value implies that

$$\phi = \frac{1}{0.58} \approx 1.7,$$

which accords reasonably well with priors.[19] As is apparent, the intercept comes out insignificant in the regression. An interpretation of this finding is that $\frac{\alpha}{d\phi} \approx 1$, which allows for a final consistency check. Suppose $\phi = 1.7$, and $\alpha = 1/3$, then the implied rate of depreciation when capital if fully utilized is $d \approx 0.2$. According to the data reported in Figure 1, the average rate of capital utilization in the US economy, from 1974 to the present day, is about 0.69. Taken together these numbers yield an average depreciation rate for the US of

$$\delta \approx 0.2 \cdot (0.69)^{1.7} \approx 0.11.$$

If $\alpha = 0.4$ the calculated depreciation rate rises to 13 percent, which corresponds exactly to the average estimated depreciation rate, obtained by Epstein and Denny (1980) for US manufacturing.

As a robustness check the log of income per worker in 1988 was used instead of the relative investment price as a proxy for q. In terms of the relationship between K/Y and β the results are virtually unchanged. The estimate for γ_1 is -0.57, with essentially the same standard error, at 0.31. Income per worker is highly significant in the regression, as one would expect based on the correlation seen from Figure 2. While encouraging, these cross-country results are clearly only suggestive in nature. More comparable data

[19] The point estimate is perhaps slightly in the high end. Classical measurement error could, in principle, be responsible for this result. A downward bias of γ_1 implies an upward bias on ϕ.

on capital utilization would certainly be necessary for a more powerful test to be conducted.

However, taken together, the evidence presented above, based on data at different frequencies and for different countries, does seem to be broadly consistent with the main mechanisms of the model. In addition, a reasonable range for ϕ appears to be something like 1.4 to 1.7. This range will form the basis of the quantitative exercises which follow.

4.2 Cross-Country Growth Accounting Revisited

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

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

where $\alpha = 1/3$ is used, and $h(t)$ is calculated primarily on the basis of information about years of schooling, and Mincerian returns to 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, by-and-large, TFP can account for the observed growth differences. Indeed, more than 90 percent of the variation in growth in income per worker can be accounted for by variation in TFP growth.

However, their empirical investigation also raised a couple of puzzles. First, in a cross section of countries, the growth rates of TFP and κ are *negatively* correlated. In fact the correlation coefficient is as high as -0.42. From a theoretical perspective this finding, which is reproduced in Figure 4, is concerning. 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 4, a rather large number of countries appear to have undergone "technical regress" over the period 1960-85. Specifically, this is the case for 24 countries. The average rate of decline in TFP for this group of countries is 1.13 percent per year.

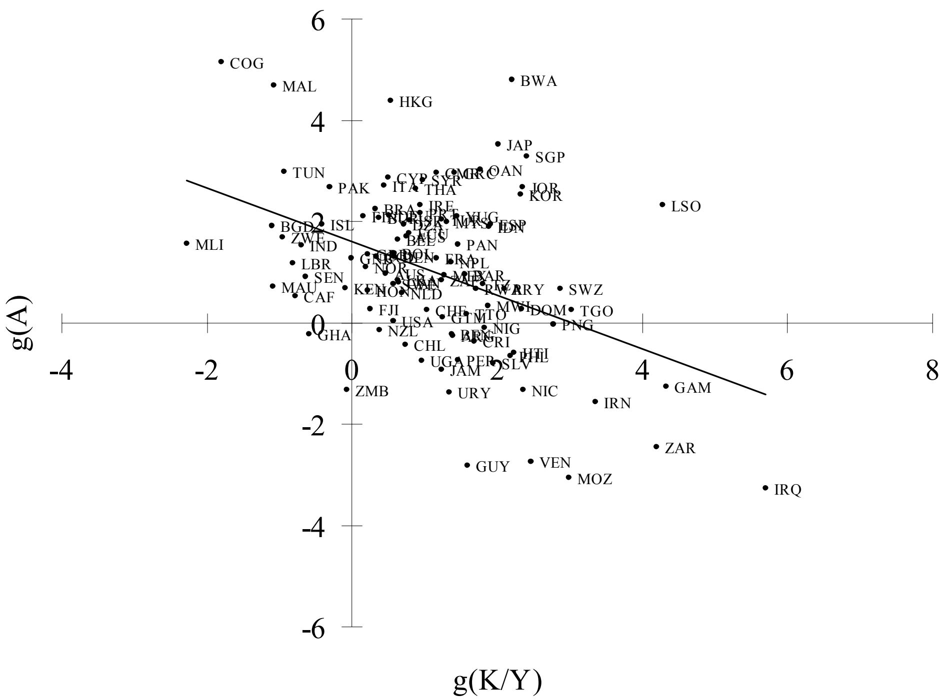

Figure 4: **TFP growth vs. growth in the capital - output ratio**. *Data source*: Klenow and Rodriguz-Clare (1997). Note: The solid line is estimated by least squares.

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

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

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

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

In order to push this issue at little further, note that the model developed in Section 3 implies that changes in utilization rates are related to changes in the capital-output ratio, $\dot{\kappa}(t)/\kappa(t)$ (cf. equation (6)):

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

It is assumed that q stays approximately constant over the period in question, in accordance with the theoretical model developed in Section 3. Substituting this expression back into equation (14) yields

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

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. According to the evidence presented in Section 4.1, a reasonable range for ϕ is 1.4 to 1.7. Moreover, a plausible range for capital's gross share is 1/3 to 0.4. Using these numbers new "utilization adjusted" TFP growth rates are calculated using equation (15).[20] Figure (5) shows the result for $\phi = 1.4$ and $\alpha = 0.4$. This constellation of parameters leads to the highest numerical value for $\alpha/\left[(1-\alpha)\phi\right]$ given the admissible ranges for α and ϕ. As can be seen the correlation drops dramatically. The pure correlation between the two series is now only -0.05.

[20] Since, on average, the capital-output ratio rose in the sample at hand, the inferred capital utilization rate declined by roughly 15 percent from 1960 to 1985 for the average country in the sample, assuming $\phi = 1.4$. For the median country, capital utilization declined by 16 percent. Without actual data on rates of capital utilization, however, it is difficult to say how well this, in general, matches up with the actual experiences of individual countries.

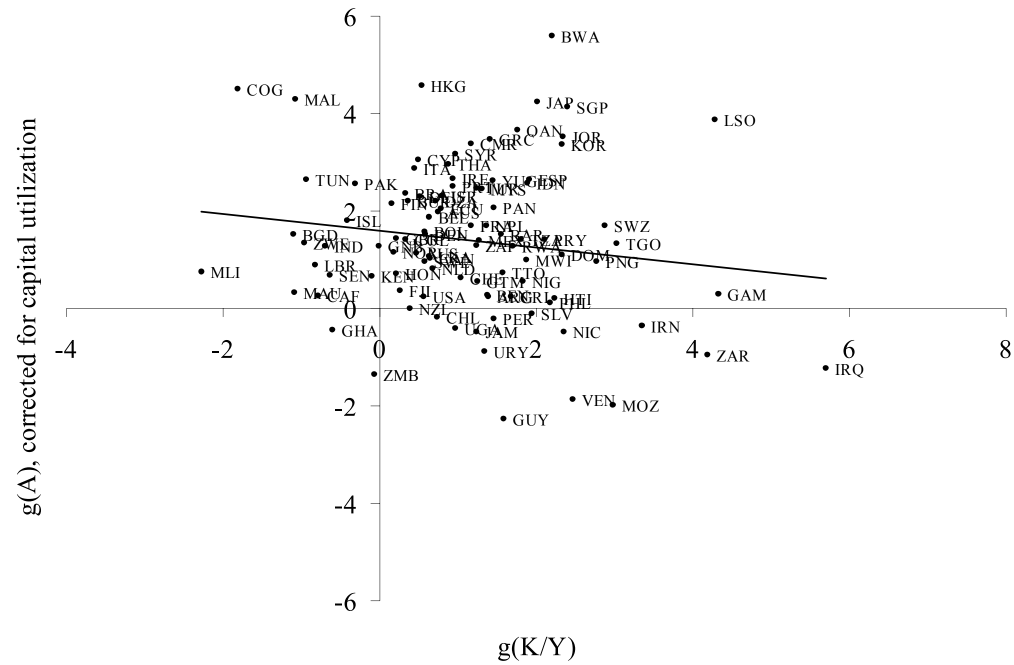

Figure 5: **TFP growth corrected for capital utilization vs. growth in the capital - output ratio**. *Data source*: Klenow and Rodriguz-Clare (1997) and own calculations. Note: (a) The solid line is estimated by least squares. (b) The illustration is based on the assumption that $\alpha = 0.4$ and $\phi = 1.4$.

Moving to the other extreme, where the size of $\alpha / [(1-\alpha)\phi]$ is maximized ($\alpha = 1/3$, $\phi = 1.7$) the correction is less successful in removing the negative correlation. In this case the correlation coefficient is -0.2. Still, even this case corresponds to cutting the original negative correlation in half. Moreover, the association between TFP growth rates and growth in capital-output ratios ceases to be significant at the five percent level.

The correction for capital utilization also matters for the prevalence of negative TFP growth rates; allowing for time varying capital utilization entails that the number of countries with negative calculated TFP growth falls considerably. Again the extent to which the correction modifies the original calculations of KR depend on assumptions made regarding ϕ and α. If

$\alpha = 0.4$ and $\phi = 1.4$, the number of countries featuring negative TFP growth rates declines from 24 to 14. If $\phi = 1.7$ and $\alpha = 1/3$, 17 countries continue to feature negative TFP growth after the correction. In both cases the average rate of decline in TFP is reduced.[21]

These findings could be taken 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 some way in reconciling the TFP estimates with a prior belief that technology may stagnate but never shrink.[22]

4.3 Levels-Accounting Revisited

Another way of analyzing the sources of productivity differences consists of decomposing the variation of the *level* of income per worker into contributions from capital (physical and human) and TFP. A representative study is that of Hall and Jones (1999) (HJ), who calculate levels of TFP for a large cross-section of countries in 1988. Table 1, column 1 shows the results from performing a variance decomposition of income per worker, using HJ's data. The results convey the fundamental message that the bulk of the variations in income per worker can be ascribed to variation in TFP, rather than stocks of capital. Specifically, distributing the covariances evenly between the individual components implies that TFP can account for roughly 60 percent of the total variation in income per worker in 1988.

[21] In the case where $\phi = 1.4$ and $\alpha = 0.4$ the average rate of decline is 0.7 percent per year, compared with 1.13 percent according to KR calculations. If $\phi = 1.7$, $\alpha = 1/3$ the average rate is -0.8 percent per annum.

[22] Recently, Pritchett (2000) has argued that capital stock estimates, particularly 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 50 percent. Accordingly, this argument is complementary to the one pursued here, where the idea is that TFP estimates become misleading since they are derived under the assumption that capital services rise with the capital stock. If utilization declines, they may not.

Table 1: Variance decomposition

	1	2	3
VAR $(\ln h)/\text{VAR}(\ln y)$	0.07	0.32	0.32
$\text{VAR}(\frac{\alpha}{1-\alpha}\ln\kappa)/\text{VAR}(\ln y)$	0.09	0.05	0.05
$\text{VAR}(\ln A)/\text{VAR}(\ln y)$	0.46	0.50	0.37
COV $(\ln A, \ln h)/\text{VAR}(\ln y)$	0.09	0.02	-0.03
$\text{COV}(\ln A, \frac{\alpha}{1-\alpha}\ln\kappa)/\text{VAR}(\ln y)$	0.05	0.02	0.03
$\text{COV}(\ln h, \frac{\alpha}{1-\alpha}\ln\kappa)/\text{VAR}(\ln y)$	0.05	0.02	0.02
$\text{VAR}(\frac{\alpha}{1-\alpha}\ln\beta)/\text{VAR}(\ln y)$			0.06
$\text{COV}(\ln A, \frac{\alpha}{1-\alpha}\ln\beta)/\text{VAR}(\ln y)$			0.04
$\text{COV}(\ln h, \frac{\alpha}{1-\alpha}\ln\beta)/\text{VAR}(\ln y)$			0.05
$\text{COV}(\frac{\alpha}{1-\alpha}\ln\kappa, \frac{\alpha}{1-\alpha}\ln\beta)/\text{VAR}(\ln y)$			-0.01
Sample size	N=127	N=10	N=10
$\text{VAR}(\ln y)$	1.16	0.08	0.08

In order to get an impression of how much capital utilization matters for the decomposition, column 3 takes capital utilization into account. The sample consists of the 10 EC countries for which comparable data are available for 1989. Accordingly the level of TFP is calculated as

$$A = \frac{Y/L}{(\beta K/Y)^{\alpha/(1-\alpha)}\, h} = \frac{A^{HJ}}{\beta^{\alpha/(1-\alpha)}},$$

where A^{HJ} is the measure of TFP calculated by HJ. Hence the measure of TFP in column 3 is a slightly different one than featured in the other columns. For the purpose of comparison, column 2 shows the results of the decomposition *without* taking capital utilization into account, but for the same group of countries for which data on β is available. It is interesting to begin by observing that even in the smaller sample consisting of relatively rich countries, TFP is the major contributor to the variance of log income per worker: 54 percent of the variance is accounted for by A, as calculated by HJ. Moving on to column 3, it is clear that capital utilization offers a non-negligible contribution. Crudely distributing covariances evenly across the individual input factors implies that 14 percent of the differences in income per worker can be attributed to variations in capital utilization. Another perspective on the finding is that the importance of the physical capital component rises from 9 percent without adjustments for utilization to 23 percent when β is controlled for. Although the importance of TFP declines, it still accounts for more than 40 percent of the variation across the 10 EC countries. While care should be taken in drawing too strong conclusions from this analysis, bearing the relatively small sample in mind, the results do suggest quite strongly that capital utilization might be important for the understanding of the sources of productivity differences across countries.

4.4 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.[23]

Currently the leading reconciliation of the neoclassical growth model with a rate of convergence around two percent is that due to Mankiw, Romer and Weil (1992). As is well known, the reason why a lower rate of convergence is obtained by the authors is that the tendency toward diminishing returns to capital, broadly defined to include human capital, is dampened. The same mechanism lead the authors to conclude that capital can account for the bulk of observed productivity differences, in a large cross section of countries. However, recent empirical studies, such as those discussed in the previous sections, have raised serious doubts as to whether capital is as important

[23] Structural estimation of the Solow model was pioneered by Mankiw, Romer and Weil (1992) (MRW). Their original convergence estimate of 2-3 percent has 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 go on to show that this brings the rate of convergence back to roughly 2-3 percent.

as suggested by Mankiw, Romer and Weil. Indeed the emerging consensus seems to be that differences in productivity are not predominantly due to differences in physical stocks of capital. As a result, the confidence one might have in the Mankiw, Romer and Weil approach to lowering the rate of convergence is somewhat diminished.

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.[24] Table 2 shows the values that μ can take, allowing for different assumptions regarding capital's (gross) share in total income, $\alpha \in (1/3 : 0.4)$ and $\phi \in (1.4 : 1.7)$.

Table 2: Values for μ

$\phi \backslash \alpha$	1/3	0.4
1.40	0.12	0.16
1.56	0.15	0.19
1.70	0.17	0.22

Now, using the same values for g and n as above, Table 3 gives the implied rates of convergence for varying values of μ.

Table 3: Implied λ

$\phi \backslash \alpha$	1/3	0.4
1.40	.0264	.0252
1.56	.0255	.0243
1.70	.0249	.0234

Note: n=0.01,g=0.02

As can be seen, λ lies in a range that 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

[24] Recall that $\mu \equiv \alpha(\phi - 1)/(\phi - \alpha)$.

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.[25]

Moreover, given the range of values for μ, the model would also indicate a lesser role for capital in explaining income differences. The implied elasticity of income per worker, with respect to the capital-output ratio, is $\frac{\mu}{1-\mu}$ (cf. equation (10)), which ranges from 0.15 to 0.27 depending on assumptions regarding α and ϕ, which is considerably lower than 1/2 to 2/3 implied by the standard Solow model. The low implied elasticity of output with respect to capital is consistent with the findings of Dowrick and Rogers (2002). They estimate an aggregate (Cobb-Douglas) production function on a panel of 51 countries covering the 1970-90 period, while allowing for technology transfer to occur. Their estimate for the elasticity of capital with respect to output lies in the range (0.17 : 0.23), depending on the exact specification and choice of instruments. These findings accord well with the numbers for μ, reported in Table 2.

5 Concluding Remarks

The main message of this 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 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

[25] It 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 C. However, if one were to consider an 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 3. See Rumbos and Auernheimer (2001) for details.

for underdevelopment lies in failing technological progress or a highly distorted investment climate. 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.

COLOPHON JEL Classification: O41, O47. Keywords: Capital Utilization, Growth, Convergence, Total Factor Productivity. Address of the author: University of Copenhagen, Institute of Economics, Studiestraede 6, 1455-Copenhagen, Denmark. tel.: +45 35 32 44 07, e-mail: carl.johan.dalgaard@econ.ku.dk. I would like to thank Shekhar Aiyar, Lennart Erickson, Christian Groth, Jacob Gyntelberg, Henrik Hansen, Martin Kaae Jensen, Peter Birch Sørensen, Jon Temple, Fabrizio Zillibotti, seminar participants at the University of Copenhagen, North Carolina State University and, in particular, the editor, Chad Jones, and two anonomous referees for useful comments and suggestions. The usual disclaimer applies. The activities of EPRU (Economic Policy Research Unit) are financed through a grant from The Danish National Research Foundation.

A The Production Function in 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)):

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

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

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

B Comparative statics: Distortions and Long-run Productivity

Income per worker in steady state is given by:

$$\begin{aligned}
y^* &= E^{\frac{1}{1-\mu}}\left(\left(\frac{k}{y}\right)^*\right)^{\frac{\mu}{1-\mu}} h, \\
&= E^{\frac{1}{1-\mu}}\left(\frac{s\phi q-\alpha}{\phi q(n+g)}\right)^{\frac{\mu}{1-\mu}} h, \qquad (16)
\end{aligned}$$

where

$$E \equiv (\alpha / (\phi d q))^{\alpha/(\phi-\alpha)}. \tag{17}$$

As a preliminary matter, we derive the savings rate associated with the golden rule. The problem is to

$$\max_{k^*} c^* = E (k^*)^{\mu} h^{1-\mu} - (n+g) k^*.$$

FOC:

$$\begin{aligned} \frac{\partial c^*}{\partial k^*} &: \quad \mu \frac{E (k^*)^{\mu} h^{1-\mu}}{k^*} = (n+g) \\ &= \quad \mu \left(\frac{y}{k}\right)^* = (n+g) \end{aligned}$$

substituting for $\left(\frac{y}{k}\right)^*$ yields:

$$\mu \frac{n+g}{\tilde{s}} = (n+g),$$

so the golden rule net savings rate is $\tilde{s}^{gr} = \mu$, or stated in terms of the gross savings rate, s,:

$$s^{gr} = \mu + \frac{\alpha}{\phi q}.$$

It will prove useful below to parameterize the distance between the actual gross savings rate, s, and the golden rule level, s^{gr}. Accordingly, let

$$s \equiv \sigma \left(\frac{\alpha}{\phi q} + \mu \right), \ \sigma \gtreqless 1, \tag{18}$$

where $\sigma = 1$ corresponds to setting $s = s^{gr}$; $\sigma > 1$ implies that $s > s^{gr}$ (dynamic inefficiency), and $\sigma < 1$ that $s < s^{gr}$.

Inserting equation (18) into equation (16) yields:

$$\begin{aligned} y^* &= E^{\frac{1}{1-\mu}} \left(\frac{\sigma \left(\frac{\alpha}{\phi q} + \mu \right) \phi q - \alpha}{\phi q (n+g)} \right)^{\frac{\mu}{1-\mu}} h \\ &= E^{\frac{1}{1-\mu}} \left(\frac{(\sigma - 1) \alpha + \sigma \mu \phi q}{\phi q (n+g)} \right)^{\frac{\mu}{1-\mu}} h. \end{aligned}$$

Positive net savings requires

$$\sigma > \frac{\alpha}{\alpha + \mu\phi q} \equiv \hat{\sigma} < 1.$$

Next, take logs, while ignoring terms that do not involve q:

$$\ln y^* = \frac{1}{1-\mu} \ln E + \frac{\mu}{1-\mu} \ln \left((\sigma - 1)\, \alpha + \sigma\mu\phi q \right) - \frac{\mu}{1-\mu} \ln q$$

Differentiation wrt q yields

$$\frac{\partial \ln y^*}{\partial q} = \frac{1}{1-\mu} \frac{\partial \ln E}{\partial q} + \frac{\mu}{1-\mu} \frac{\sigma\mu\phi}{(\sigma - 1)\, \alpha + \sigma\mu\phi q} - \frac{\mu}{1-\mu} \frac{1}{q}.$$

From equation (17) it follows that:

$$\ln E = \frac{\alpha}{\phi - \alpha} \left(\ln \alpha - \ln \phi - \ln q - \ln d \right).$$

Consequently

$$\frac{\partial \ln y^*}{\partial q} = -\frac{1}{1-\mu} \frac{\alpha}{\phi - \alpha} \frac{1}{q} + \frac{\mu}{1-\mu} \frac{\sigma\mu\phi}{(\sigma - 1)\, \alpha + \sigma\mu\phi q} - \frac{\mu}{1-\mu} \frac{1}{q},$$

or, collecting terms:

$$-\left(\frac{1}{1-\mu} \frac{\alpha}{\phi - \alpha} + \frac{\mu}{1-\mu} \right) \frac{1}{q} + \frac{\mu}{1-\mu} \frac{\sigma\mu\phi}{(\sigma - 1)\, \alpha + \sigma\mu\phi q}. \tag{19}$$

In order to reduce this expression, we start by noting that

$$\begin{aligned} 1 - \mu &\equiv 1 - \alpha \frac{\phi - 1}{\phi - \alpha} = \frac{\phi - \alpha - \alpha(\phi - 1)}{\phi - \alpha} \\ &= \frac{\phi - \alpha - \alpha\phi + \alpha}{\phi - \alpha} = \frac{\phi}{\phi - \alpha} (1 - \alpha) \end{aligned}$$

and therefore that

$$\begin{aligned} \frac{\mu}{1-\mu} &\equiv \frac{\alpha \frac{\phi - 1}{\phi - \alpha}}{\frac{\phi}{\phi - \alpha} (1 - \alpha)} \\ &= \frac{(\phi - \alpha)\, \alpha\, (\phi - 1)}{\phi\, (1 - \alpha)\, (\phi - \alpha)} \\ &= \frac{\phi - 1}{\phi} \frac{\alpha}{1 - \alpha}. \end{aligned}$$

Substituting for $(1-\mu)^{-1}$ and $\mu/(1-\mu)$ in equation (19):

$$\begin{aligned}
& -\left(\frac{\phi-\alpha}{\phi(1-\alpha)}\frac{\alpha}{\phi-\alpha}+\frac{\phi-1}{\phi}\frac{\alpha}{1-\alpha}\right)\frac{1}{q}+\frac{\phi-1}{\phi}\frac{\alpha}{1-\alpha}\frac{\sigma\mu\phi}{(\sigma-1)\alpha+\sigma\mu\phi q} \\
= & -\left(\frac{\alpha}{\phi(1-\alpha)}+\frac{\phi-1}{\phi}\frac{\alpha}{1-\alpha}\right)\frac{1}{q}+\frac{\phi-1}{\phi}\frac{\alpha}{1-\alpha}\frac{\sigma\mu\phi}{(\sigma-1)\alpha+\sigma\mu\phi q} \\
= & -\frac{\alpha}{1-\alpha}\frac{1}{q}+\frac{\phi-1}{\phi}\frac{\alpha}{1-\alpha}\frac{1}{q}\frac{\sigma\mu\phi}{(\sigma-1)\frac{\alpha}{q}+\sigma\mu\phi} \\
= & \frac{\alpha}{1-\alpha}\frac{1}{q}\left(\frac{\phi-1}{\phi}\frac{\sigma\mu\phi}{(\sigma-1)\frac{\alpha}{q}+\sigma\mu\phi}-1\right).
\end{aligned}$$

Observe that $\sigma>\hat{\sigma}$ is equivalent to $(\sigma-1)\frac{\alpha}{q}+\sigma\mu\phi>0$. Hence, straight forward manipulation of the condition

$$\frac{\phi-1}{\phi}\frac{\sigma\mu\phi}{(\sigma-1)\frac{\alpha}{q}+\sigma\mu\phi}\gtreqless 1$$

implies that

$$\text{if } \frac{\alpha/q}{\mu+\alpha/q}\gtreqless\sigma\Rightarrow\frac{\partial\ln y^*}{\partial q}\gtreqless 0.$$

Summing up. The relationship between q and y^* is, in general, ambiguous. At low savings rates, productivity *rises* if q increases, while at sufficiently high levels of investment, the opposite is true. The exact intervals, expressed in terms of the deviation of s from s^{gr}, are

$$\begin{aligned}
\text{if } \hat{\sigma} & < \sigma\leq\frac{\alpha/q}{\mu+\alpha/q}\Rightarrow\frac{\partial\ln y^*}{\partial q}\geq 0 \\
\text{if } \sigma & > \frac{\alpha/q}{\mu+\alpha/q}\Rightarrow\frac{\partial\ln y^*}{\partial q}<0.
\end{aligned}$$

Observe that $\frac{\alpha/q}{\mu+\alpha/q}<1$, so if $s=s^{gr}$, then $\frac{\partial\ln y^*}{\partial q}<0$.

The above conditions can also be stated in terms of the savings rate, s, by replacing σ and $\hat{\sigma}$ by

$$\sigma\equiv\frac{s}{s^{gr}}=\frac{s}{\mu+\frac{\alpha}{\phi q}}\wedge\hat{\sigma}\equiv\frac{\frac{\alpha}{q}}{\frac{\alpha}{q}+\mu\phi}.$$

The result is

$$\text{if } \frac{\alpha}{q}\frac{\mu+\frac{\alpha}{\phi q}}{\mu\phi+\frac{\alpha}{q}} \quad < \quad s \leq \frac{\alpha}{q}\frac{\mu+\frac{\alpha}{\phi q}}{\mu+\frac{\alpha}{q}} \Rightarrow \frac{\partial \ln y^*}{\partial q} \geq 0$$

$$\text{if } s \quad > \quad \frac{\alpha}{q}\frac{\mu+\frac{\alpha}{\phi q}}{\mu+\frac{\alpha}{q}} \Rightarrow \frac{\partial \ln y^*}{\partial q} < 0.$$

C 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: $q = h = 1$.

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

$$\dot{k} = \beta(t)^\alpha k(t)^\alpha - c(t) - (n+g+\delta(t))\, k(t), \; k(0) \text{ given} \tag{20}$$

$$\delta(t) = d\beta(t)^\phi, \; \phi > 1. \tag{21}$$

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

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

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

The first order conditions are

$$H_c : c(t)^{-\theta} = \lambda(t) \tag{22}$$

$$\begin{aligned} H_\beta &: \lambda(t)\left(\alpha\beta(t)^{\alpha-1} k(t)^\alpha - d\phi\beta(t)^{\phi-1} k(t)\right) = 0 \\ &\Updownarrow \\ \beta(t) &= \left(\frac{\alpha}{d\phi}\frac{y(t)}{k(t)}\right)^{1/\phi} \end{aligned} \tag{23}$$

$$H_k : \left(\alpha\frac{y(t)}{k(t)} - d\beta(t)^\phi - n - g\right)\lambda(t) = -\dot{\lambda}(t) + (\rho - n - (1-\theta)g)\,\lambda(t). \tag{24}$$

Thus using equations (21) - (23) and (24) leads to:

$$\frac{\dot{c}(t)}{c(t)} = \frac{1}{\theta}\left(\alpha\frac{y(t)}{k(t)} - \left(\frac{\alpha}{\phi}\right)\frac{y(t)}{k(t)} - \rho - \theta g\right) = \frac{1}{\theta}\left(\left(\alpha - \frac{\alpha}{\phi}\right)\frac{y(t)}{k(t)} - \rho - \theta g\right). \tag{25}$$

While equation (20) along with equations (21) and (23) yield:

$$\dot{k}(t) = \left(1 - \frac{\alpha}{\phi}\right) y(t) - c(t) - (n+g)\, k(t). \tag{26}$$

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 (25) and (26) allows the dynamic system of the model to be written 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, almost identical to the standard Ramsey-Cass-Koopmans model. As a result, the modified model has 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 unit of labor, and the long-run rate of capital utilization. The latter is given by:

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

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

Define

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

and 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 of the relationship between the time path of the savings rate and the rate of convergence.) However, 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 was around two percent 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 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.

D Data on Capitals' Share in Denmark

The data used for Figure 3 can be downloaded from http://www.statistikbanken.dk (the site is also available in English). More specifically, labors' share was calculated using the series called: "compensation of employees (payable by res. prod.)" along with GDP at factor costs. These numbers are found in the table: "NAT15: Main accounts per capita (current prices, DKK) by kind of account".[26] Moreover, following Gollin (2002) the wage income of the self-employed, which traditionally is attributed to capital income, is corrected by assuming that the wage rate among self-employed is equal to the average wage among wage earners. Correcting for self-employed is important in the present case, as the number of self-employed declined significantly over the period 1966 to 2002, as a result of declining employment in agriculture. If no corrections are made, capital's share exhibits a (mild) downward trend over the period. The trend essentially disappears once corrections are made.

Consequently, the number of self-employed was calculated by subtracting "Wage and salary earners excl. leave" from "total employment". These numbers are available in the table: "NAT07: Production etc. (DKK mil.) by kind of activity, variable and price unit". The corrected labor share was calculated by multiplying total wage compensation by

$$1 + \frac{\text{self-employed}}{\text{Wage and salary earners}}.$$

Capital's gross share is then determined as 1 minus the labor share. The net capital share was calculated by subtracting the ratio of "consumption of fixed capital" to GDP at factor costs, from the gross share. Figure 6 shows the evolution of capital's share in Denmark from 1966-2002, both with and without adjustments for self-employment. The figure presented in the main text is based on the adjusted shares. Using the unadjusted shares implies that the calibrated average value for ϕ rises to 2.22.

[26] I have no idea why the title of this table contains " per capita". It seems to be a misprint.

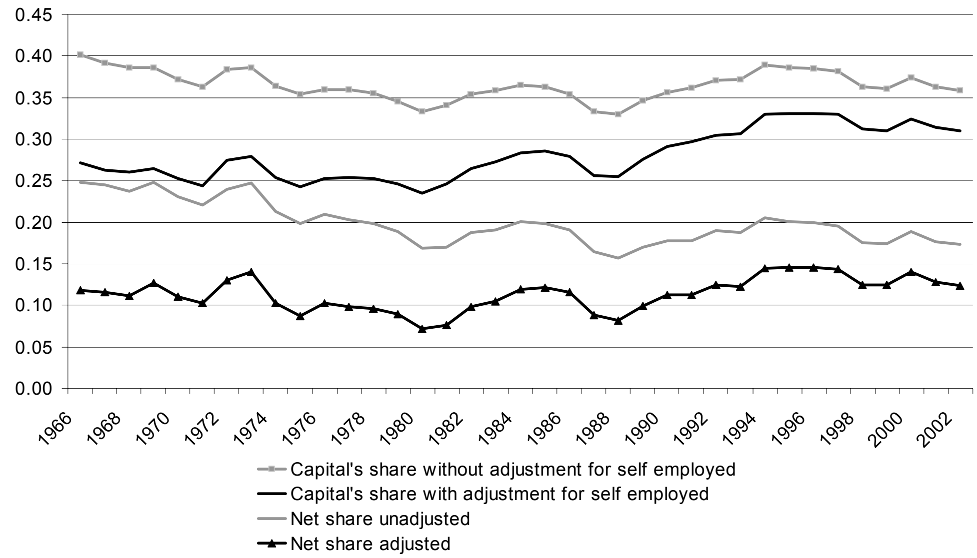

Figure 6: **Gross and Net Capital Shares in Denmark, with and without adjustment for self-employment : 1966-2002.**

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