The Composition of Capital and Cross-country Productivity Comparisons

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Abstract

The role of physical capital is typically found to be limited in accounting for differences in GDP per worker, but this result may be because capital is customarily assumed to be a homogenous unit. This assumption is misleading, as different types of capital assets have different marginal products and richer countries tend to invest more in high-marginal product assets. We take this perspective to a global dataset, the Penn World Table, to improve cross-country productivity comparisons. We show that, properly measured, differences in capital input can account for a greater share of income variation, but (total factor) productivity differences remain dominant.

Income levels differ greatly across countries: the average income level in 2011 in Denmark (at the 90th percentile of the cross-country income distribution) was about 30 times higher than in Haiti (at the 10th percentile). We can aim for a better understanding of these differences by trying to account for as much as possible of these income differences using the tool of development accounting. In development accounting, income differences are partly attributed to differences in observed levels of human and physical capital with the remainder attributed to differences in total factor productivity (TFP).[2] A typical result is that approximately half of income differences are due to differences in (human and physical)

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2 See in particular Caselli (2005) and Hsieh and Klenow (2010) for overview articles.

capital input and half due to TFP differences.

Yet there are good reasons to believe that the role of physical capital in development accounting is underestimated. This is, in part, because usually only the contribution from standard 'National Accounts' assets are considered, while there are good reasons to expand asset coverage to include other intangible assets (Chen, 2018) and subsoil assets (Freeman, Inklaar and Diewert, 2018). But even when focusing on the set of assets covered in the National Accounts, we may still be underestimating the role of (physical) capital.[3] This is because countries differ systematically in their investment patterns: high-income countries tend to invest more in short-lived assets, such as computers and software, and less in long-lived assets like office buildings or roads. These differences are due to the higher relative cost of short-lived assets in low-income countries (Hsieh and Klenow, 2007) and lack of complementary assets, such as human capital (Caselli and Wilson, 2004). Yet the impact of these differences for development accounting are not yet well understood.

To gauge the impact of these differences on comparative levels of capital input and productivity, we rely on the conceptual tools introduced by Jorgenson and Nishimizu (1978) and in particular their methodology.[4] These tools have—so far—only been partially implemented in comparing productivity levels on a global scale. Most notably, the Penn World Table (PWT), (Feenstra, Inklaar and Timmer, 2015) compares productivity across countries using a measure of capital input that does not appropriately account for differences in the marginal product of the various capital assets.[5] In this article, we go a step further by estimating the user cost of capital and comparing the rental price of capital and the level of capital services rather than capital stocks. While this is not the first article to do so, we cover a much broader set of countries than previously in the literature, which means we can speak to the broader development accounting

3 Note that this set has changed over time. In the accounting rules of the System of National Accounts (SNA) 1993, much of spending on software was recategorized from an expense to an investment and in the SNA 2008, a major change was to recognize spending on research and development as an investment. Different countries follow different versions of the SNA, with very few still using SNA 1968 and approximately half of the countries using SNA 1993 and half using SNA 2008, according to the UN National Accounts Official Country Data.

4 See e.g. Jorgenson, Nomura and Samuels (2016), Inklaar and Timmer (2009) and Schreyer (2007) for more recent implementations of this methodology.

5 Feenstra et al. (2015) build on Diewert and Morrison (1986) and Caves, Christensen and Diewert (1982), who in turn build on Jorgenson and Nishimizu (1978).

literature.[6]

In this study, we implement the user cost/capital services methodology in a global setting over the period since 1950 and assess the impact on international differences in capital input and productivity compared with the 'capital stock' measure that is used in recent versions of PWT. In this process, we improve measurement in three areas.

First, PWT assumes that when a country's data are first observed, its nominal capital-output ratio is 2.6, based on contemporaneous evidence (Feenstra *et al.* 2015). Using historical series for 38 countries, we show that across the development spectrum, nominal capital-output ratios have been increasing over time. We implement a method for estimating initial capital stocks using country-specific information, in combination with the observed global trend to allow for more reliable estimation of capital input when a country's data are first observed.

Second, the return on capital plays an important role in the literature, in particular the Lucas (1980) paradox of why capital is not flowing towards low-income countries. More recently, Caselli and Feyrer (2007) argue that, properly measured, the marginal product of capital (MPK) does not vary with country income level. Conversely, David, Henriksen and Simonovska (2016) argue that, over the long run, low-income countries do have a higher MPK, with higher risk explaining the Lucas paradox. The method of Jorgenson and Nishimizu (1978) requires an estimate of the internal rate of return on capital (IRR), which is a more accurate measure of the return to capital than the MPK because it accounts for differences in the composition of the capital stock. Our findings accord with those of David *et al.* (2016), that low-income countries have higher (real) IRRs and we show that a single-year comparison of returns can easily be misleading for the long-run patterns.

Third, in PWT's capital stock-based methodology, the weight given to short-lived assets is too low compared to the conceptually appropriate capital services methodology. We confirm that high-income countries invest more in short-lived assets than low-income countries. By moving to a capital services methodology, capital input of high-income countries is thus increased relative to capital input in low-income countries. We show that, as a result, cross-country differences in capital input can account

6 The data we develop in this article are part of version 9.1 of the Penn World Table, available at www.ggdc.net/pwt.

for a greater share of cross-country income variation, increasing from 4.4 to 7.5 per cent in 2011. Even then, though, productivity differences remain the dominant source of income variation at 64.8 per cent.

In the following sections we will outline the conceptual framework for development accounting, productivity measurement and capital measurement. We will then discuss our implementation, with specific attention to our new method for estimating initial capital stocks and the choices necessary to estimate capital services. We finally show results for the new capital measures and the implications for the importance of cross-country differences in capital input in accounting for cross-country income differences.

Development Accounting

As detailed in Caselli (2005), the typical starting point in development accounting is an aggregate production function for country m:

$$Y_m = A_m f(K_m, L_m) = A_m K_m^{\alpha} L_m^{1-\alpha} \tag{1}$$

A country's GDP, Y, is produced using production function f with input of capital K and labour L and total factor productivity level A. In equation (1) we assume a constant-returns to scale Cobb-Douglas production function with a constant output elasticity of capital α for expositional simplicity. In the next section, on productivity measurement, we will move to a translog function. Similarly, the production function in equation (1) shows overall capital input and in the section on capital measurement, we will show how this is computed based on detailed asset stocks and their rental prices. Let a lower-case variable denote a quantity divided by country population, P_m, and let us express quantities relative to the United States, so that, for example, relative GDP per capita is defined $\tilde{y}_m = \frac{Y_m/P_m}{Y_{US}/P_{US}}$. We can then decompose a country's GDP per capita level relative to the United States into the contribution from differences in factor inputs and differences in productivity levels:

$$\tilde{y}_m = \tilde{A}_m \tilde{k}_m^{\alpha} \tilde{l}_m^{1-\alpha} \tag{2}$$

As discussed in Hsieh and Klenow (2010), this accounting for differences in GDP per capita levels answers the hypothetical question: by how much would GDP per capita increase if one of the factor inputs or productivity were to increase, holding constant the other two elements. This can be a sensible hypothetical when comparing growth over a short period of time as it is plausible to assume that the economy has not yet moved from one steady state to another. Yet when comparing across countries, it seems more plausible that the comparison is between countries in a (Solow model) steady state, i.e. where the investment response to the level of technology has worked itself out.

Hsieh and Klenow (2010) argue that a more sensible hypothetical in a cross-country context would be:

$$\tilde{y}_m = \tilde{A}_m^{\frac{1}{1-\alpha}} \left(\frac{\tilde{k}_m}{\tilde{y}_m}\right)^{\frac{\alpha}{1-\alpha}} \tilde{l}_m \qquad (3)$$

This rearranges the production function in intensive form and the hypothetical question for this decomposition is how GDP per capita would change if total factor productivity or labour input per capita were to change, allowing capital per person to adjust in response. This reduces the effect of differences in capital input, since part of the differences in capital per worker are an endogenous response to differences in productivity and labour input, whose contributions are, in turn, magnified.

Given data for all terms of equation (3), we will assess the role of each term in accounting for income differences by estimating the following regressions:

$$\frac{1}{1-\alpha} \log(\tilde{A}_m) = \beta^A \log(\tilde{y}_m) + \epsilon_m^A \qquad (4)$$

$$\frac{\alpha}{1-\alpha} \log\left(\frac{\tilde{k}_m}{\tilde{y}_m}\right) = \beta^K \log(\tilde{y}_m) + \epsilon_m^K \qquad (5)$$

$$\log(\tilde{l}_m) = \beta^L \log(\tilde{y}_m) + \epsilon_m^L \qquad (6)$$

Since the sum of the dependent variables equals the independent variable, the coefficients β^A, β^K and β^L add up to one and inform us of the relative importance of each term in accounting for cross-country income differences.[7] We will implement equation (3) for three alternative measures of capital input and then compare β^A and β^K for each alternative.

Measuring Productivity

A common justification for the Cobb-Douglas function used in the previous section is the work of Gollin (2002). He showed that the standard estimate of the output elasticity of capital α, the share of capital income in GDP, does not systematically vary with a country's income

7 This is an alternative to the variance decomposition used in Caselli (2005), which has as a downside that covariances between inputs and productivity need to be allocated. The approach in equations (4), (5) and (6) is applied in the context of accounting for trade patterns in Redding and Weinstein (2018) and the adding-up property means that no ad-hoc allocation of covariances is necessary.

level. However, when distinguishing multiple types of capital and/or labour inputs, assuming that all input shares are identical is unlikely to hold. Such a situation calls for a more flexible functional form and here we follow Jorgenson and Nishmizu (1978), Schreyer (2007), Feenstra *et al.* (2015) and Inklaar and Diewert (2016) and assume a translog production function. This allows us to compare the level of factor inputs, Q, in country m relative to country c as:

$$\log Q_{m,c} = \alpha_{m,c}[\log K_m - \log K_c] + (1 - \alpha_{m,c})[\log L_m - \log L_c] \quad (7)$$

with $\alpha_{m,c} = \frac{1}{2}(\frac{r_m K_m}{r_m K_m + w_m L_m} + \frac{r_c K_c}{r_c K_c + w_c L_c})$ the two-country average share of capital income in GDP.[8] This implementation of α implies assuming constant returns to scale, so that total income equals total cost, and perfect competition in factor markets so that inputs are used up to the point where marginal product equals marginal costs. If, in addition, perfect competition in output markets is assumed, the resulting estimate of total factor productivity can be interpreted as a measure of comparative technology. We follow much of the development accounting literature and assume that labour input is well-captured by a measure of total hours worked H_m multiplied by a human capital index h_m that depends on the average years of schooling and an (assumed) rate of return to schooling.[9] In addition, note that this is (for expositional purposes) a two-input specification, but a key feature of this article is that we distinguish multiple types of capital assets. Extending equation (2) to cover multiple assets K_i is discussed below.

Equation (2) shows the input index for a comparison between countries m and c but with multiple countries $c = 1, \ldots, C$, the resulting index will be dependent on the base country c. The solution is to make a multilateral comparison as discussed in, for example, Inklaar and Diewert (2016). Given the translog production function we assume, the multilateral input index can be expressed as:

$$\log Q_{m,\cdot} = \alpha_{m,\cdot}[\log K_m - \overline{\log K}] + (1 - \alpha_{m,\cdot})[\log L_m - \overline{\log L}] \quad (8)$$

8 As the equation for $\alpha_{m,c}$ makes clear, this share—as all others in this article—is defined in terms of current price values.

9 We follow the standard implementation of Caselli (2005), though see Lagakos, Moll, Porzio, Qian and Schoellman (2018) for a broader view of human capital in a development accounting context.

Where $\alpha_{m,\cdot}$ is the average of the capital income share in country m and of the cross-country average capital income share, $\alpha_{m,\cdot} = \frac{1}{2}(\frac{r_m K_m}{r_m K_m + w_m L_m} + \frac{1}{c}\sum_{c=1}^{C} \frac{r_c K_c}{r_c K_c + w_c L_c})$ and $\overline{\log K}$ the cross-country average of capital input levels, $\overline{\log K} = \frac{1}{c}\sum_c \log K_c$. Equation (8) gives the input index relative to a hypothetical average country, but that index can be recast relative to any reference country, such as the United States.[10]

Measuring Capital

A key objective of this article is to estimate comparative capital input based on multiple capital assets, which involves estimating, for a range of capital assets $i = 1, \ldots, I$, capital input K_i and rental prices r_i. Following the framework of Jorgenson and Nishimizu (1978)—and more recently discussed in the OECD (2009) capital manual—the asset rental price at time t can be approximated as:[11]

$$r_{i,t} = p^N_{i,t-1} i_t + p^N_{i,t}\delta_i - p^N_{i,t-1}(p^N_{i,t} - p^N_{i,t-1}) \quad (9)$$

where i_t is the required rate of return on capital (on which more below), p^N_i is the purchase price of asset i, and δ_i is the geometric depreciation rate.

The quantity of capital input K_i is typically not directly observable. Instead it is based on estimated net capital stocks N_i, which are in turn based on the total accrued investment I_i depreciated over time using the perpetual inventory method:

$$N_{i,t} = (1 - \delta_i)N_{i,t-1} + I_{i,t} \quad (10)$$

An important challenge in implementing equation (9) is the estimation of the capital stock in the initial year, $N_{i,1}$, which we discuss in detail below.

Assuming that the flow of capital inputs from a particular asset is proportional to the stock of that asset, $N_i \propto K_i$, we can express the income flow from asset i as $r_i N_i$ and estimate relative capital input for equation (8) as:

$$\log(K_{m,\cdot}) = \sum_i \frac{1}{2}(v_{i,m} + v_{i,\cdot})(\log N_{i,m} + \overline{\log N_t}) \quad (11)$$

where $v_{i,m} = \frac{r_{i,m}K_{i,m}}{\sum_i r_{i,m}K_{i,m}}$ is the share

10 The multilateral productivity measures we have introduced here, imply a small modification to the development accounting introduced in equations (4)-(6). Rather than relying on a single α, we use $\alpha_{m,\cdot}$.

11 This formulation of the rental price abstracts from terms related to the tax treatment of investment and profits.

of asset i in total compensation in country m, $v_{i,\cdot} = \frac{1}{c}\sum_c v_{i,c}$ is the cross-country average compensation share and $\overline{\log N_i} = \frac{1}{c}\sum_c \log N_{i,c}$ the cross-country average capital stock.

It is helpful to contrast the conceptually preferred measure of equation (11) to current practice in the Penn World Table, which for our analysis is the status quo. PWT's capital input measure is a measure of the overall capital stock:

$$\log N_{m,\cdot} = \sum_i \frac{1}{2}(w_{i,m} + w_{i,\cdot}) (\log N_{i,m} + \overline{\log N_i}) \tag{12}$$

where $w_{i,m} = \frac{p_i^N N_i}{\sum_i p_i^N N_i}$ is the share of asset i in the total current-cost net capital stock. The main difference with our approach is that the measure of capital input in equation (12) does not consider that different assets have different rental prices. Compared to equation (11), equation (12) overstates the importance of long-lived assets, which tend to have a relatively low rental price (because of a low δ_i) and a high share $w_{i,m}$. When moving from measuring capital using equation (12) to equation (11), we expect countries with a relatively high share of long-lived assets to show a decline in relative capital input levels.

Data and Implementation

For implementing the development accounting equation (3), our starting point is the Penn World Table. Our measure of comparative GDP, population, employment, average hours worked, the share of labour income in GDP and average years of schooling are as described in Feenstra *et al.* (2015) and at www.ggdc.net/pwt. PWT (version 9.1) covers up to 182 countries from 1950 to 2017, but the maximum number of countries in our analysis is 117, because for some we do not have the requisite data to implement the development accounting method.

For estimating capital input, the starting point for both the current PWT approach and our new analysis is data on investment by asset type. Here, too, we use the same data, which distinguishes nine asset types: residential buildings, other structures, information technology, communication technology, other machinery, transport equipment, software, other intellectual property products and cultivated assets (such as livestock for breeding and vineyards).[12] As discussed in PWT documentation, these investment data are drawn from country National Accounts data, supplemented by estimates based on to-

12 See also Table 3 in the results section.

tal supply of investment goods (import *plus* production *minus* exports) and data on spending on information technology. Note that coverage is limited to assets currently covered in the System of National Accounts. This means we omit land and inventories, as well as other forms of intangible capital—such as product design or organization capital—and subsoil assets—such as oil or copper.

Initial Capital Stocks

Our estimate of asset capital stocks is based on the perpetual inventory method, so the capital stock at time t is based on all previous investments (equation 10). But given that we only observe investment data for a limited period of time (for PWT, 1950 is the earliest year), an important challenge is to estimate the capital stock in the first year of the data, $N_{i,1}$. There are two main approaches in the literature. The first is to assume the economy in the steady-state of the Solow model at time t, in which case the initial stock is equal to:

$$N_{i,1} = \frac{I_{i,1}}{g_i + \delta_i} \tag{13}$$

where $I_{i,1}$ is investment in the initial year and g_i is an estimate of the steady-state growth rate of investment in that asset, typically implemented as an average growth rate in the first years of the observation period.

The second method is to use a data-driven approach to select an initial capital level. The nominal capital-output ($p^N N/p^Y Y$) ratio is a helpful quantity in this approach. In the Solow model, the $p^N N/p^Y Y$ ratio is constant while capital per worker increases with income, matching two of the Kaldor facts, and observation also shows this ratio to be bounded. Feenstra *et al.* (2015) observed in the PWT data that (a) the $p^N N/p^Y Y$ ratio did not vary systematically by income level, and (b) the $p^N N/p^Y Y$ ratio did not systematically change over time. This motivated the choice for selecting an initial $p^N N/p^Y Y$ ratio based on contemporaneous data that did not vary across countries or over time. In PWT versions 8.0, 8.1 and 9.0, the initial current-cost net capital was set at a level of 2.6 times GDP at current prices for each country. This choice can be justified if the main goal is to select an N_i that does not systematically over- or underestimate capital input by income level, but this approach ignores country-specific information.

Recent data development has provided further scope for improvement. Gallardo Albarrán (2018) has collected investment data for 38 countries across the world and spanning much of the development spectrum for the period before 1950, with data coverage varying between countries, from Sweden (data starting in 1800) to Korea (data starting in 1911). As a result, the $p^N N/p^Y Y$ ratio we observe in 1950 for these 38 countries can be taken as reliable initial capital stocks. The data for these 38 countries thus provides a more extensive basis for assessing the stylized facts underlying PWT, in particular the finding that there is no time trend in the $p^N N/p^Y Y$.

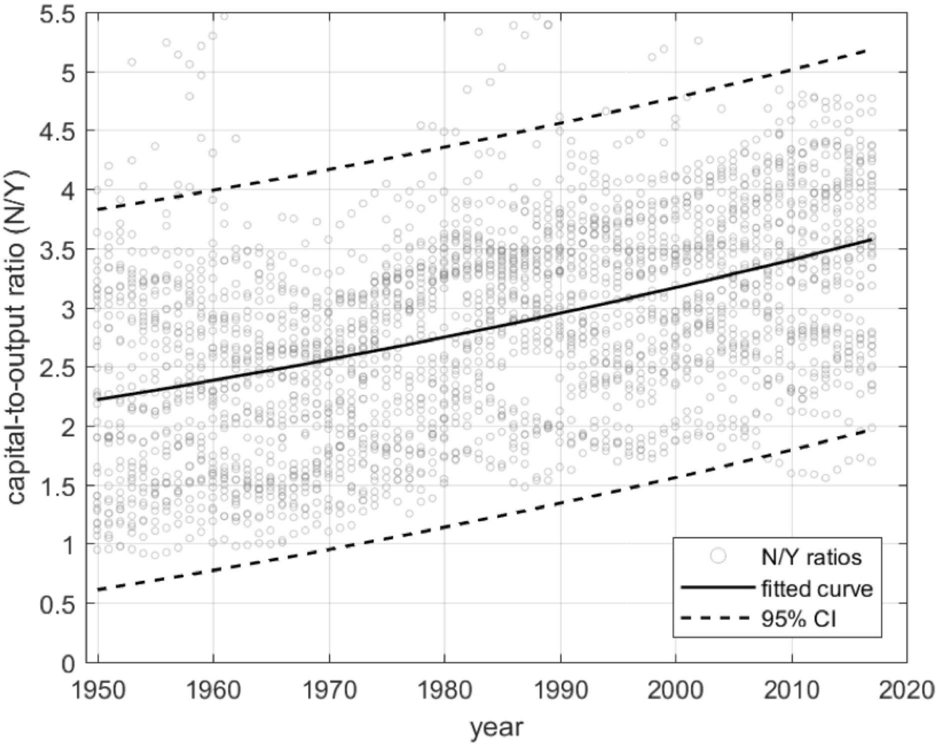
Chart 1 plots the $p^N N/p^Y Y$ ratio for the 38 countries since 1950. A first important observation is that there is a time trend: the $p^N N/p^Y Y$ ratio increases from, on average, 2.2 in 1950 to 3.5 in 2017 for an increase of approximately 0.02 per year. Second, this chart illustrates the large cross-country variation, with 1950 ratios varying between 0.9 and 4.0. The choice of 2.6 in recent PWT versions is thus only (somewhat) appropriate on average.

To estimate initial capital stocks for the countries without long-run (pre-1950) investment data in a way that does justice to the rising trend and the cross-country variation, we devise a new procedure, which we illustrate in Chart 2. First, we determine the point in each country's time series at which the choice of the initial capital stock has faded enough in importance; we denote this point by t^*. To determine t^*, we estimate $p^N N/p^Y Y$ ratios based on extreme initial stocks: an $p^N N/p^Y Y$ ratio of 0.5 on the low end and an $p^N N/p^Y Y$ ratio of 4 on the high end. These extremes are inspired by the extremes in Chart 1. Point t^* is chosen as the first year for which the difference in estimated capital stocks from both extremes is less than 10 per cent. This point can come sooner or later depending on the composition of the capital stock (short- vs. long-lived assets) and the growth rate of investment. In the example for Turkey in Chart 2, $t^* = 1990$, which means that from 1990 onwards, the choice of the initial capital stock is practically immaterial.

The next step in the procedure is to take the mid-point $p^N N/p^Y Y$ ratio at year t^* and project this level backwards using the average annual change in the $p^N N/p^Y Y$ ratio of 0.02 from Chart 1. We realize this growth rate will not be appropriate for each country, but over time frames of 30-40 years, most countries do show increases in the $p^N N/p^Y Y$ ratio. Compared to assuming a single initial $p^N N/p^Y Y$ ratio for every country, this procedure does more justice to each country's experiences.

We were able to apply this procedure successfully for 92 countries. For some countries the available investment series were too short in length to converge to within our defined bandwidth, so no t^* could be determined.

Chart 1: Capital-to-Output Ratios, 1950-2017



Notes: Annual capital-to-output ratios for 38 countries for which long run (pre-1950) investment data are available.

For those cases we base the starting level of the $p^N N/p^Y Y$ ratio on the average observed for that year for the 130 countries for which we have estimates of the $p^N N/p^Y Y$ ratio.

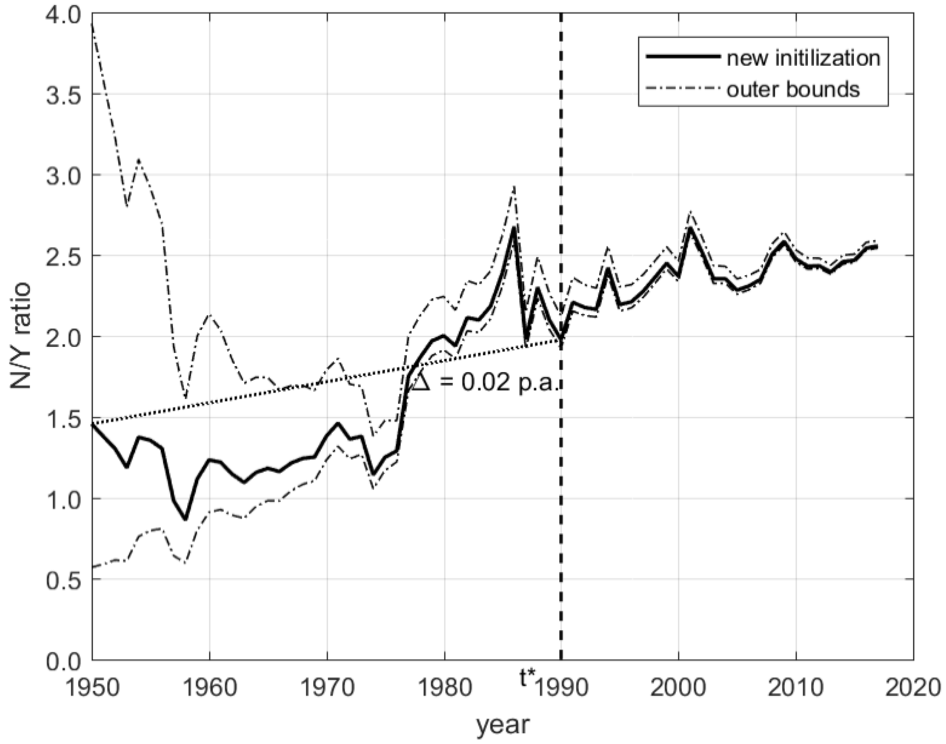
Rental Prices

Recall that the rental prices are determined by the required rate of return on capital, the depreciation rate and a revaluation term, reflecting the change in the asset price. The revaluation term as specified in equation (9) is not ideal in practice, because asset prices can be quite volatile. Especially in the case of structures, with its low depreciation rates, this can be problematic and lead to negative rental prices.[13] To avoid this, we use a five-year moving average for the change in asset prices:

$$p^K_{i,t} = p^N_{i,t-1} i_t + p^N_{i,t}\delta_k - p^N_{i,t-1}\frac{1}{5}\left(\sum_{\tau=t-4}^{t}\widehat{p}^N_{i,\tau}\right) \qquad (14)$$

13 See also Inklaar (2009).

Chart 2: Example of Estimation Procedure Initial Capital-to-Output Ratio, Turkey



Notes: The starting $p^N N/p^Y Y$ ratio for the upper bound is 4.0. The lower bound starts at 0.5. 't^*' marks the year where the lower- and upper bound converge to within a margin of 10 per cent. The slope of the dashed line represents the assumed growth of the $p^N N/p^Y Y$ ratio at 0.02 per annum between the first year [1950] and t^* [1990]. The solid black line shows the resulting capital-output ratio based on the estimate for the initial $p^N N/p^Y Y$ ratio.

In the standard Jorgensonian approach to rental prices, the required rate of return on capital is chosen to exhaust the income left after subtracting labour income from GDP. This gives an internal rate of return on capital and an important advantage is that this return sets 'pure profits' to zero and is thus consistent with the maintained assumption of perfect competition. An important drawback, in a global context, is that in some countries the rents from extracting natural resources like oil and gas is a sizeable fraction of GDP (Lange, Wodon and Carey, 2018). For those countries, computing the internal rate of return based on the income that does not flow to labour would substantially overestimate the required rate of return on assets.[14] So instead, we determine the income flowing to capital as nominal GDP minus labour income minus natural resource rents:

14 Ideally, natural resources should be recognized as production factors in their own right. That is beyond the scope of this article but see Freeman, Inklaar and Diewert (2018).

15 Natural resource rents are from the World Development Indicators.

$r_t N_t \equiv p_t^Y Y_t - w_t L_t - p^Z Z$.[15] The (nominal) internal rate of return on capital is then determined to ensure capital compensation adds up to total capital income:

$$i_t = \frac{r_t N_t - \sum_i p_{i,t}^N \delta_i N_{i,t}}{\sum_i p_{i,t-1}^N N_{i,t}} + \frac{\sum_i p_{i,t-1}^N \frac{1}{5}(\sum_{\tau=t-4}^{t} \widehat{p}_{i,\tau}^N) N_{k,t}}{\sum_i p_{i,t-1}^N N_{i,t}} \quad (15)$$

For a cross-country comparison of the returns to capital we also estimate the real internal rate of return (R), a new variable in PWT version 9.1:[16]

$$R_t = \frac{r_t N_t - \sum_i p_{i,t}^N \delta_i N_{i,t}}{\sum_i p_{i,t}^N N_{i,t}} \quad (16)$$

The rental prices are also relevant for comparing the level of capital input in different countries. In the original PWT method (i.e. equation 12), capital stocks are made comparable across countries using data on the relative prices of investment goods, $p_{i,m}^N / p_{i,US}^N$. Yet when comparing capital input according to equation (11), the appropriate price comparison is based on the rental price from equation (14), so $p_{i,m}^K / p_{i,US}^K$. This adjusts the relative price of investment goods for differences across countries in the user cost of capital. Since we assume the same depreciation rate for a given asset in all countries, differences in the user cost of capital are due to differences in the (country-level) internal rate of return i_t and due to differences in the (five-year average) rate of asset price inflation. Especially for computers, communication equipment and software, cross-country differences in asset price inflation (or deflation) can be affected by the degree to which country statistical agencies adjust for quality change. So as in previous versions of PWT, we apply US asset price changes, adjusted for differences in the change in the overall deflator for gross fixed capital formation, to all countries.

Results

In this section, we first discuss how our new initial capital stock estimates influence capital-output ratios and how they compare to the $p^N N / p^Y Y$ ratios in the previous PWT. Next,

16 Note we also used the asset-specific investment price for the current year ($p_{i,t}^N$) instead of the previous year in the denominator for the calculation of the real IRR. Rapid inflation would otherwise cause the real IRR to fluctuate wildly. The correlation between the mean real IRR based on current year and previous year prices for countries who experienced below-average price changes is 0.998, for countries with above-average inflation this correlation is 0.794. The correlation between the standard deviations is 0.934 and 0.223 respectively. For the latter set of countries the standard deviation based on the previous-year method is much higher; 0.290 versus 0.055 for the current-year method.

we analyze the variation in the internal rates of return across countries and over time. Finally, we implement the development accounting procedure from equations (3-6) to assess to what extent our new, more conceptually appealing measure of capital input can account for more of the cross-country variation in income levels.

Capital-Output Ratios

For selected years, Table 1 summarizes the $p^N N/p^Y Y$ ratios based on the new, country-specific initial capital stocks compared to the previous method, where all countries had the same initial capital-output ratio. For our full sample of countries, the rising trend in the $p^N N/p^Y Y$ ratios observed in Chart 1 is confirmed: the average $p^N N/p^Y Y$ ratio climbs from 2.1 in 1950 to 3.5 in 2000.[17] The standard deviation, minimum and maximum values confirm that there are indeed sizable variations in the $p^N N/p^Y Y$ ratios between countries. The comparison between the 'new' and 'original' initialization shows the average adjustment in the $p^N N/p^Y Y$ ratios is most pronounced for earlier years. This is to be expected, as the $p^N N/p^Y Y$ ratios depend ever less on the initial stock. Already by 1990, the differences between the new and original initial capital stocks have mostly disappeared. The standard deviation and range of $p^N N/p^Y Y$ ratios for the original series remain lower for the original initial stocks, which reflects that the new initialization allows for variation in the starting capital-to-output ratios reflecting country-specific factors.

Internal Rates of Return

Chart 3 shows the development over time of the real internal rate of return R_t from equation (16). As discussed above, R_t is a proxy for the (expected) real returns to capital. We run an ordinary least squares regression of R_t on country and year dummies and plot year dummies with their 95-per cent confidence interval in the left panel Chart 3. This show the average R_t declining from 20.0 per cent in 1950 to 11.7 per cent in 2017. The distribution of R_t is skewed to the right, so the trend in the median is informative as well. To that end, the right panel of Chart 3 shows the results from a least median squares regression of R_t on country and year dummies. This shows the median decreasing from 14.4 per cent in 1950 to 8.5 per cent in 2017.

Table 2 reports the real IRR across three country groups (distinguished

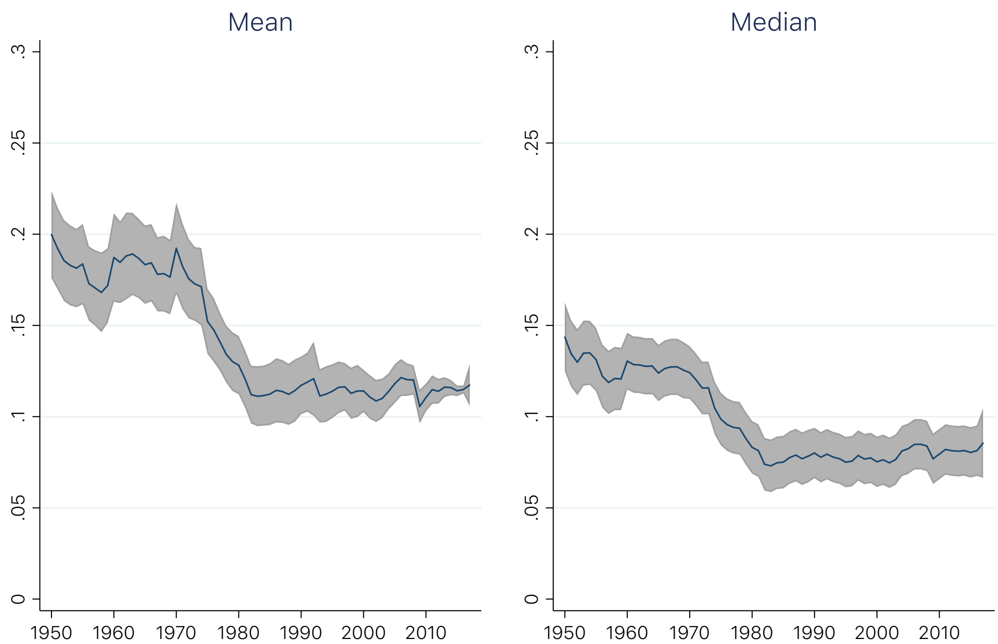
17 Note that the sample of countries for which we can estimate the capital stocks changes over time. The trend increase can still be observed if we hold the sample constant, however.

Table 1: Comparison of $p^N N/p^Y Y$ Ratios Between New- and Original Initiatlization, Selected Years

Year	Countries	New initialization				Original initialization			
		Mean	Stdev.	Min.	Max.	Mean	Stdev.	Min.	Max.
1950	55	2.1	0.9	0.5	4.0	2.6	0.0	2.6	2.6
1960	110	2.2	1.0	0.6	7.0	2.5	0.8	1.0	6.9
1970	156	2.1	0.9	0.6	5.4	2.4	0.6	0.8	4.9
1980	156	2.5	1.0	0.5	5.6	2.7	0.9	0.6	5.2
1990	180	3.0	1.6	0.6	18.2	3.1	1.6	0.6	17.4
2000	180	3.5	2.5	0.7	25.0	3.4	2.3	0.8	22.7
2011	180	3.3	2.5	1.0	30.2	3.3	2.3	1.0	27.6
2017	180	3.4	2.0	1.0	19.3	3.3	1.9	1.0	17.7

Note: The 'new initialization' relies on the procedure described in the 'starting stocks' section above to estimate the initial N/Y ratio for each country separately. The 'original initialization' assumes the initial level of N/Y for each country is equal to 2.6, mirroring the method used for previous versions of the PWT. Both the 'new' and 'original' series apply the same PIM procedure, discussed above, to construct the capital stocks and N/Y ratios for all subsequent years.

Chart 3: Real Internal Rate of Return Time Trend, 1950-2017



Note: The chart shows the coefficients and 95 per cent confidence interval for year dummies in an ordinary least squares regression of R_t from equation (16) regressed on country and year dummies (left panel) and the year dummies from the same regression but then estimated using least median squares. The sample size increases over time from 55 countries in 1950 to 135 in 2017.

Table 2: Real Internal Rate of Return by Income Group

Portfolio	1950-2017		1970-2017		2011
	(1)	(2)	(3)	(4)	(5)
1	0.124***	0.112***	0.110***	0.105***	0.101
2	0.139***	0.127***	0.128***	0.124***	0.120
3	0.094*	0.078**	0.090	0.084	0.086
US	0.078	0.057	0.075	0.068	0.075
Year dummies	N	Y	N	Y	N
Observations	7,586	7,586	6,080	6,080	135
Adjusted R^2	0.11	0.15	0.1	0.11	0.05

Notes: The portfolios are based on the approach of David et al. (2016), appendix F. The portfolio categories for countries missing in the David et al. dataset were estimated based the mean GDP p. capita observed between 1950 and 2008. In 2011 the (unweighted) average log of GDP p. capita for portfolio 1 was [8.1], for portfolio 2 [9.5], for portfolio 3 [10.5], and for the US [10.8]. *** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$.

by income level) for different periods, with or without year dummies, mirroring the approach of David *et al.* (2016). The results show that for the 1950-2017 period, the real IRR for the low- and middle-income countries was significantly higher than that observed for the United States. The implicit return to capital for high-income countries (other than the United States) was also higher, but this is only significant at the 10 per cent level. The result for low- and middle-income countries holds up if we include year dummies or limit the period to 1970-2017. If we focus on 2011 alone, the differences between the real IRR across the different country groupings are no longer significant. More in general, the explanatory power of these models is limited, so other factors must have also been important. For one, the year-to-year variation in the IRR will depend on the state of the business cycle, as during downturns the realized returns on capital are typically lower. The low explanatory power can also point to the importance of omitted assets, such as land and inventories (e.g. Inklaar, 2009). All this does suggest that drawing conclusions on a single cross-section worth of data, as in Caselli and Feyrer (2007) can lead to missing out on patterns that are clear in the data once more years are taken into account.

Capital Services

Using the internal rate of return discussed above and the asset-specific rates of depreciation listed in Table 3, we estimate the rental price of capital and the capital compensation shares (v_i) for the nine assets in our dataset and compare them to the average share in current-cost net capital stocks (w_i).

Table 3 summarizes these shares for all countries and years in our sample. As is to be expected, v_i exceeds w_i for assets with higher de-

Table 3: Depreciation, Shares and the Relationship with Income Level

Asset	Depreciation Rate (1)	Stock Share, w_i (2)	Services Share, v_i (3)	Services/Stock Share, v_i/w_i (4)	Coefficient log(GDP/capita) (5)
Information equipment	31.5	0.2	1.1	4.8	0.574*** (0.0126)
Communication equipment	11.5	1.3	2.3	1.8	0.251***(0.0144)
Other machinery	12.6	11	17.4	1.6	-0.005 (0.0054)
Transport equipment	18.9	4.4	8.2	1.8	-0.055*** (0.0061)
Software	31.5	0.2	0.9	3.9	0.720*** (0.0144)
Other intellectual property	15	1.2	2.5	2.1	0.555*** (0.0200)
Cultivated assets	12.6	0.1	0.2	2.3	-0.852***(0.0436)
Residential structures	1.1	39.1	28.6	0.7	0.024*** (0.0049)
Other construction	3.1	42.4	38.7	0.9	-0.054*** (0.0047)

Notes: The table shows (1) the asset-specific rates of depreciation; (2) the assets' average share in the total current-cost net capital stocks (for all years and countries in our sample); (3) the assets' average share in capital compensation; (4) the ratio between the capital services and the capital stock share; and (5) the beta coefficients for a regression of the log of GDP per capita on the log of nominal capital compensation ($p_i^K K_i$) over nominal output ($p^Y Y$). Robust standard errors in parentheses, *** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$.

preciation rates (and for assets where price deflation was more pronounced, notably IT-equipment). For example, capital compensation for other machinery accounts for 17.4 per cent on average, compared to the 11 per cent of the capital stock share, reflecting the higher service flow from such assets. In the final column we regress the nominal capital-to-output ratio for each asset on log GDP per capita. The coefficients show that high-income countries, on average, have higher stocks of short-lived assets and low-income countries have higher stocks of transport equipment, cultivated assets and other construction. This result mirrors similar earlier findings (e.g. Caselli and Wilson, 2004; Hsieh and Klenow, 2007) and suggests that employing a capital services input measure will lead to relatively higher levels of capital input in high-income countries. The only exception to this pattern is residential structures, whose stocks increase with income levels. Despite this, we would expect that capital input is more important in accounting for cross-country income differences when based on our new measure of capital services compared with the earlier capital stock measure.

Development Accounting

Table 4 shows the results from estimating equations (4-6) on data for 2011. The first row shows capital input measured as in equation (12), $N_{m,\cdot}$, and uses the original initial capital stocks, i.e. assuming a nominal capital-output ratio of 2.6 in the first observed year. The second row still uses $N_{m,\cdot}$ from equation (12) but based on the new estimates of the initial capital stock. The final row is based on $K_{m,\cdot}$, from equation (11). The coefficient on labour input, β^L is constant across the rows as measurement is unchanged. Changing the procedure for estimating the initial stock has very little impact on β^K and

Table 4: Development accounting results for 2011

	Capital input, β^K	Labour Input, β^L	Total Factor Productivity, β^A
$N_{m,\cdot}$, original initial stocks	0.044	0.277***	0.679***
	(0.0330)	(0.0241)	(0.0445)
$N_{m,\cdot}$, new initial stocks	0.050	0.277***	0.673***
	(0.0340)	(0.0241)	(0.0457)
$K_{m,\cdot}$	0.075**	0.277***	0.648***
	(0.0311)	(0.0241)	(0.0376)

Notes: The table show the beta coefficients for regression of capita input, labor input and productivity on GDP per capita, see equations (4-6), where instead of a single α, we use each country's share of capital income in GDP, $\alpha_{m,\cdot}$. $N_{m,\cdot}$ is computed as in equation (12), $K_{m,\cdot}$ as in equation (11). Data are for 117 countries. Standard errors between parentheses. *** p < 0.01; ** p < 0.05; * p < 0.10.

β^A, which was to be expected from Table 1 since by 2011 there is little difference between the two approaches. Going from $N_{m,\cdot}$ to $K_{m,\cdot}$ does have a substantial impact: β^K increases from 0.050 to 0.075, indicating that the new capital input measure can account for considerably more of the cross-country variation in income levels. At the same time, the effect on β^A is (relatively) smaller, going from 0.681 to 0.647. So, despite accounting for more of the cross-country income variation, productivity differences remain the dominant sources of income differences.

Conclusions

In this article, we have addressed two important shortcomings in the measurement of capital input in the widely-used Penn World Table. First, we have estimated initial capital stocks based on better data and an improved procedure that does more justice to country-specific experiences. Second, we have implemented a capital services methodology in accordance with standard productivity measurement theory. By doing so, we are able to account for more of the cross-country variation in income levels. This is because high-income countries tend to invest more in short-lived assets with higher marginal products.

Applying the capital services/rental prices methodology on a global scale for comparisons across countries highlights the challenges in this methodology. As discussed, the role of natural resources in generating income cannot be ignored, as otherwise the return that is imputed to fixed assets is considerably overestimated, in particular in resource-rich countries such as Qatar or Saudi Arabia. A related challenge is that we omit land and inventories from the set of assets due to lack of reliable data, and that, too, biases the estimated return on capital and can thus influence the comparison of capital input across countries. Yet we feel our current analysis serves a useful purpose in highlighting these challenges and pointing the way for future research in this area. And despite measurement shortcomings, our improved capital input measure can account for more of the cross-country differences in income levels.

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