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Accounting for productivity: is it OK to assume that the world is Cobb-Douglas?*

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Abstract

The development accounting literature almost always assumes a Cobb-Douglas (CD) production function. However, if in reality the elasticity of substitution between capital and labor deviates substantially from 1, the assumption is invalid, potentially casting doubt on the commonly held view that factors of production are relatively unimportant in accounting for differences in labor productivity. We use international data on relative factor shares and capital-output ratios to formulate a number of tests for the validity of the CD assumption. We find that the CD specification performs reasonably well for the purposes of cross-country productivity accounting.

1 Introduction

A critical decision in any development accounting analysis, which aims to decompose GDP per worker into its fundamental components (physical capital, human input and total factor productivity), is the choice of aggregate production function. The standard choice is a Cobb-Douglas (CD) specification, and the common finding is that observed differences in labor productivity cannot be adequately accounted for by differences in physical and human capital. Instead, total factor productivity (TFP) accounts for the lion's share of observed differences in GDP per worker.

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Stricktly speaking, however, the CD assumption is not an appropriate choice for this type of analysis. Under competitive markets (which is a maintained assumption in development accounting), the CD assumption implies that we should expect zero variation in relative factor shares, when comparing countries at different stages of development. This implication can be resoundly rejected; factor shares do vary from country to country. For example, in a recent data set constructed by Bernanke and Gürkaynak (2001), labor's share falls in a range from 0.53 (Venezuela) to 0.78 (Sri Lanka). Therefore, for the purpose of applied work, a more general CES specification would be a better choice, since it can be consistent with this dimension the cross-country data.

A CES approach, in combination with technology entering in a Harrod neutral way, may lead to new results from development accounting, if one employs an elasticity of substitution (ES) between capital and labor above 1. That is, if the ES is larger than the one implicit in the CD assumption (ES=1). If the ES>1 assumption is warranted, the existing accounting literature underestimates the importance of rival factors of production. However, if the appropriate choice is an ES below 1, the opposite is true. Hence, the central question is whether an ES above or below 1 is more plausible.[1] The work of Duffy and Papageorgiou (2000) would add weight to the claim that the ES is above 1. Using aggregate cross country data, they estimate a CES production function and find the ES to be around 1.5.

The first contribution of this paper consists of developing two simple tests which aims to reassess this issue, assuming technology enters the aggregate production function in a Harrod neutral way. The first simple test relates to the predicted correlation between capital's share and the capital-output ratio. If the appropriate choice for ES is above 1, we would expect a positive correlation to emerge, whereas the two variables should be negatively associated in the

[1] It is worth remarking that the issue of the size of ES is important in other contexts than development accounting. In general the ES matters for whether endogenous growth is feasible or not (*e.g.* Pitchford. 1960), whether multiplicity of steady state equilibria can emerge or not (*e.g.* Galor, 1996) and whether standard endogenous growth models feature scale effects or not (Dalgaard and Jensen, 2007).

case where ES is below 1. Using various data sources for capital-output ratios and factor shares we generally find a negative, but insignificant, correlation. This finding is consistent with a production function where the elasticity of substitution is slightly lower than 1.[2] Our second test exploits the information contained in the observed *variation* in factor-shares and capital-output ratios across countries. Using a general CES production function, we show how to relate this observed variation in a simple way to the elasticity of substitution between capital and human input. We find that the elasticity of substitution calibrated in this manner falls in a interval from 0.8 to 0.9. Given this range of estimates for ES, a CD based approach and the more general CES approach (assuming Harrod neutral technological change) will yield very similar results; the role of factors will be only slightly smaller according to the CES-based analysis.

The second contribution of this paper consists of extending the analysis to include a more general form of biased technological change. Caselli (2006) is, to our knowledge, the first to perform development accounting under the assumption that technology manifests itself simultaneously in a Harrod and Solow neutral fashion. Interestingly, under this technological assumption, an ES *below* 1 allows for an elevated role of factors. Indeed, Caselli shows that if the ES can be as low as 0.5 the *entire* variation in GDP per worker can be accounted for by factors. This is in itself surprising: when Harrod neutral technological change is assumed an ES *above* 1 raises the impact from factors. We clarify the reason for the apparent "reversal" of the impact from ES on the accounting results, and proceed to revisit our two tests in light of this possible "world view".

If indeed technology is simultaneously Harrod and Solow neutral, the simple tests mentioned above fail to convey accurate information about the size of the ES. However, assuming the tests fail to identify the size of the ES, one can demonstrate that the information they do convey is nevertheless sufficient to

[2] Again, under the standard assumptions of development accounting we would have to reject that the production function is *exactly* CD, as it would imply zero variation in relative factorshares, which is counterfactural.

provide *a lower bound* on the ES.[3] To be specific, we find that if technology enters the production function simultaneously in a Harrod and Solow neutral fashion the lower bound for the ES is 0.77. As shown below, if the ES is bounded from below by 0.77, the results from performing development accounting with the simpler CD specification will not yield misleading results, *even if* the more appropriate assumption were a CES specification with Harrod and Solow neutral technology.

Taken together therefore these results provide a strong case that, for the purpose of development accounting, using an aggregate CD production function is a reasonable shortcut to using a more general CES production function. With a more general CES function the bias of technological change becomes a meaningful concept. Moreover, the nature of the bias (Harrod, Solow etc.) inevitably impinges upon what is a reasonable assumption for the ES, given observations on capital-output ratios, labor shares etc. The tests and calibrations of ES we perform tell us, however, that no matter what the true bias of technological change is, the relevant ES will always be of a size such that the CD approximation is reasonably accurate in the context of development accounting. Thus, even though we do not know a priori whether technological change actually manifests itself as Harrod neutral, Solow neutral or both, nonetheless the conclusion emerges: it is OK to assume that the world is Cobb-Douglas when accounting for productivity.

The paper proceeds as follows. The next section lays out the consequences, for the result stemming from development accounting, of employing a general CES function where technological change is Harrod neutral. Section 3 presents evidence on the empirical relationship between factor shares and capital-output ratios, and Section 4 shows our calibration of the elasticity of substitution. Section 5 discusses the implications, for accounting and our tests, of simultaneously allowing for Harrod and Solow neutral technological change, and provides

[3] As demonstrated by Diamond et al. (1978), if the direction of the bias in technological change is unknown the other technological parameters (e.g. the ES) cannot be identified in general. The theorem does not rule out, however, that a lower bound on the ES can be established.

a range of ES consistent with the new technology assumption and data on relative shares and capital-output ratios. Section 6 discusses our results, and relates them to previous findings. Finally Section 7 concludes.

2 Preliminaries: Development Accounting with a CES Production Function

Consider the following specification for the aggregate production function

$$Y = \begin{cases} \left[\alpha K^{\frac{\epsilon-1}{\epsilon}} + (1-\alpha)(AhL)^{\frac{\epsilon-1}{\epsilon}}\right]^{\frac{\epsilon}{\epsilon-1}} & \text{if } \epsilon \neq 1 \\ K^{\alpha}(AhL)^{1-\alpha} & \text{if } \epsilon = 1 \end{cases},$$

where Y is GDP, K is capital, A is an index of technology or efficiency, h is human capital and L is the size of the labor force. This leaves two parameters: the distribution parameter, α, and the elasticity of substitution $\epsilon \in [0, \infty]$. In the $\epsilon \to 1$ limit, the CES function "collapses" to a CD function. Notice the way A enters the CES specification, *i.e.*, in a "Harrod neutral" fashion. We adopt this specification as our benchmark for two reasons.

First, it is well known that this specification is the *only* one which allows for a steady state, if nested in standard models of economic growth.[4] Any other specification (Solow or Hicks neutral technological change) will not allow for a path featuring constant growth in key aggregates such as GDP along with a constant capital-output ratio, constant real rate of interest and constant relative factor shares. In short, only the above specification will admit a steady state which mimics Kaldor's stylized facts. In our view, it seems reasonable to adopt a specification for empirical work which simultaneously has proved to be theoretically useful.[5]

Second, this specification allows us to "dichotomize" the level of technology from "factors", much like what is possible when using a CD production function.

[4] See Jones and Scrimgeour (2008) for a recent discussion and (a new) proof of this Theorem.

[5] Recently, Acemoglu (2003) have provided some micro-foundations for the *direction* of technological change, drawing on the work of e.g. Samuelson (1965). This theory predicts that (only) in the long-run will technological change be Harrod neutral. From the perspective of this theory our assumption amounts to a "steady state" assumption. In any case, the assumption of purely Harrod neutral technical change is relaxed in Section 5.

This makes the results comparable when the elasticity of substitution is varied. To see this, notice that by way of a few simple manipulations we can rewrite the CES function in the following way[6]

$$y = Ah \cdot \left(\frac{1-\alpha}{1-\alpha\kappa^{\frac{\epsilon-1}{\epsilon}}} \right)^{\frac{\epsilon}{\epsilon-1}}, \tag{1}$$

where $y \equiv Y/L$ and κ is the capital-output ratio, K/Y. In the CD case ($\epsilon \to 1$), the corresponding decomposition is the one suggested by Klenow and Rodriguez-Clare (1997):

$$y = Ah\kappa^{\frac{\alpha}{1-\alpha}}.$$

There is a virtue to having κ entering the right hand side. According to Kaldor's stylized facts, the capital-output ratio is roughly constant over time. By implication, since technology tends to progress, κ must therefore be (roughly) independent of *the level* of A; otherwise, it would not be trend free. Standard growth models allow for a steady state where this is the case, as mentioned a moment ago. For example, in a steady state of a Solow model we have $\kappa = s/(n+\delta+x)$, where s is the savings rate, n the rate of labor force growth, δ is the rate of capital depreciation while x is the growth rate of technology. Hence, in theory variation in κ can be thought of as implicitly capturing variation in structural characteristics which matter to factor accumulation.

It should be recognized, of course, that Kaldor's fact of a constant capital-output ratio is not equally true everywhere. During some periods, or in some countries, κ does rise over time, as would be consistent with the transitional dynamics of neoclassical growth models. Hence, the independence of κ from A is obviously not guaranteed. Still, under some circumstances it does hold true. In contrast, $k \equiv K/L$ and A are unlikely to ever be independent. As a result, if TFP is calculated (in the CD case) as $A = y/k^{\alpha}h^{1-\alpha}$ part of the variation attributable to A will almost inevitably be assigned to factors. Consequently, factors will seem more important.[7]

[6] The derivations are given in Appendix A.

[7] Caselli (2006) calculates TFP as $y/k^{\alpha}h^{1-\alpha}$. This is the fundamental reason why some of our result in this section deviates from his, albeit the underlying raw data is the same. Our decomposition approach will support a lesser role for factors, than Caselli's.

To see how switching to the CES specification matters to the results of a development accounting analysis, we begin by revisiting the Cobb-Douglas case. The underlying data for y,h,κ comes from Caselli (2006), and we set the distribution parameter α to 0.4, which can be viewed as the upper limit to the range usually admitted. The challenge is to account for differences in GDP per worker, y. In the Caselli data the ratio of GDP per worker in the 90 percentile of the distribution, to that of the 10th, is a factor of 21. If we look at the distribution for κ and h, the corresponding numbers are 3.5 and 2.2. As a result, "factors" can motivate at most ($\alpha = 0.4$)

$$\frac{(3.5)^{\frac{2}{3}} \cdot 2.2}{21} \cdot 100 \approx 24\%$$

of the observed income gap.

Next consider the CES function. To be comparable with CD (in the sense of the limit), we maintain $\alpha = 0.4$, and use $\epsilon = 1.5$, which is the estimate from Duffy and Papageorgiou (2000). We are now in a position to account for

$$\frac{\left(\frac{1-(0.4)\cdot(0.79)^{\frac{1.5-1}{1.5}}}{1-(0.4)\cdot(2.8)^{\frac{1.5-1}{1.5}}}\right)^{\frac{1.5}{1.5-1}} \cdot 2.2}{21} \cdot 100 \approx 32\%,$$

a considerably larger fraction of the "90/10" income ratio. Another way to appreciate this result is to note that observed variation in κ and h can motivate a difference in GDP per worker of a factor of 5 under CD, whereas the CES case with ES =1.5 motivates a factor 7 difference. Of course, this implication of adopting the CES specification evaporates if we choose an ES near 1. Suppose, for example, that $\epsilon = 0.8$. Then we can account for

$$\frac{\left(\frac{1-(0.4)\cdot(0.79)^{\frac{.8-1}{.8}}}{1-(0.4)\cdot(2.8)^{\frac{.8-1}{.8}}}\right)^{\frac{.8}{.8-1}} \cdot 2.2}{21} \cdot 100 \approx 21\%,$$

which is only slightly less than the CD case.

As should be clear, these results do not overturn the fundamental proposition, stemming from development accounting, that TFP seemingly is overwhelmingly important in accounting for differences in GDP per worker. However, they do illustrate that capital may be much more effective "growth engine" if the ES is high. Moreover, as shown below, the results are much more dramatically affected by changes in the ES insofar as technological change is both Harrod and Solow neutral. In any case, the question is what a reasonable assumption for the ES might be.

3 A Simple Test: Correlations

Consider the CES function above, and assume competitive markets for factors and goods. In this case it is straight forward to show that the share of capital, S_K, is given by

$$S_K = \alpha\kappa^{\frac{\epsilon-1}{\epsilon}} \Rightarrow \log(S_K) = \log\alpha + \frac{\epsilon-1}{\epsilon}\log(\kappa). \qquad \text{(Sk)}$$

Thus, in the limit where $\epsilon = 1$, the share of capital is simply α. But if $\epsilon \neq 1$, we would expect to see either a positive or a negative association between S_K and κ, depending on whether $\epsilon \gtrless 1$.

In a recent paper Gollin (2002) examines the association between S_K and y, and shows the two series are statistically unrelated, once the factor shares have been corrected for the income of the self-employed. It is worth noting, however, that examining the association between S_K and y, rather than S_K and κ, does not allow for a clear-cut assessment of the size of the ES. Appendix B provides an example of how a lack of correlation between y and S_K is fully compatible with a CES production function with arbitrary elasticity of substitution.[8]

Figure 1 and 2 plots the relationship between capital-output ratios and labour shares adjusted for the wage income of the self-employed. The former are obtained from Easterly and Levine (2001) whereas the latter are taken from Gollin (2002).[9] Gollin reports several adjustments. Here we focus on "adjust-

[8] In spite of this, Gollin's results have been taken (implicitly and explicitly) to provide evidence of $\epsilon = 1$ in several recent contributions to the applied literature on economic growth. A non-exhaustive list includes: Bernanke and Gürkaynak (2001), Hendicks (2002) and Restuccia (2004). One may speculate that the reason is a belief (on the part of the researcher) that y and κ in practise are highly correlated, for which reason a comparison between y and S_K, or between S_K and κ, should yield similar results. To our knowledge, however, no-one has systematically examined whether this is in fact true or not.

[9] Easterly and Levine in turn draw on Penn World Tables 5.6 (the data set is available at http://www.worldbank.org/research/growth/GDNdata.htm). All countries and years for which both labour shares and capital-output data are available are shown in the figure.

ment 1" and "adjustment 2", so as to obtain as large coverage as possible.[10]

>Figures 1 and 2 about here<

It is immediately clear that there is no discernable relationship between the capital-output ratios and the factor shares using either correction method. The simple correlation is 0.05 and 0.08 using adjustment 1 and 2, respectively.

Recognizing that data on capital are likely to be rather noisy, we also examined the relationship between Gollin's labour shares and capital-output ratios constructed by Nehru and Dhareshwar (1993). Coverage differs only slightly and the results are very similar: Figure 3 shows the cross-plot for adjustment 2 (the graph for adjustment 1 is essentially identical). The three isolated dots in the south-eastern corner are Jamaica for 1980, 1985 and 1988. If the correlation between shares and capital-output ratios is calculated on the full sample, the result is a very respectable -0.39. However, if the observations for Jamaica are omitted, the correlation drop sharply to -0.04.

>Figure 3 about here<

As a final check we revisited the study by Bernanke and Gürkaynak (2001) who expand Gollin's data set to include more countries. The dataset constructed by Bernanke and Gürkaynak also contain data on investment rates from the updated Penn World Table 6.0.[11] On the basis of the latter we created capital-output ratios for 1992 using the perpetual inventory method. Confining ourselves to countries with full investment data 1950-92 we are able to obtain a 38 country sample of labour shares and 1992 capital-output ratios.[12] As is clear

[10] "Adjustment 1" simply reclassifies the entire operating surplus of private unincorporated enterprises (OSPUE) as labour compensation. "Adjustment 2" assumes that OSPUE contains the same mix of capital and labour compensation as the rest of the economy. See Appendix C for complete dataset.

[11] The data set is available from Bernanke's web page: http://www.princeton.edu/~bernanke/data.htm.

[12] We apply the same methodology as Bernanke and Gürkaynak. That is, we estimate the capital stock in 1949 using the formula: Investment 1950/(Growth in GDP by the chain method, 1950-60 + the depreciation rate, which is set to 0.06). Using this initial stock estimate we use the perpetual inventory method to calculate capital stocks for the period 1950-92. Since we confine ourselves to countries with complete investment series 1950-92 the choice of

from Figure 4 these data does not shatter the image of no significant relationship between shares and capital-output ratios obtained so far.

> Figure 4 <

Finally, in Table 1 we report the results from regressing the log of capitals share on the log of the capital-output ratios, using the data sets underlying figures 1-4.

> Table 1<

As is apparent, we fail to find any statistically significant association between the two variables. These findings are not straight forward to reconcile with a view of a production function featuring Harrod neutral technical change, along with an ES substantially above 1. Instead the results are more suggestive of a CES specification where the ES is fairly close to 1. Moreover, if we take the sign of the point estimates seriously, the data generally suggest the ES is (slightly) smaller than 1.[13]

4 Another Simple Test: Variation

The previous section showed that there is no systematic relationship between capital-output ratios and the labor share. The fact remains, however, that both ratios do vary across time and space. In this section we ask whether factor shares vary "a lot" or not, which implicitly contains information about the size of the ES.[14]

a depreciation rate of 6 percent implies that only 8 percent of the initial stock estimate is left by 1992. We derive the capital-output ratio by dividing the capital stock in 1992 by GDP (i.e. rgdpch92*pop92). For some countries Bernanke and Gürkaynak report several estimates of labor's share. We follow the authors, and Caselli (2006), in using the value in column "Actual OSPUE" if available (this corresponds to Gollin's "adjustment 2"); if "Actual OSPUE" is not available, we use "imputed OSPUE". Insofar as none of these are available, we use "LF". The latter adjustment assumes that the wage income of self employed is equal to the average wage income of employed. Hence labour's share = (wage compensation/total value added)*(1+(self employed)/(paid employees)). The resulting data set is listed in Appendix C.

[13] It is worth observing that the capital data used by Duffy and Papageorgiou (2000) are the ones underlying Figure 3. As can be seen from Table 1, using the Nehru and Dhareswar (1993) capital data is the only case where the point estimate climbs above zero; consistent with ES>1.

[14] Years ago Solow (1958) examined a similar issue in the context of the time-series evidence on labor shares for the US. In particular, Solow argued that the observed path of labor's

To see this, we begin with Equation (Sk) which shows the theoretically expected narrow association between levels of factor shares, and capital-output ratios which we have focused on so far. At this stage, however, we are not interested in correlations, but rather variations. Rearranging terms in equation (Sk) and taking variances leads to:

$$var\left[\log\left(\tilde{S}_K\right)\right] = \frac{1}{\epsilon^2} var\left[\log\left(\kappa\right)\right], \tag{2}$$

where $\log\left(\tilde{S}_K\right) \equiv \log\left(S_K\right) - \log\left(\kappa\right)$. Equation (2) shows the relationship between variations in factor shares and capital-output ratios. The expected relative size of the variation in $\log\left(\kappa\right)$ and $\log\left(\tilde{S}_K\right)$ depends on the elasticity of substitution. Since both $var([\log\left(\kappa\right)]$ and $var\left[\log\left(\tilde{S}_K\right)\right]$ is observed we may proceed to calibrate the elasticity of substitution which would be exactly consistent with these:

$$\epsilon = \sqrt{\frac{var\left[\log\left(\kappa\right)\right]}{var\left[\log\left(\tilde{S}_K\right)\right]}}.$$

Specifically, we calculated ϵ using the three data sets examined above. The results are remarkably uniform.

Using the data underlying Figure 2 we find $\epsilon = 0.82$, shifting to Nehru and Dhareshwar's capital data we find $\epsilon = 0.87$, and finally, in the "Bernanke/ Gürkaynak sample" we find $\epsilon = 0.86$. Accordingly, the variations in the data would be consistent with a CES function with an elasticity of substitution in the range 0.8 to 0.9, provided technological change is Harrod neutral.

As is clear from Section 2, these estimates for the ES imply that results from a CES exercise, and those resulting from using a CD production function, are very similar.[15]

share in the US (1929-55) was consistent with the observed increase in the capital-labor ratio given an elasticity of substitution around 2/3. In theory, however, this calculation may be misleading since it ignores technical progress. For this reason we focus on variations in K/Y ratios and labor shares in the calculation which follows.

[15] These findings corroborate the results in Aiyar and Dalgaard (2005), which however only pertains to the OECD area. Comparing the results from a CD decomposition to those stemming from a general methodology to development accounting, which does not impose a unitary elasticity of substitution between capital and labor, we find a very high degree of concordance. The pure correlation between the two sets of estimates is as high as 0.99 and yield very similar results with respect to decompositions.

5 Solow and Harrod Neutral Technical Change

So far we have assumed that technological change is Harrod neutral. While this assumption is attractive for reasons mentioned above, alternatives cannot be ruled out *a priori*. Hence, suppose we extend the analysis by admitting Solow neutral technological change as well. That is, the production technology in the CES case becomes

$$Y = \left[\alpha \left(BK\right)^{\frac{\epsilon-1}{\epsilon}} + (1-\alpha)\left(AhL\right)^{\frac{\epsilon-1}{\epsilon}}\right]^{\frac{\epsilon}{\epsilon-1}}. \quad (3)$$

This extension influences both development accounting as well as our simple approach to eliciting information about ϵ.

5.1 Accounting Revisited

Starting with the accounting part, the new version of equation (1) is

$$y = A \cdot h \cdot \left(\frac{1-\alpha}{1-\alpha\left(B\kappa\right)^{\frac{\epsilon-1}{\epsilon}}}\right)^{\frac{\epsilon}{\epsilon-1}}. \quad (4)$$

The problem with this expression should be obvious; the seperation of factors and "technology" has been lost in the sense that we need B to assess the influence from κ; and its *size* will influence the results.

Following Caselli (2006) we may still perform an interesting counterfactural to study the influence of factors in accounting for GDP per worker differences under varying assumptions about ϵ. In order to do so, we begin by fixing B to what could be considered a proxy for "the frontier"; its level in the US. We use the fact that given competitive markets and the new production technology, capital's share becomes

$$S_K = \alpha B^{\frac{\epsilon-1}{\epsilon}} \kappa^{\frac{\epsilon-1}{\epsilon}},$$

which can be "inverted" to yield a number for $\alpha B^{\frac{\epsilon-1}{\epsilon}}$ in the US:

$$\alpha B^{\frac{\epsilon-1}{\epsilon}} = S_{K,US}\left(\frac{y_{US}}{K_{US}}\right)^{\frac{\epsilon-1}{\epsilon}}.$$

Since $S_{K,US} \approx 1/3$ and $\frac{y_{US}}{K_{US}} \approx 2.2$ we can now calculate the fraction of the "90/10" income ratio, which can be accounted for by factors, assuming all countries had access to the frontier technology. The result is:

$$\frac{\left(\frac{1-\frac{1}{3}\left(\frac{1}{2.2}\right)^{\frac{\epsilon-1}{\epsilon}}(0.79)^{\frac{\epsilon-1}{\epsilon}}}{1-\frac{1}{3}\left(\frac{1}{2.2}\right)^{\frac{\epsilon-1}{\epsilon}}(2.8)^{\frac{\epsilon-1}{\epsilon}}}\right)^{\frac{\epsilon}{\epsilon-1}} \cdot 2.2}{21},$$

which depends on ϵ. Figure 5, which reproduces Caselli's Figure 21, depicts it

> Figure 5 <

The result is startling; it is now the case that factors can account for almost all the variation in GDP per worker, if the elasticity of substitution is sufficiently *below* 1. Indeed, if $\epsilon = 0.5$ we can generate a larger difference in GDP per worker than what is actually observed. Two things are, however, worth observing with regards to this result.

First, it is essentially due to the choice of "normalization": $\alpha B^{\frac{\epsilon-1}{\epsilon}} = S_{K,US} \cdot \left(\frac{y_{US}}{K_{US}}\right)^{\frac{\epsilon-1}{\epsilon}}$. To see this, observe that (1) and (4) are identical if we instead put $B = 1$. Consequently, with this normalization we would conclude, as in Section 2, that an elasticity above 1 is required to better account for labor productivity. Still, this assumption would arguably be less defendable than Caselli's approach, for which reason we stick with the latter. Second, the association depicted in Figure 5 is highly non-linear; if ϵ equals 0.7, one can only account for about 25% of the income difference, very nearly the result when the production function is assumed to be CD.

The central message from this exercise is that the standard approach to development accounting (the CD approach) is misleading, insofar as the actual ES is (sufficiently) *smaller* than one *and* the technology conforms with equation (3). The tests conducted in the last sections suggested that an ES below 1 is indeed a reasonable. Unfortunately, these tests are no longer valid, if "the world works" in accordance with the above framework. Accordingly, we need to revisit both tests, in light of the new production technology.

5.2 Revisiting Test # 1

Given the technology (3), equation (Sk) now becomes

$$\log\left(S_K\right) = \log\alpha + \frac{\epsilon-1}{\epsilon}\log\left(B\right) + \frac{\epsilon-1}{\epsilon}\log\left(\kappa\right). \tag{5}$$

If this is the true state of affairs our regressions from Table 1 suffer from omitted variable bias. It is indeed possible that omitting $\log(B)$ could explain why $\log(S_K)$ and $\log(\kappa)$ are nearly uncorrelated, as documented above. To see this more precisely, observe that the OLS estimate of $\frac{\epsilon-1}{\epsilon}$ – if $\log(S_K)$ is regressed on $\log(\kappa)$ – can be written

$$\frac{\hat{\epsilon}-1}{\hat{\epsilon}} = \frac{\epsilon-1}{\epsilon}\left[1 + \frac{E\left[\log\left(B\right)\cdot\log\left(\kappa\right)\right]}{var\left[\log\left(\kappa\right)\right]}\right].$$

Accordingly, depending on the sign of the covariance, $E\left[\log(B)\cdot\log(\kappa)\right]$, we will over-or underestimate the "true value" of ES, i.e. $\hat{\epsilon} \gtreqless \epsilon$.

As it turned out, we found $\frac{\hat{\epsilon}-1}{\hat{\epsilon}} \approx 0$. For this finding to be ascribed to omitted variable bias we would require $E\left[\log(B)\cdot\log(\kappa)\right] \approx -var\left[\log(\kappa)\right]$. It should be clear that if $E\left[\log(B)\cdot\log(\kappa)\right] \neq -var\left[\log(\kappa)\right]$ our results above can only be explained by ϵ in fact being close to 1. Unfortunately, as we cannot calculate B, absent a known value for ϵ, there is no way to check whether $E\left[\log(B)\cdot\log(\kappa)\right] \approx -var\left[\log(\kappa)\right]$ or not.

However, supposing $E\left[\log(B)\cdot\log(\kappa)\right] \approx -var\left[\log(\kappa)\right]$ we may ask how this association would influence our *second* test. Indeed, as we shall see, contingent on $E\left[\log(B)\cdot\log(\kappa)\right] \approx -var\left[\log(\kappa)\right]$ we are able to calibrate a range of ES, based on the second testing approach, which is consistent with the stipulated production function and observed variations in relative shares and capital-output ratios. With this range in hand we may refer back to the results depicted in Figure 5 so as to assess how development accounting is affected, compared with the ES=1 CD case, in a situation where technological change is simultaneously Harrod and Solow neutral.

5.3 Revisiting Test # 2

The new version of equation (2) is

$$\begin{aligned} var\left[\log\left(\tilde{S}_k\right)\right] &= \left(\frac{1}{\epsilon}\right)^2 var\left[\log(\kappa)\right] + \left(\frac{\epsilon-1}{\epsilon}\right)^2 var\left[\log(B)\right] \\ &\quad + E\left[\frac{\epsilon-1}{\epsilon}\log(B)\cdot\left(-\frac{1}{\epsilon}\right)\log(\kappa)\right]. \end{aligned}$$

This somewhat complicated expression can be simplified under the assumption that test #1 failed to produce accurate information. That is, assuming $E\left[\log(B)\cdot\log(\kappa)\right] \approx -var\left[\log(\kappa)\right]$. Using this we obtain:

$$var\left[\log\left(\tilde{S}_k\right)\right] = \frac{1}{\epsilon} var\left[\log(\kappa)\right] + \left(\frac{\epsilon-1}{\epsilon}\right)^2 var\left[\log(B)\right], \tag{6}$$

which is still not operational, as $var(\log B)$ is unknown. However, for the purpose of contructing a range for ES, we can proceed by noting that the correlation between $\log(B)$ and $\log(\kappa)$ (which in the present case must be bounded between 0 and -1) is given by

$$\rho \equiv \frac{E\left[\log(B)\cdot\log(\kappa)\right]}{\sqrt{var\left[\log(B)\right]}\sqrt{var\left[\log(\kappa)\right]}} = -\sqrt{\frac{var\left[\log(\kappa)\right]}{var\left[\log(B)\right]}},$$

where the last equality follows from applying, yet again, $E\left[\log(B)\cdot\log(\kappa)\right] \approx -var\left[\log(\kappa)\right]$. Solving for $var\left[\log(B)\right]$ in the above equation, and substituting the result into equation (6) yields:

$$var\left[\log\left(\tilde{S}_k\right)\right] = \frac{1}{\epsilon} var\left[\log(\kappa)\right] + \left(\frac{\epsilon-1}{\epsilon\rho}\right)^2 var\left[\log(\kappa)\right].$$

This equation has the useful property that $var\left[\log\left(\tilde{S}_k\right)\right]$, $var\left[\log(\kappa)\right]$ and ρ are either known or bounded. Moreover, we may rewrite this equation as a second order polynomial in ES:

$$\epsilon^2 - \left(2-\rho^2\right)\frac{a}{a-\rho^2}\epsilon + \frac{a}{a-\rho^2} = 0,$$

where $a \equiv \frac{var[\log(\kappa)]}{var\left[\log\left(\tilde{S}_k\right)\right]}$; the ratio which pinned down ϵ in the case of Harrod neutral change. In the present context, the solution for ϵ is more complex:

$$\epsilon = \frac{\left(2-\rho^2\right)\cdot\frac{a}{a-\rho^2} \pm \sqrt{\left(\left(2-\rho^2\right)\cdot\frac{a}{a-\rho^2}\right)^2 - 4\frac{a}{a-\rho^2}}}{2}.$$

Nevertheless, since we know a we can calculate a range for ϵ, by allowing ρ to "run" from -1 to zero.

>Table 2<

With high (absolute) assumed correlations there is a unique solution for ES. It is comparable to our results from Section 4. As we reduce the absolute value of ρ multiple solutions arise. Nevertheless, an interesting finding emerges: the implied ES is never below 0.77 for $\rho \in (-1, 0)$. As is clear from Figure 5, as long as the ES > 0.7 the CD approach will not be critically misleading, albeit it likely overestimates the "true" importance of factors. This reinforces our conclusion from Sections 3 and 4.

It is worth stressing that these results do *not* suggest a CD function is an accurate description of reality. On the contrary, a CD function is not consistent with the observed variation in shares. However, as it turns out, the CD approach to development accounting will produce results which are rather similar to those emerging if a more "general" CES structure were adopted, given our calibrated range for ϵ.

It is also worth reiterating that the results from Table 2 apply to the situation where $E[\log(B) \cdot \log(\kappa)] \approx -var[\log(\kappa)]$. That is, the case where the empirically detected lack of a correlation between labor shares and capital-output ratios is attributable to the fact that we do not control for $\log(B)$. If the restriction $E[\log(B) \cdot \log(\kappa)] \approx -var[\log(\kappa)]$ does not hold, *i.e.* if the (unknown) covariance is either larger or smaller than the variance term this interpretation is not viable.

However, if this is so then the test results reported in Table 1 is in fact accurate in the sense that they supply valid information about the size of ϵ, which then must be very close to one. This finding would also point to the conclusion that the CD approach to development accounting does not yield misleading results.

6 Discussion and Comparison with Previous Estimates

The first set of results reported above (Sections 3 and 4) relate to the case where the identifying assumption is that technological change manifests itself in a *Harrod neutral* way: if this assumption is correct our key finding is that the elasticity of substitution is not significantly different from 1. More precisely, our preferred regression results involve PWT 6.0 data for K/Y, and the data from Bernanke and Gürkaynak (2001) on the labor share. The reported point estimate for ϵ $\left(= 1/\left[1-\hat{b}\right]\right)$ is 0.93 (cf. Table 1). The standard deviation is 0.08 (calculated using the Delta method), which implies a 95% confidence interval of $(0.77, 1.09)$.[16] Our subsequent calibration (invoking the same data, but involving cross-country variations) in Section 4 yields $\epsilon = 0.86$. Reassuringly, this number falls squarely within the previously obtained confidence interval. When we consider the more general case where technological change is *not* solely Harrod neutral we (only need to) establish a lower bound for ϵ. Invoking the same raw data, this lower bound is 0.77 (Section 5). Interestingly, 0.77 also marks the lower bound on the 95% confidence interval from the special case of Harrod-neutral technological change, using the same underlying data.

To our knowledge the only previous study which has tried to estimate the elasticity of subsitution between capital and (raw) labor, on aggregate cross-country data, is Duffy and Papageorgiou (2000) (DP).[17] This study estimates an elasticity of substitution of 1.5, which is considerably higher than the point estimates we obtain when technological progress manifests itself in a Harrod neutral way.

However, DP assume that technological change is *Hicks* neutral fashion. Hence, our first set of results are not directly comparable with theirs since the

[16] Specifically, the standard deviation for $\hat{\epsilon}$ is given by the formula $std(\epsilon) = std\left(\hat{b}\right) / \left(1-\hat{b}\right)^2$.

[17] Duffy et al. (2004) examine a more general specification which allows for capital-skill complementarity. The discussion of this more general approach, and how accounting result would be affected by employing a C-D simplification in this more general setting, is left to future research.

identifying assumptions are different. If technological change *is* Harrod neutral the regression model examined by DP is misspecified; if technological change is *not* Harrod neutral our first set of results are biased and thus misleading. A direct comparison is therefore meaningless.

In our second set of calibrations, by contrast, a comparison is feasible. To see this, observe that if technological change is Hicks neutral, C, we can write the production function as

$$Y = \left[\alpha (CK)^{\frac{\epsilon-1}{\epsilon}} + (1-\alpha)(ChL)^{\frac{\epsilon-1}{\epsilon}}\right]^{\frac{\epsilon}{\epsilon-1}},$$

which is just the special case of equation (3), where $A = B \equiv C$. Our lower bound result is perfectly compatible with their point estimate of 1.5. If indeed ϵ is in the neighbourhood of 1.5, *and* technology manifests itself in a non-Harrod fashion, the CD specification is fairly accurate (cf. Figure 5).

7 Concluding Remarks

In this paper we have utilized data on capital-output ratios and labour shares to inquire whether the use of an aggregate CD production function is problematic for the purpose of development accounting. Making this assessment requires us to examine what might be a reasonable assumption for the elasticity of substitution between capital and labor (ES), when invoking a more general CES production technology.

The observed lack of any clear correlation between relative shares and capital-output ratios suggest an ES close to 1. Under the assumption of Harrod neutral technological change, this is a simple yet powerful test of whether a "large" ES is plausible. The data suggest it is not. Moreover, the observed variation in factor shares is consistent with a CES production function featuring an elasticity of substitution around 0.8. The results from using a CES function with ES=0.8, and a CD approach to development accounting are very similar.

Accordingly, a CD technology is not a bad approximation, *for the purposes of development accounting*, although it does overestimate the importance of factors of production relative to the residual. The same conclusion is reached, if we allow technological change to be biased in a more general way, *i.e.* when the production technology feature Harrod and Solow neutral technological change.

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A Rewriting the CES Production Function For the Purpose of Accounting

We begin with

$$Y = \left[\alpha \left(BK\right)^{\frac{\epsilon-1}{\epsilon}} + \left(1-\alpha\right)\left(AhL\right)^{\frac{\epsilon-1}{\epsilon}}\right]^{\frac{\epsilon}{\epsilon-1}}$$

which can be restated

$$\begin{aligned} Y^{\frac{\epsilon-1}{\epsilon}} &= \alpha \left(BK\right)^{\frac{\epsilon-1}{\epsilon}} + \left(1-\alpha\right)\left(AhL\right)^{\frac{\epsilon-1}{\epsilon}} \\ &\Updownarrow \\ Y^{\frac{\epsilon-1}{\epsilon}}\left(1-\alpha\left(B\kappa\right)^{\frac{\epsilon-1}{\epsilon}}\right) &= \left(1-\alpha\right)\left(AhL\right)^{\frac{\epsilon-1}{\epsilon}} \end{aligned}$$

where $\kappa \equiv K/Y$. Straight forward rearrangements yield:

$$\frac{Y}{L} \equiv y = \left(\frac{1-\alpha}{1-\alpha\left(B\kappa\right)^{\frac{\epsilon-1}{\epsilon}}}\right)^{\frac{\epsilon}{\epsilon-1}} Ah,$$

which is equation (4). If $B \equiv 1$, the expression equals equation (1).

B Why zero correlation between y and S_K is uninformative about ϵ

Consider the per capita production function

$$y = AL\left[\alpha k^{\sigma} + (1-\alpha)\right]^{\frac{1}{\sigma}} \equiv Af(k).$$

Now assume – to make the point – the presence of *threshold externalities*.

$$A = \bar{A} \text{ if } k > \tilde{k}$$

$$A = \underline{A} \text{ if } k < \tilde{k}$$

Suppose capital accumulates according to

$$\dot{k} = sy - (n+\delta)\,k.$$

Next, suppose the A's and $\tilde{k}$ is chosen such that there exists two steady states, *i.e.* club convergence arises. Clearly, in any steady state, we have

$$\left(\frac{y}{k}\right)^{*} = \frac{n+\delta}{s}$$

which implies that capital's share is

$$S_K = \alpha\left[\frac{K}{Y}\right]^{\sigma} = \alpha\left(\frac{s}{n+\delta}\right)^{\sigma},$$

whereas output is

$$y^{*} = \begin{cases} \bar{A}\left[\alpha\left(k^{*}\right)^{\sigma} + (1-\alpha)\right]^{\frac{1}{\sigma}} \\ \underline{A}\left[\alpha\left(k^{*}\right)^{\sigma} + (1-\alpha)\right]^{\frac{1}{\sigma}} \end{cases}$$

depending on initial conditions.

Consider two countries with same s, n. In this case, Y/L may differ (due to A), but S_K does not. Hence, lack of correlation between y and S_K does not prove CD is appropriate, since a lack of any correlation could arise even assuming a CES function, with an arbitrary elasticity of substitution.

Appendix C: Data on factor shares and capital-output ratios

Year	Country	Adjustment 1	Adjustment 2	Capital-Output ratio (Easterly and Levine / PWT 5.6)	Capital-output ratio (Nehru, V., and A. Dhareshwar)
1970	Australia	0,74	0,70	1,18	2,90
1975	Australia	0,77	0,73	1,23	3,12
1980	Australia	0,76	0,71	1,25	3,27
1985	Australia	0,73	0,68	1,27	3,36
1990	Australia	0,73	0,68	1,34	3,46
1980	Belgium	0,83	0,80	0,90	2,63
1985	Belgium	0,79	0,74	1,07	2,71
1990	Belgium	0,77	0,72	1,08	2,83
1980	Bolivia	0,83	0,69	1,32	2,74
1985	Bolivia	0,93	0,83	1,34	4,03
1988	Bolivia	0,83	0,63	1,24	4,29
1975	Botswana	0,69	0,59	0,62	3,97
1980	Botswana	0,52	0,47	0,63	NA
1985	Botswana	0,35	0,32	0,72	NA
1986	Botswana	0,37	0,34	0,66	NA
1970	Cote d'Ivoire	0,79	0,67	0,15	1,61
1975	Cote d'Ivoire	0,79	0,67	0,18	1,67
1977	Cote d'Ivoire	0,81	0,69	0,18	1,99
1970	Ecuador	0,94	0,84	1,60	3,50
1975	Ecuador	0,84	0,68	1,27	2,69
1980	Ecuador	0,81	0,64	1,41	2,91
1986	Ecuador	0,82	0,57	1,74	3,14
1970	Finland	0,76	0,70	1,56	3,19
1975	Finland	0,80	0,75	1,67	3,41
1980	Finland	0,77	0,72	1,70	3,47
1985	Finland	0,76	0,73	1,76	3,52
1990	Finland	0,76	0,72	1,79	3,52
1970	France	0,83	0,77	0,92	2,27
1975	France	0,85	0,80	1,11	2,64
1980	France	0,81	0,77	1,17	2,80
1985	France	0,80	0,75	1,26	2,99
1990	France	0,76	0,71	1,24	3,01
1970	India	0,87	0,86	0,60	2,21
1975	India	0,86	0,85	0,68	2,36
1980	India	0,84	0,83	0,72	2,55
1970	Italy	0,88	0,81	1,02	2,73
1975	Italy	0,90	0,86	1,16	3,05
1980	Italy	0,81	0,73	1,06	2,89
1985	Italy	0,79	0,70	1,14	3,07
1990	Italy	0,79	0,71	1,11	3,04
1980	Jamaica	0,68	0,64	0,98	5,89
1985	Jamaica	0,60	0,54	0,91	5,85
1988	Jamaica	0,62	0,57	0,78	5,31
1970	Japan	0,66	0,58	1,31	1,84

1975Japan	0,75	0,70	1,31	2,57
1980Japan	0,72	0,68	1,61	2,91
1985Japan	0,72	0,67	1,69	3,12
1990Japan	0,71	0,67	1,77	3,29
1975Korea	0,84	0,69	1,13	1,39
1980Korea	0,76	0,65	1,29	1,98
1985Korea	0,74	0,64	1,23	2,15
1990Korea	0,76	0,69	1,17	2,29
1980Malta	0,72	0,65	**NA**	2,40
1985Malta	0,75	0,68	**NA**	2,96
1985Mauritius	0,77	0,67	0,35	3,13
1990Mauritius	0,77	0,67	0,40	2,63
1985Netherlands	0,69	0,65	1,12	3,34
1990Netherlands	0,70	0,66	1,12	3,32
1975Norway	0,77	0,74	2,05	3,96
1980Norway	0,67	0,63	1,82	3,92
1985Norway	0,65	0,61	1,70	3,91
1990Norway	0,68	0,64	1,76	4,25
1980Philippines	0,80	0,64	0,80	2,09
1985Philippines	0,85	0,69	1,06	3,07
1990Philippines	0,80	0,64	0,83	2,82
1986Portugal	0,83	0,76	0,86	3,60
1990Portugal	0,82	0,75	0,79	3,52
1970Sweden	0,83	0,80	1,04	2,46
1975Sweden	0,81	0,78	1,14	2,66
1980Sweden	0,83	0,81	1,26	2,86
1985Sweden	0,79	0,76	1,27	2,91
1990Sweden	0,82	0,80	1,50	3,03
1970United Kingdom	0,79	0,77	0,72	2,27
1975United Kingdom	0,83	0,81	0,82	2,53
1980United Kingdom	0,79	0,77	0,85	2,66
1985United Kingdom	0,76	0,72	0,83	2,68
1990United Kingdom	0,81	0,77	0,85	2,71
1970United States	0,79	0,76	0,88	2,65
1975United States	0,77	0,74	0,96	2,78
1980United States	0,76	0,73	0,95	2,75
1985United States	0,76	0,73	0,96	2,70
1990United States	0,77	0,74	1,01	2,72

COUNTRY	wbcode	Labor's share	KY 1992 (PWT 6.0, own calculations)
AUSTRALIA	AUS	0,68	2,66
AUSTRIA	AUT	0,70	2,83
BELGIUM	BEL	0,74	2,44
BOLIVIA	BOL	0,67	1,09
CANADA	CAN	0,68	2,62
COLOMBIA	COL	0,65	1,13
COSTA RICA	CRI	0,73	1,54
DENMARK	DNK	0,71	2,89
EGYPT	EGY	0,77	0,68

EL SALVADOR	SLV	0,58	0,81
FINLAND	FIN	0,71	3,92
FRANCE	FRA	0,74	2,85
IRELAND	IRL	0,73	2,44
ISRAEL	ISR	0,70	2,37
ITALY	ITA	0,71	2,66
JAPAN	JPN	0,68	3,13
MAURITIUS	MUS	0,57	1,13
MEXICO	MEX	0,55	2,01
MOROCCO	MAR	0,58	1,35
NETHERLANDS	NLD	0,67	2,61
NEW ZEALAND	NZL	0,67	2,63
NIGERIA	NGA	0,66	0,73
NORWAY	NOR	0,61	3,76
PANAMA	PAN	0,73	1,67
PERU	PER	0,56	2,54
PHILIPPINES	PHL	0,59	1,67
PORTUGAL	PRT	0,72	2,07
S.AFRICA	ZAF	0,62	1,44
SPAIN	ESP	0,67	2,46
SRI LANKA	LKA	0,78	1,11
SWITZERLAND	CHE	0,76	3,06
THAILAND	THA	0,77	2,41
TRINIDAD&TOBAGO	TTO	0,69	1,24
TURKEY	TUR	0,60	1,68
UNITEDKINGDOM	GBR	0,75	2,25
UNITEDSTATES	USA	0,74	1,86
URUGUAY	URY	0,58	1,49
VENEZUELA	VEN	0,53	1,98

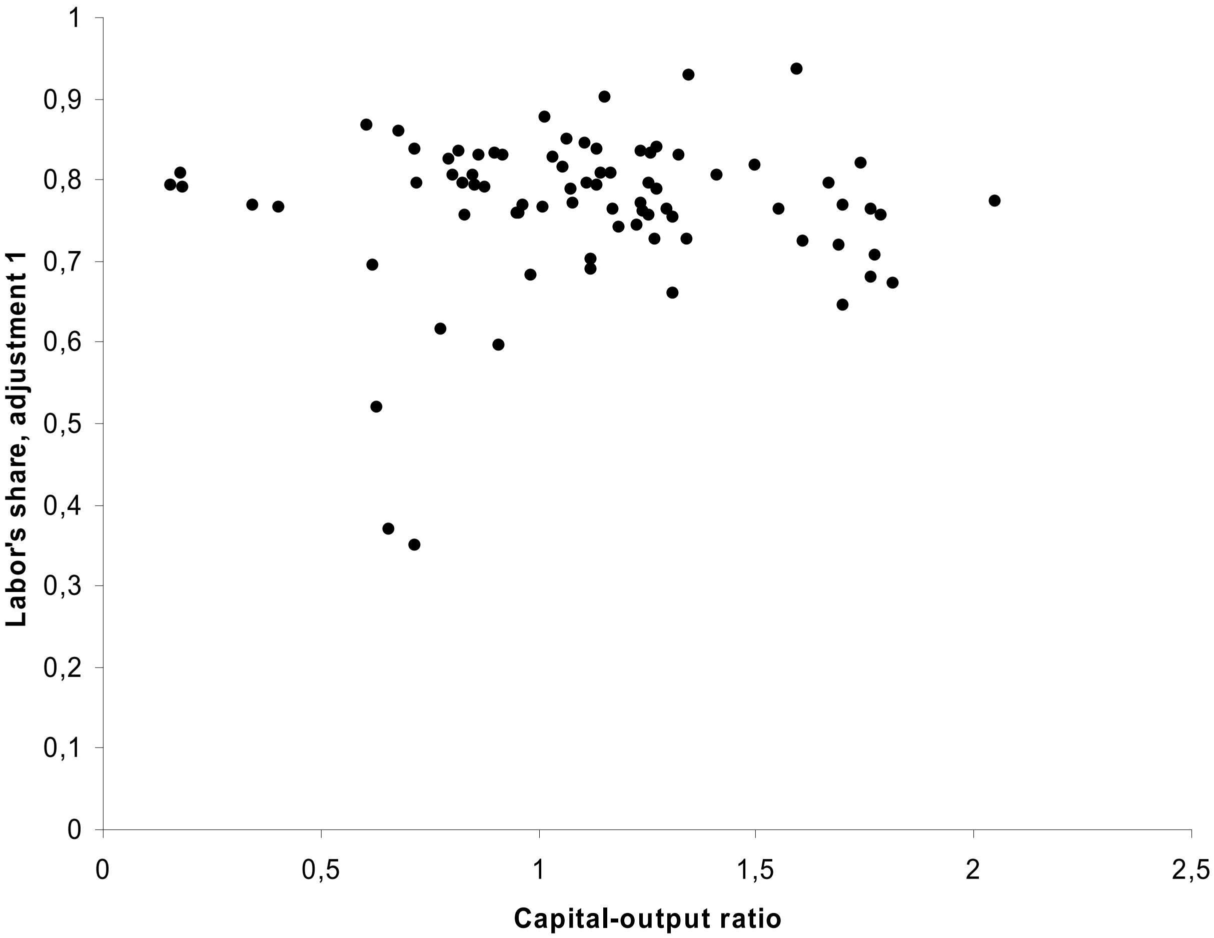

Figure 1. Labor's share (adj. 1) vs. Capital-Output ratios: Cross country and time series various years. Source: Capital-Output ratios are taken from Easterly and Levine (2001). Labor shares: Gollin (2002).

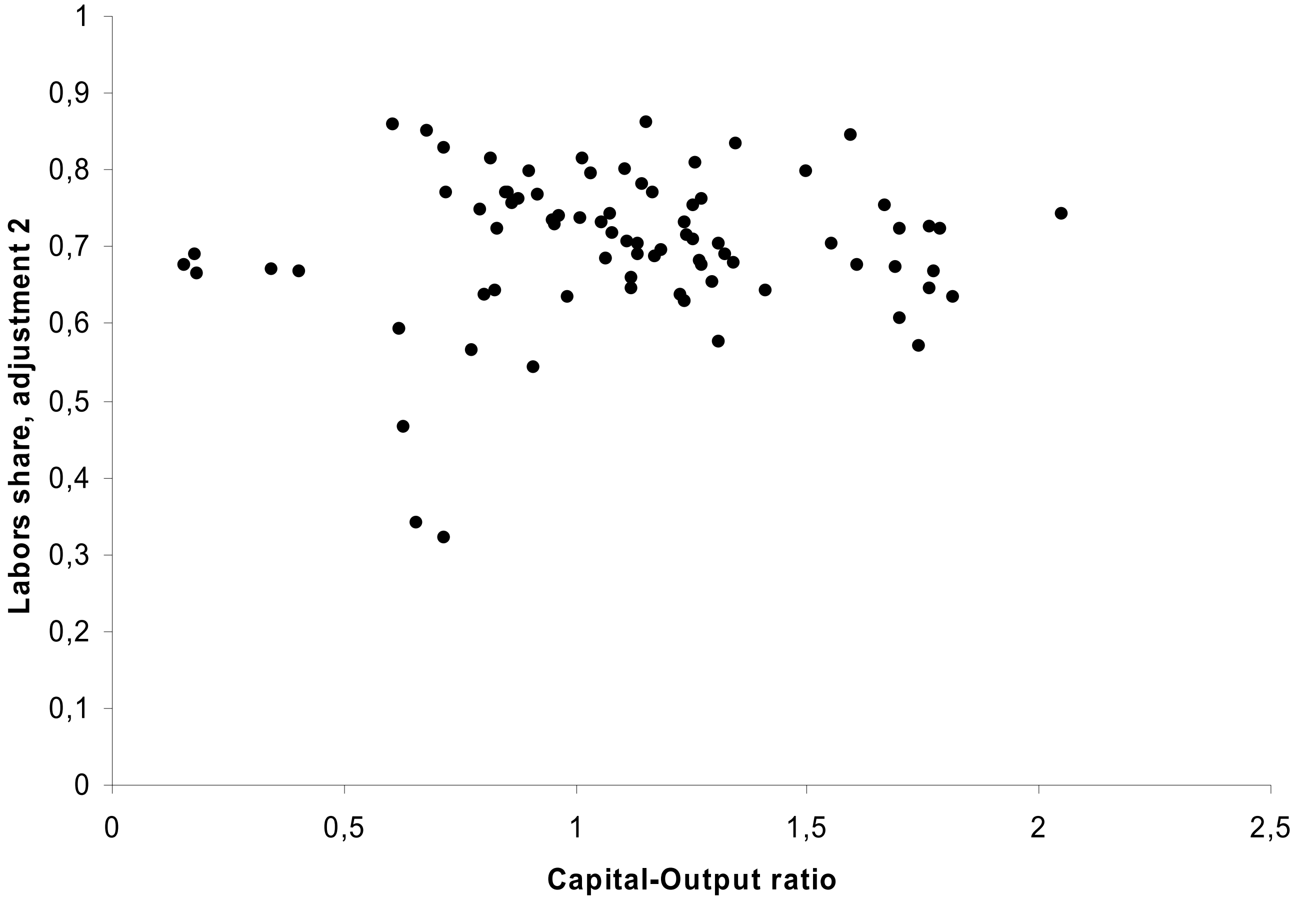

Figure 2. Labor's share (adj. 2) vs. Capital-Output ratios: Cross country and time series various years. Source: Capital-Output ratios are taken from Easterly and Levine (2001). Labor shares: Gollin (2002)

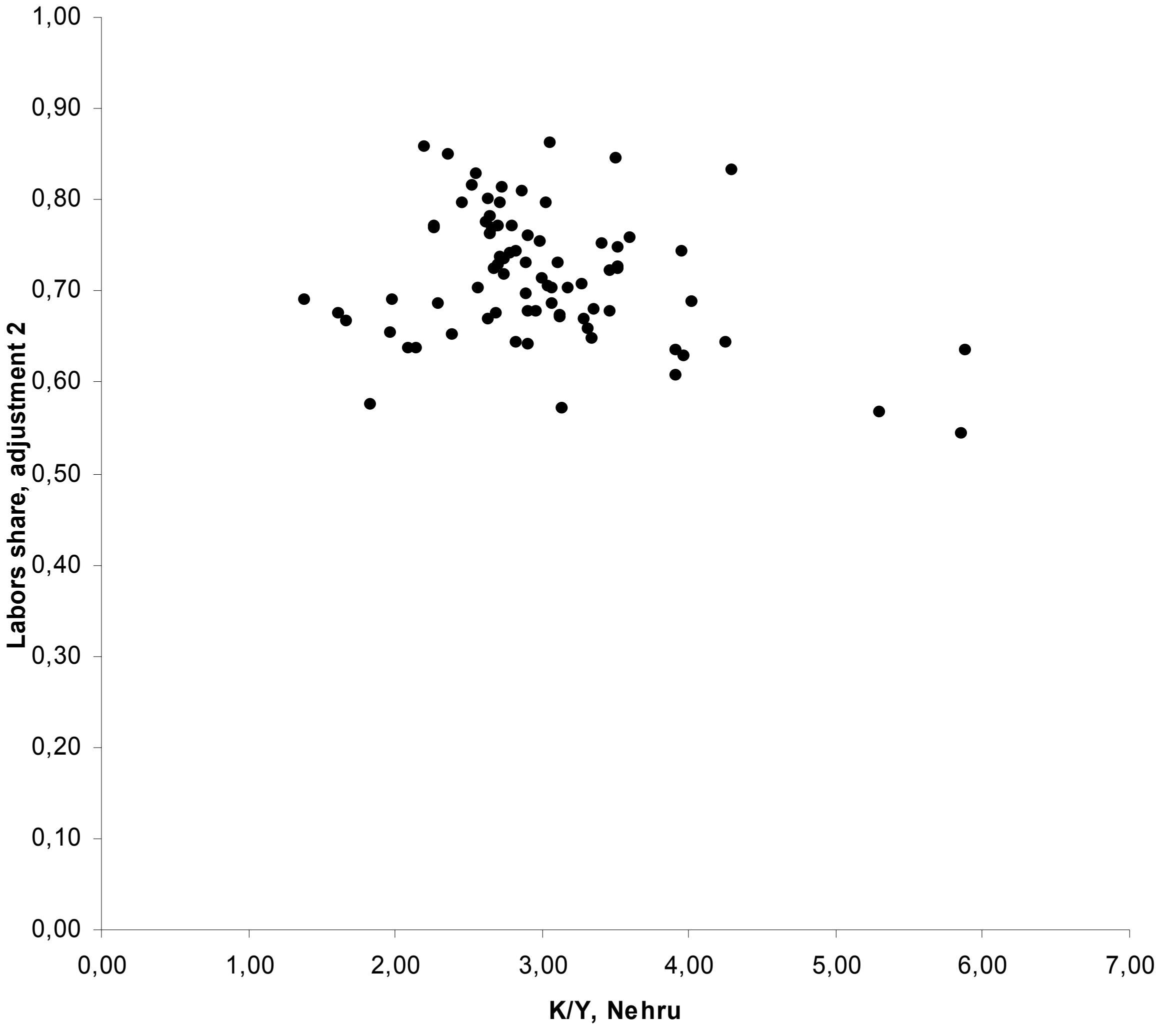

Figure 3. Labor's share (adj. 2) vs. Capital-Output ratios: Cross country and time series various years. Source: Capital-Output ratios are taken from Nehru and Dhareshwar (1993). Labor shares: Gollin (2002)

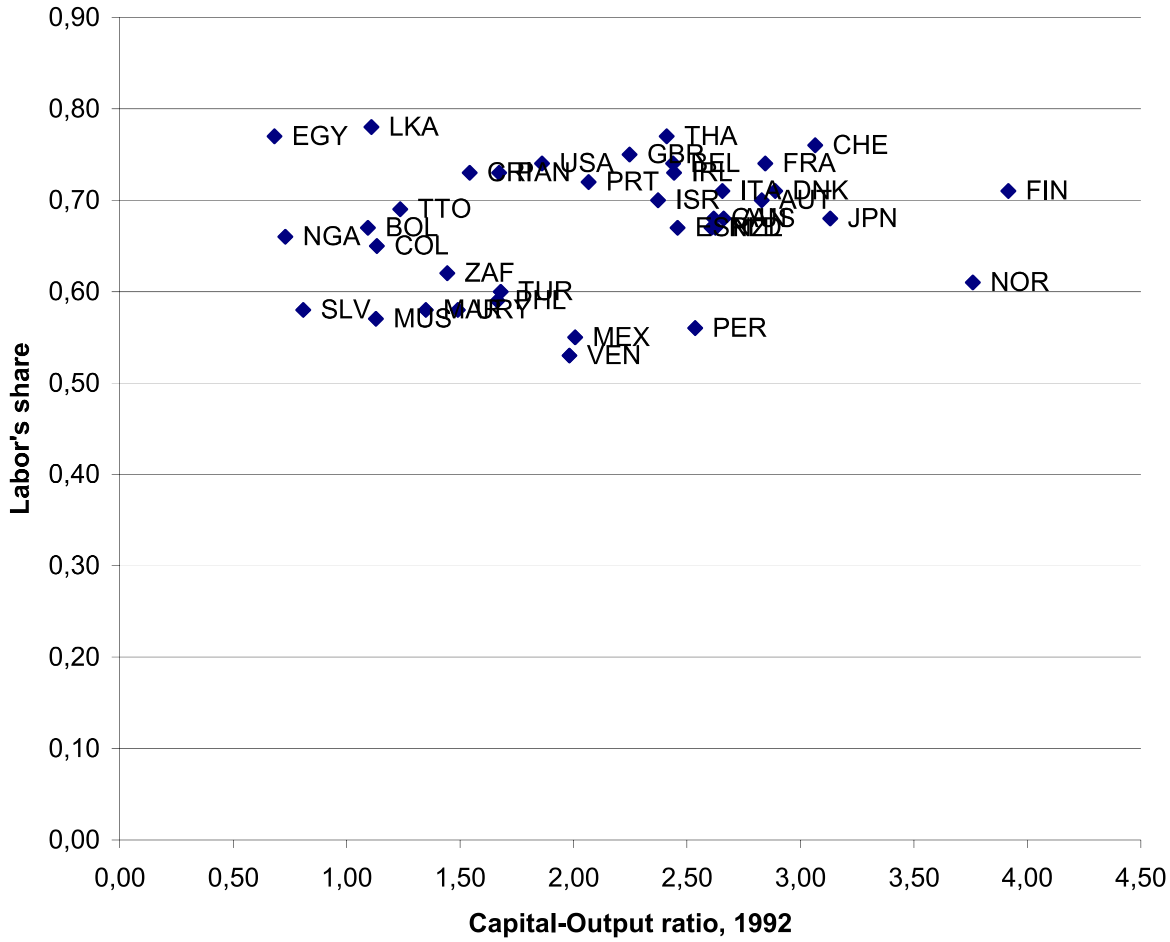

Figure 4. Labour's Share vs. Capital-Output ratios: Cross-Country only. Note: Capital-Output ratios are for 1992. Data sources: Labour shares are from Bernanke and Gürkaynak, 2001 Table X. Capital-output ratios: Penn World Tables 6.0 and own calculations.

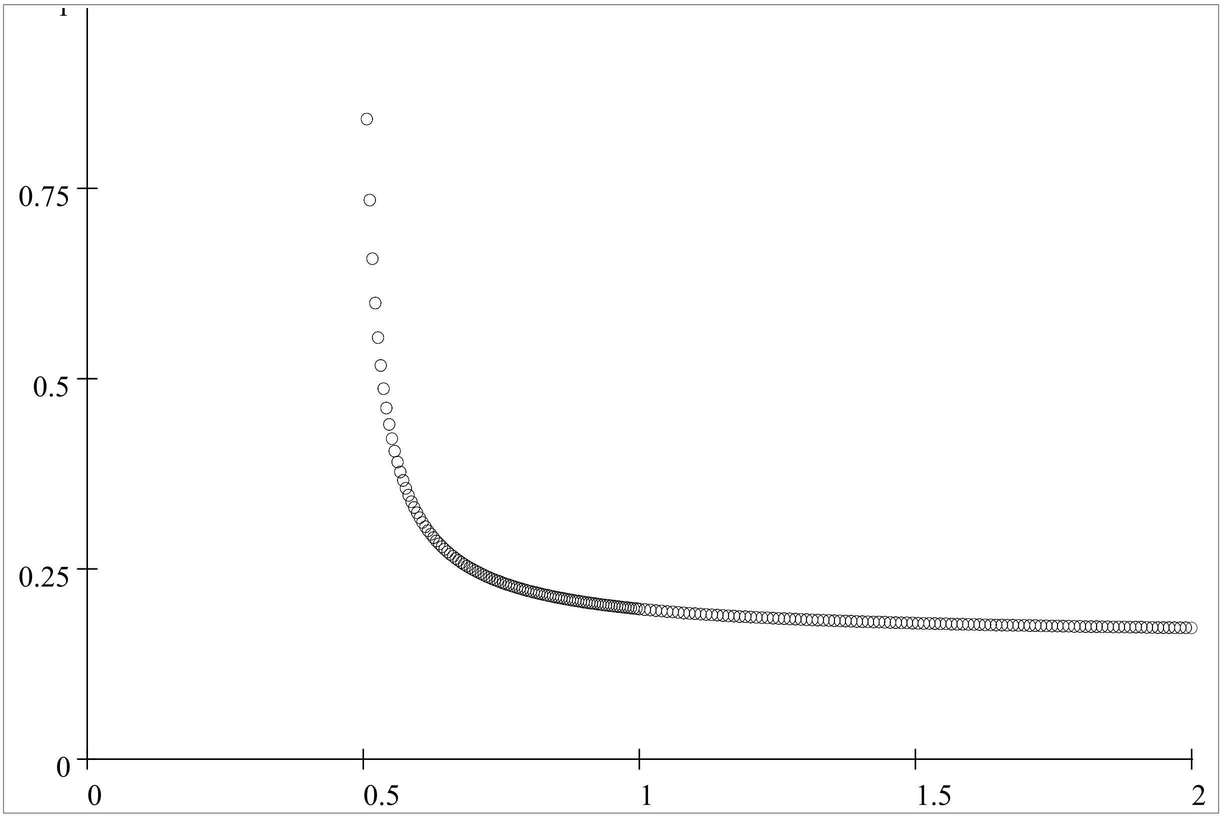

Figure 5. The figure shows the fraction of the "90/10" ratio, which is accounted for by physical and human capital under varying assumptions about the elasticity of substitution (ranging from zero to 2)

Table 1. Regression results

Data source	Gollin (2002), Adjustment 1	Gollin (2002), Adjustment 2	Bernanke and Gürkaynak
Easterly and Levine (2001)	-0.02 (0.07)	-0.05 (0.05)	
Nehru and De	0.26 (0.17)[a] 0.03 (0.2)[b]	0.17 (0.14)[a] 0.003 (0.15)[b]	
PWT 6.0			-0.07 (0.09)

Notes: The following model is estimated by OLS: $\ln(S_K) = a + b*\ln(\kappa)$. The numbers reported in the table are the estimates for b. Robust standard errors in parenthesis. a) Jamaica included in the sample. b) Jamaica excluded

Table 2. Implied elasticity of substitution with Harrod and Solow neutral technology

$-\rho$	ε_{MIN}	$\varepsilon_{MA\Xi}$
1.0	-3.45	0.77
0.9	-10.6	0.78
0.8	0.79	11.12
0.7	0.80	3.89
0.6	0.81	2.46
0.5	0.83	1.85
0.4	0.85	1.52
0.3	0.87	1.31
0.2	0.90	1.18
0.1	0.95	1.07

Note: The calculations assume a=0.85[2]