1 Introduction

Is the world's capital stock efficiently allocated across countries? If so, then all countries have roughly the same aggregate marginal product of capital (MPK). If not, the MPK will vary substantially from country to country. In the latter case, the world foregoes an opportunity to increase global GDP by reallocating capital from low to high MPK countries. The policy implications are far reaching.

Given the enormous cross-country differences in observed capital-labor ratios (they vary by a factor of 100 in the data used in this paper) it may seem obvious that the MPK must vary dramatically as well. In this case we would have to conclude that there are important frictions in international capital markets that prevent an efficient cross-country allocation of capital.[1] However, as Lucas (1990) pointed out in his celebrated article, poor countries also have lower endowments of factors complementary with physical capital, such as human capital, and lower total factor productivity (TFP). Hence, large differences in capital-labor ratios may coexist with MPK equalization.[2]

It is not surprising then that considerable effort and ingenuity have been devoted to the attempt to generate cross-country estimates of the MPK. Banerjee and Duflo (2005) present an exhaustive review of existing methods and results. Briefly, the literature has followed three approaches. The first is the cross-country comparison of interest rates. This is problematic because in financially repressed/distorted economies interest rates on financial assets may be very poor proxies for the cost of capital actually borne by firms.[3] The second is some variant of regressing ΔY on ΔK for different sets of counties and comparing the coefficient on ΔK. Unfortunately, this approach typically relies on unrealistic identification assumptions. The third strategy

[1]The credit-friction view has many vocal supporters. Reinhart and Rogoff (2004), for example, build a strong case based on developing countries' histories of serial default, as well as evidence by Alfaro, Kalemli-Ozcam, and Volosovych (2003) and Lane (2003) linking institutional factors to capital flows to poorer economies. Another forceful exposition of the credit-friction view is in Stulz (2005).

[2]See also Mankiw (1995), and the literature on development-accounting [surveyed in Caselli (2005)], which documents these large differences in human capital and TFP.

[3]Another issue is default. In particular, it is not uncommon for promised yields on "emerging market" bond instruments to exceed yields on US bonds by a factor of 2 or 3, but given the much higher risk these bonds carry it is possible that the *expected* cost of capital from the perspective of the borrower is considerably less. More generally, Mulligan (2002) shows that with uncertainty and taste shocks interest rates on any particular financial instruments may have very low – indeed even negative – correlations with the rental rate faced by firms.

is calibration, which involves choosing a functional form for the relationship between physical capital and output, as well as accurately measuring the additional complementary factors – such as human capital and TFP – that affect the MPK. Since giving a full account of the complementary factors is quite ambitious, one may not want to rely on this method exclusively. Both within and between these three broad approaches results vary widely. In sum, the effort to generate reliable comparisons of cross-country MPK differences has not yet paid off.

This paper presents estimates of the aggregate MPK for a large cross-section of countries, representing a broad sample of developing and developed economies. Relative to existing alternative measures, ours are extremely direct, impose extremely little structure on the data, and are extremely simple to calculate. The general idea is that under conditions approximating perfect competition on the capital market the MPK equals the rate of return to capital, and that the latter multiplied by the capital stock equals capital income. Hence, the aggregate marginal product of capital can be easily recovered from data on total income, the value of the capital stock, and the capital share in income. We then combine data on output and capital with data on the capital share to back out the MPK.[4]

Our main result is that MPKs are essentially equalized: the return from investing in capital is no higher in poor countries than in rich countries. This means that one can rationalize virtually all of the cross-country variation in capital per worker without appealing to international capital-market frictions. We also quantify the output losses due to the (minimal) MPK differences we observe: if we were to reallocate capital across countries so as to equalize MPKs the corresponding change in world output would be negligible.[5] Consistent with the view that financial markets have become more integrated worldwide, however, we also find some evidence that the cost of credit frictions has declined over time.

The path to this result offers additional important insights. We start from a "naive" estimate of the MPK that is derived from the standard neoclassical one-sector model, with labor and reproducible capital as the only inputs. Using this initial measure, the average MPK in the developing economies in our sample is more than twice

[4]Mulligan (2002) performs an analogous calculation to identify the rental rate in the US time series. He finds implicit support for this method in the fact that the rental rate thus calculated is a much better predictor of consumption growth than interest rates on financial assets.

[5]Our counter-factual calculations of the consequences of full capital mobility for world GDP are analogous to those of Klein and Ventura (2004) for labor mobility.

as large as in the developed economies. Furthermore, within the developing-country sample the MPK is three times as variable as within the developed-country sample. When we quantify the output losses associated with these MPK differentials we find that they are very large (about 25 percent of the aggregate GDP of the developing countries in our sample). These results seem at first glance to represent a big win for the international credit-friction view of the world.

Things begin to change dramatically when we add land and other natural resources as possible inputs. This obviously realistic modification implies that standard measures of the capital share (obtained as 1 minus the labor share) are not appropriate to build a measure of the marginal productivity of reproducible capital. This is because these measures conflate the income flowing to capital accumulated through investment flows with natural capital in the form of land and natural resources. By using data recently compiled by the World Bank, we are able to separate natural capital from reproducible capital and calculate the share of output paid to reproducible capital that is our object of interest. This correction alone significantly reduces the gap between rich and poor country capital returns. The main reason for this is that poor countries have a larger share of natural capital in total capital, which leads to a correspondingly larger overestimate of the income and marginal-productivity of reproducible capital when using the total capital-income share. The correction also reduces the GDP loss due to MPK differences to a fraction of the amount implied by the naive calculation.[6]

The further and final blow to the credit-friction hypothesis comes from generalizing the model to allow for multiple sectors. In a multi-sector world the estimate of MPK based on the one-sector model (with or without natural capital) is – at best – a proxy for the average *physical* MPK across sectors. But with many sectors physical MPK differences can be sustained even in a world completely unencumbered by any form of capital-market friction. In particular, even if poor-country agents have access to unlimited borrowing and lending at the same conditions offered to rich-country agents, the physical MPK will be higher in poor countries if the relative price of capital goods is higher there. Intuitively, poor-country investors in physical capital need to be compensated by a higher physical MPK for the fact that capital is more expensive there

[6]We are immensely grateful to Pete Klenow and two referees for bringing up the issue of land and natural resources. Incidentally, these observations extend to a criticism of much work that has automatically plugged in standard capital-share estimates in empirical applications of models where all capital is reproducible. We plan to pursue this criticism in future work.

(relative to output). Or, yet in other words, the physical MPK measures output per unit of physical capital invested, while for the purposes of cross-country credit flows one wants to look at output per unit of output invested. Accordingly, when we correct our measure to capture the higher relative cost of capital in poor countries we reach our result of MPK equalization.[7]

We close the paper by returning to Lucas' question as to the sources of differences in capital-labor ratios. Lucas proposed two main candidates: credit frictions – about which he was skeptical – and differences in complementary inputs (e.g. human capital) and TFP. Our analysis highlights the wisdom of Lucas' skepticism vis-a-vis the credit friction view. However, our result that physical MPKs differ implies that different endowments of complementary factors or of TFP are not the only cause of differences in capital intensity. Instead, an important role is also played by a third proximate factor: the higher relative price of capital in poor countries. When we decompose differences in capital-labor ratios to find the relative contributions of complementary factors and relative prices we find a roughly 50-50 split among the two: the higher cost of installing capital (in terms of foregone consumption) in poor countries is as important as their lower overall endowment of other factors in explaining why so little capital flows to them.[8]

The important role of the relative price of capital in our analysis underscores the close relationship of our contribution with an influential recent paper by Hsieh and Klenow (2003). Hsieh and Klenow show, among other things, that the relative price of output is the key source for the observed positive correlation of real investment rates and per-capita income, despite roughly constant investment rates in domestic prices. We extend their results by drawing out their implications – together with appropriately-measured reproducible capital shares – for rates of return differentials,

[7] In a paper largely addressing other issues, Taylor (1998) has a section which makes the same basic point about price differences and returns to capital, and presents similar calculations for the MPKs. Our paper still differs considerably in that it provides a more rigorous theoretical underpinning for the exercise; it provides a quantitative model-based assessment of the deadweight costs of credit frictions; and it presents a decomposition of the role of relative prices v. other factors in explaining cross-country differences in capital-labor ratios. Perhaps most importantly, in this paper we use actual data on reproducible capital shares instead of assuming that these are constant across countries and equal to the total capital share. This turns out to be quite important. Cohen and Soto (2002) also briefly observe that the data may be roughly consistent with rate of return equalization.

[8] A small role is also played by cross-country differences in the reproducible-capital share in income.

and the debate on the missing capital flows to developing countries.[9]

Our results have implications for the recently-revived policy debate on financial aid to developing countries. The existence of large physical MPK differentials between poor and rich countries would usually be interpreted as *prima facie* support to the view that increased aid flows may be beneficial. But such an interpretation hinges on a credit-friction explanation for such differentials. Our result that financial rates of return are fairly similar in rich and poor countries, instead, implies that any additional flow of resources to developing countries is likely to be offset by private flows in the opposite direction seeking to restore rate-of-return equalization.[10]

2 MPK Differentials

2.1 MPK Differentials in a One-Sector Model

Consider the standard neoclassical one-sector model featuring a constant-return production function and perfectly competitive (domestic) capital markets. Under these (minimal) conditions the rental rate of capital equals the marginal product of capital, so that aggregate capital income is $MPK\text{x}K$, where K is the capital stock. If α is the capital share in GDP, and Y is GDP, we then have $\alpha = MPK\text{x}K/Y$, or

$$MPK = \alpha \frac{Y}{K}. \tag{1}$$

[9] Another important contribution of Hsieh and Klenow (2003) is to propose an explanation for the observed pattern of relative prices. In their view poor countries have relatively lower TFP in producing (largely tradable) capital goods than in producing (partially non-tradable) consumption goods. Another possible explanation is that poor countries tax sales of machinery relatively more than sales of final goods [e.g. Chari, Kehoe, and McGrattan (1996)]. Relative price differences may also reflect differences in the composition of output or in unmeasured quality. None of our conclusions in this paper is affected by which of these explanations is the correct one, so we do not take a stand on this.

[10] Our conclusion that a more integrated world financial market would not lead to major changes in world output is in a sense stronger than Gourinchas and Jeanne (2003)'s conclusion that the welfare effects of capital-account openness are small. Gourinchas and Jeanne (2003) find large (calibrated) MPK differentials, and consequently predict large capital inflows following capital-account liberalization. However, they point out that in welfare terms this merely accelerates a process of convergence to a steady state that is independent of whether the capital-account is open or closed. Hence, the discounted welfare gains are modest. Our point is that, even though differences in physical $MPKs$ are large, differences in rates of return are small, so we should not even expect much of a reallocation of capital in the first place.

In the macro-development literature it is common to back out the "capital share" as one minus available estimates of the labor share in income (we review these data below). But such figures include payments accruing to both reproducible and non-reproducible capital, i.e. land and natural resources. By contrast, the standard measure of the capital stock is calculated using the perpetual inventory method from investment flows, and therefore represents only the reproducible capital stock. As is clear from the formula above, therefore, using standard measures of α leads to an overestimate of the marginal productivity of reproducible capital. In turn, this bias on the estimated levels of the MPKs will translate into a twofold bias in cross-country comparisons. First, it will exaggerate absolute differences in MPK, which is typically the kind of differences we are interested in when comparing rates of return on assets (interest-rate spreads, for example, are absolute differences).[11] Second, and most importantly, since the agricultural and natural-resource sectors represent a much larger share of GDP in poor countries, the overestimate of the MPK when using the total capital share is much more severe in such countries, and cross-country differences will once again be inflated (both in absolute and in relative terms).

Of course equation (1) holds (as long as there is only one sector) whether or not non-reproducible capital enters the production function or not. The only thing that changes is the interpretation of α. Hence, these considerations lead us to two possible estimates of the MPK:

$$MPKN = \alpha_w \frac{Y}{K},$$

and

$$MPKL = \alpha_k \frac{Y}{K}.$$

In these formulas, Y and K are, respectively, estimates of real output and the reproducible-capital stock; α_w is one minus the labor share (the standard measure of the capital share); and α_k is an estimate of the reproducible-capital share in income. The suffix "N" in the first measure is a mnemonic for "naive," while the suffix "L" in the second stands for "land and natural-resource corrected."

It is important to observe that, relative to alternative estimates in the literature,

[11] As an example, suppose that all countries have the same share of land and natural resources in the total capital share, say 20%. Using the total-capital share instead of the reproducible-capital will simply increase all the MPKs by the same proportion. If the US' "true" MPK is 8% and India's 16% (a spread of 8 percentage points), the MPKs computed with the total capital share are 10% and 20% (a spread of 10 percentage points).

this method of calculating MPK requires no functional form assumptions (other than linear homogeneity), much less that we come up with estimates of human capital, TFP, or other factors that affect a country's MPK. Furthermore, the assumptions we do make are typically shared by the other approaches to MPK estimation, so the set of restrictions we impose is a strict subset of those imposed elsewhere.[12] This calculation is a useful basis for our other calculations because it encompasses the most conventional set of assumptions in the growth literature.

2.2 MPK Differentials in a Multi-Sector Model

The calculations suggested above are potentially biased because they ignore an important fact – the price of capital relative to the price of consumption goods is higher in poor countries than in rich countries. To see why this matters consider an economy that produces J final goods. Each final good is produced using capital and other factors, which we don't need to specify. The only technological restriction is that each of the final goods is produced under constant returns to scale. The only institutional restriction is that there is perfect competition in good and factor markets within each country. Capital may be produced domestically (in which case it is one of the J final goods), imported, or both. Similarly, it does not matter whether the other final goods produced domestically are tradable or not.

Consider the decision by a firm or a household to purchase a piece of equipment and use it in the production of one of the final goods, say good 1. The return from this transaction is

$$\frac{P_1(t)MPK_1(t) + P_k(t+1)(1-\delta)}{P_k(t)},$$

where $P_1(t)$ is the domestic price of good 1 at time t, $P_k(t)$ is the domestic price of capital goods, δ is the depreciation rate, and MPK_1 is the *physical* marginal product of capital in the production of good 1. When do we have frictionless international capital markets? When the firms/households contemplating this investment in all countries have access to an alternative investment opportunity, that yields a common world interest rate R^*. Abstracting for simplicity from capital gains, then, frictionless

[12]This is not to say that these restrictions are innocuous, of course. For example, we rule out adjustment costs to the stock of capital – which in certain models could drive a wedge between the rental rate on capital and the MPK.

international capital markets imply

$$\frac{P_1 MPK_1}{P_k} = R^* - (1-\delta). \tag{2}$$

Hence, frictionless international credit markets imply that the value of the marginal product of capital in any particular final good, divided by the price of capital, is constant across countries.

To bring this condition to the data let us first note that total capital income is $\sum_j P_j MPK_j K_j$, where K_j is the amount of capital used in producing good j. If capital is efficiently allocated domestically, we also have $P_j MPK_j = P_1 MPK_1$, so total capital income is $P_1 MPK_1 \sum_j K_j = P_1 MPK_1 K$, where K is the total capital stock in operation in the country. Given that capital income is $P_1 MPK_1 K$, the capital share in income is $\alpha = P_1 MPK_1 K/(P_y Y)$,where $P_y Y$ is GDP evaluated at domestic prices. Hence, the following holds:

$$\frac{P_1 MPK_1}{P_k} = \frac{\alpha P_y Y}{P_k K}$$

In other words, the multi-sector model recommends a measure of the marginal product of capital that is easily backed out from an estimate of the capital share in income, α, GDP at domestic prices, $P_y Y$, and the capital-stock at domestic prices, $P_k K$. Comparing this with the estimate suggested by the one-sector model [equation (1)] we see that the difference lies in correcting for the relative price of final-to-capital goods, P_y/P_k. It should be clear that this correction is fundamental to properly assess the hypothesis that international credit markets are frictionless.

All of the above goes through whether or not reproducible capital is the only recipient of non-labor income or not. Again, the only difference is in the interpretation of the capital share α. Hence, we come to our third and fourth possible estimates of the MPK:

$$PMPKN = \frac{\alpha_w P_y Y}{P_k K},$$

and

$$PMPKL = \frac{\alpha_k P_y Y}{P_k K}$$

where P_y/P_k is a measure of the average price of final goods relative to the price of reproducible capital, and the prefix "P" stands for "price-corrected."[13]

[13]Since in our model $P_j MPK_j$ is equalized across sectors j, the physical MPK in any particular sector will be an inverse function of the price of output in that sector. Since the relative price of capital is high in poor countries, this is consistent with the conjecture of Hsieh and Klenow (2003) that relative productivity in the capital goods producing sectors is low in poor countries.

Notice that the one-sector based measures, $MPKN$ and $MPKL$, retain some interest even in the multi-sector context. In particular, one can show that

$$\frac{\alpha Y}{K} = \frac{1}{\sum_j \frac{Y_j/Y}{MPK_j}}.$$

In words, the product of the capital share and real income, divided by the capital stock, tends to increase when physical marginal products tend to be high on average in the various sectors.[14] Hence, the one-sector based measures offer some quantitative assessment of cross-country differences in the average *physical* MPK.

2.3 Data

Our data on Y, K, P_y, and P_k come (directly or indirectly) from Version 6.1 of the Penn World Tables [PWT, Heston, Summers, and Aten (2004)]. Briefly, Y is GDP in purchasing power parity (PPP) in 1996. K is constructed with the perpetual inventory method from time series data on real investment (also from the PWT) using a depreciation rate of 0.06 [see Caselli (2005) for more details].[15] P_y is essentially a weighted average of final-good domestic prices, while P_k is a weighted average of domestic equipment prices. The list of final and equipment goods to be included in the measure is constant across countries. Hence, P_y/P_k is a summary measure of the prices of final goods relative to equipment goods. As many authors have already pointed out, capital goods are relatively more expensive in poor countries, so the free capital flows condition modified to take account of relative equipment prices should fit the data better than the unmodified condition if the physical MPK tends to be higher in poor countries.[16]

[14]To obtain this expression start out by the definition of P_y, which is

$$P_y = \frac{\sum_j P_j Y_j}{Y}.$$

Then substitute $P_j = \frac{\alpha P_y Y}{MPK_j K}$ from the last equation in the text, and rearrange.

[15]A potential bias arises if the depreciation rate δ differs across countries, perhaps because of differences in the composition of investment, or because the natural environment is more or less forgiving. In particular we will overestimate the capital stock of countries with high depreciation rates, and therefore underestimate their MPK. However notice from equation (2) that countries with a high depreciation rates *should* have higher MPKs. In other words variation in δ biases both sides of (2) in the same direction.

[16]See, e.g., Barro (1991), Jones (1994), and Hsieh and Klenow (2003) for further discussions of the price data.

The total capital share, α_w is taken from Bernanke and Gurkaynak (2001), who build upon and expand upon the influential work of Gollin (2002). As mentioned, these estimates compute the capital share as one minus the labor share in GDP. In turn, the labor share is employee compensation in the corporate sector from the National Accounts, plus a number of adjustments to include the labor income of the self-employed and non-corporate employees.[17]

Direct measures of reproducible capital's share of output, α_k, do not appear to be available. However, a proxy for them can be constructed from data on wealth, which has recently become available for a variety of countries from the World Bank (2006). These data split national wealth into natural capital, such as land and natural resources, and reproducible capital. If total wealth equals reproducible capital plus natural wealth, $W = P_k K + L$, then the payments to reproducible capital should be $P_k K * r$, and payments to natural wealth should be $L * r$. Reproducible capital's share of total capital income is therefore going to be proportional to reproducible capital's share of wealth (since all units of wealth pay the same return). So,

$$\alpha_k = (P_k K/W) * \alpha_w.$$

We can therefore back out an estimate of α_k from α_w as estimated by Bernanke and Gurkaynak (2001) and $P_k K/W$ as estimated by the World Bank.

Since the World Bank's data on land and natural-resource wealth is by far the newest and least familiar among those used in this paper, a few more words to describe these data are probably in order. The general approach is to estimate the value of rents from a particular form of capital and then capitalize this value using a fixed discount rate. In most cases, the measure of rents is based on the value of output from that form

[17]Bernanke and Gürkaynak use similar methods as Gollin, but their data set includes a few more countries. The numbers are straight from Table X in the Bernanke and Gürkaynak paper. Their preferred estimates are reported in the column labeled "Actual OSPUE," and they are constructed by assigning to labor a share of the Operating Surplus of Private Unincorporate Enterprises equal to the share of labor in the corporate (and public) sector. We use these data wherever they are available. When "Actual OSPUE" is not available we take the data from the column "Imputed OSPUE," which is constructed as "Actual OSPUE," except that the OSPUE measure is estimated by breaking down the sum of OSPUE and total corporate income by assuming that the share of corporate income in total income is the same as the share of corporate labor in total labor. Finally, when this measure, is also unavailable, we get the data from the "LF" column, which assumes that average labor income in the non-corporate sector equals average labor income in the corporate sector. When we use Gollin's estimates we get very much the same results.

of capital in a given year. For subsoil resources, the World Bank also needs to estimate the future growth of rents and a time horizon to depletion. For forest products, rents are estimated as the value of timber produced (at local market prices where possible) minus an estimate of the cost of production. Adjustments are made for sustainability based on the volume of production and total amount of usable timberland. The rents to other forest resources are estimated as fixed value per acre for all non-timber forest. Rents from cropland are estimated as the value of agricultural output minus production costs. Production costs are taken to be a fixed percentage of output, where that percentage varies by crop. Pasture land is similarly valued. Protected areas are valued as if they had the same per-hectare output as crop and pasture land, based on an opportunity cost argument. Reproducible capital is calculated using the perpetual inventory method. Due to data limitations, no good estimates of the value of urban land are available. A very crude estimate values urban land at 24% of the value of reproducible capital.

Table 1: Proportion of Different Types of Wealth in Total Wealth in 2000

Variable	Mean	Stdev	Median	Weighted Mean*	Corr w/ log(GDP)**
Subsoil Resources	10.5	16.4	1.5	7.0	-0.13
Timber	1.7	2.6	0.8	0.9	-0.34
Other Forest	2.2	5.4	1.1	0.3	-0.49
Cropland	11.4	15.2	5.1	3.2	-0.73
Pasture	4.5	5.4	2.7	1.9	-0.00
Protected Areas	1.9	2.5	0.3	1.4	0.01
Urban Land	13.1	4.6	13.5	16.5	0.70
Reproducible Capital	54.8	19.2	56.3	68.6	0.70

*Weighted by the total value of the capital stock.

** GDP is per worker.

Source: Authors calculations using data from World Bank (2006).

Summary statistics of the cross-country distribution of the shares of different types of wealth in total wealth are reported in Table 1. In the average country in our sample, reproducible capital represents roughly one half of total capital, while various forms of “natural” capital account for the other half. The proportion of reproducible capital is highly correlated with log GDP per worker. All other types of capital (except for urban land, which is calculated as a fraction of accumulated capital) are negatively correlated with log GDP per worker. Cropland is particularly negatively correlated with income. The weighted means are weighted by the total capital stock in each country, so that they give the proportion of each type of capital in the total capital stock of the World (as represented by our sample). The proportion of reproducible capital is much higher in the weighted means, with almost 70% of total capital.

Other data sources provide opportunities for checking the broad reliability of these data. For the US, the OMB published an accounting of land and reproducible wealth (but not other natural resources) over time [Office of Management and Budget (2005)]. They find that the proportion of land in total capital varies between 20 and 26% between 1960 and 2003, with no clear trend to the data. This range is consistent with the World Bank estimate of 26% (when, for comparability with the OMB estimates, one excludes natural resources other than land). Another check is from the sectorial dataset on land and capital shares constructed by Caselli and Coleman (2001). Our approach to estimate the reproducible capital share in GDP implies a land share in GDP in the US of 8%. According to Caselli and Coleman in the US the land share in agricultural output is about 20%, and the land share in non-agriculture is about 6%. Since the share of nonagriculture in GDP is in the order of 97%, these authors' overall estimate of the land share in the US is very close to ours.

There are a number of studies from the 60's and 70's which perform similar exercises on a variety of countries. Raymond W. Goldsmith collects some of these in Goldsmith (1985). He finds land shares in total capital in 1978 that average about 20% across a group of mostly rich countries. With the exception of Japan at 51%,the figures range from 12% to 27%.[18] This range is once again broadly consistent with the World Bank data.

The data from Bernanke and Gurkaynak (2001) puts the heaviest constraints on the sample size, so that we end up with 53 countries.[19] The entire data set is reported in Appendix Table A-1. Capital per worker, k, the relative price P_y/P_k, the total capital share, and the reproducible capital's share are also plotted against output

[18]Japan is not similarly an outlier in the World Bank data. This may reflect the relatively crude way that urban land values is estimated by the World Bank. Lacking a good cross country measure of urban land value, they simply take urban land to be worth a fixed value of reproducible capital. Given the population density of Japan this may substantially understate the value of Japanese urban land.

[19]For the calculations corrected for the reproducible capital share, we also lose Hong Kong.

per worker, y, in Appendix Figures A-1, A-2, A-3, and A-4.

2.4 MPK Results

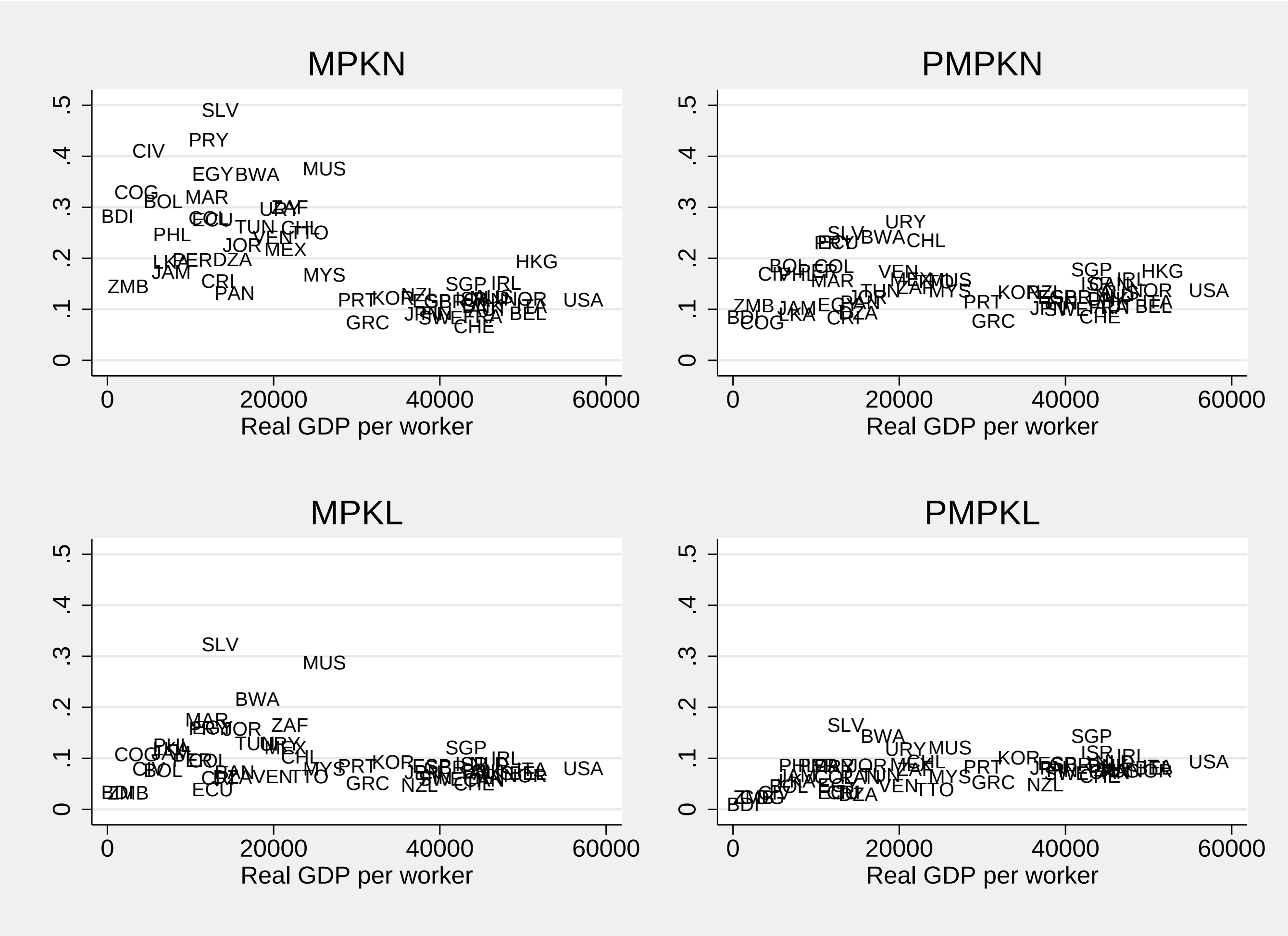
In this section we present our four estimates of the MPK. To recap, the naive version, $MPKN$, does not account for difference in prices of capital and consumption goods, and also uses the total share of capital, not the share of reproducible capital. This calculation is the simplest and will be used as a benchmark for the corrected versions. $MPKL$ is calculated using the share of reproducible capital rather than the share of total capital. $PMPKN$ is adjusted to account for differences in prices between capital and consumption goods, but reverts to the total capital share. Finally $PMPKL$, the "right" estimate, includes both the price adjustment and the natural capital adjustment. These four different versions of the implied MPKs are reported in Appendix Table A-1, and plotted against GDP per worker, y, in Figure 1.

The overall relationship between the naive estimate, $MPKN$, and income is clearly negative. However, the non-linearity in the data cannot be ignored: there is a remarkably neat split whereby the $MPKN$ is highly variable and high on average in developing countries (up to Malaysia), and fairly constant and low on average among developed countries (up from Portugal). The average $MPKN$ among the 29 lower income countries is 27 percent, with a standard deviation of 9 percent. Among the 24 high income countries the average $MPKN$ is 11 percent, with a standard deviation of 3 percent. Neither within the subsample of countries to the left of Portugal, nor in the one to the right, there is a statistically significant relationship between the $MPKN$ and y [nor with $\log(y)$].

This first simple calculation implies that the aggregate marginal product of capital is high and highly variable in poor countries, and low and fairly uniform in rich countries. If we were to stop here, it would be tempting to conclude that capital flows fairly freely among the rich countries, but not towards and among the poor countries. This looks like a big win for the credit friction answer to the Lucas question.

Once one accounts for prices and the share of natural capital a different story emerges. Figure 1 shows that each of the adjustments reduces the variance of the marginal product considerably and reduces the differences between the rich and poor countries. Taking both adjustments together eliminates the variance almost completely and the rich countries actually have a higher marginal product on average than the poor countries. Table 2 summarizes the average marginal products for each of our

Figure 1: The Marginal Product of Capital



$MPKN$: naive estimate. $MPKL$: after correction for natural-capital. $PMPKN$: after correction for price differences. $PMKL$: after both corrections. Source: Heston, Summers, and Aten (2004), Bernanke and Gurkaynak (2001), and World Bank (2006). Authors' calculations.

Table 2: Average Return to Capital in Poor and Rich Countries

	Rich Countries	Poor Countries
$MPKN$	11.4 (2.7)	27.2 (9.0)
$MPKL$	7.5 (1.7)	11.9 (6.9)
$PMPKN$	12.6 (2.5)	15.7 (5.5)
$PMPKL$	8.4 (1.9)	6.9 (3.7)

$MPKN$: naive estimate. $MPKL$: after correction for natural-capital. $PMPKN$: after correction for price differences. $PMPKL$: after both corrections. Rich (Poor): GDP at least as large (smaller than) Portugal. Standard Deviations in Parentheses. Authors' calculations.

calculation for poor and rich countries. The differences between the poor and rich countries are significant for the first three rows of the table. For the case using both corrections, the difference is only significant at the 10% level.

Interestingly, with both adjustments there is a positive and significant relationship between $PMPKL$ and output within the low income countries. The very lowest income countries in our sample have the lowest $PMPKL$ values. This would be consistent with a model where capital flows out of the country were forbidden, and where some capital flows into the country were not responsive to the rate of return. This may describe the poorest countries in our sample, where aid flows represent a significant proportion of investment capital (and all of the inward flow of capital).

3 Assessing the Costs of Credit Frictions

The existence of any cross-country differences in MPK suggests inefficiencies in the world allocation of capital. How severe are these frictions? One possible way to answer this question is to compute the amount of GDP the world fails to produce as a consequence. In particular, we perform the counter-factual experiment of reallocating the world capital stock so as to achieve MPK equalization under our various measures. We then compare world output under this reallocation to actual world output. The difference is a measure of the deadweight loss from the failure to equalize MPKs.

We stress that this is not a normative exercise: our capital reallocation is not a policy proposal. The observed distribution of output is an equilibrium outcome given certain distortions that prevent MPK equalization. The point of this exercise is to assess the welfare losses the world experiences relative to a frictionless first best, not that the first best is easily achievable by moving some capital around.

While our MPK estimates are free of functional form assumptions, in order to perform our counterfactual calculations me must now choose a specific production function. We thus fall back on the standard Cobb-Douglas workhorse. Industry j in country i has the production function

$$Y_{ij} = Z_{ij}^{\beta_{ij}} K_{ij}^{\alpha_i} (X_{ij} L_{ij})^{1-\alpha_i-\beta_{ij}}, \tag{3}$$

where Z_{ij} is the quantity of natural capital, K_{ij} the reproducible capital stock, L_{ij} the input of labor, β_{ij} is the share of natural capital in sector j in country i and X_{ij} is a summary measure of technology and is also sector and country specific. The derivation below makes it clear that to pursue our calculations we must assume that the reproducible-capital share in country i, α_i, is the same across all sectors (though it can vary across countries).

The marginal product of capital in sector j in country i is

$$MPK_{ij} = \alpha_i Z_{ij}^{\beta_{ij}} K_{ij}^{\alpha_i - 1} (X_{ij} L_{ij})^{1-\alpha_i-\beta_{ij}}.$$

Taking into account the relative prices of capital and consumption goods, rates of return within a country are equalized when

$$PMPK_{ij} = \frac{P_{ij}}{P_k} \alpha_i Z_{ij}^{\beta_{ij}} K_{ij}^{\alpha_i - 1} (X_{ij} L_{ij})^{1-\alpha_i-\beta_{ij}} = PMPK_i \quad j = 1...J. \tag{4}$$

Suppose now that capital was reallocated across countries in such a way that $PMPK_i$ took the same value, $PMPK^*$, in all countries. Assuming for the time being that Z_{ij}, and L_{ij} are unchanged in response to our counterfactual reshuffling of capital (we will check this is indeed the case later in the section), the new value of K_{ij}, K_{ij}^*, satisfies[20]

$$\frac{P_{ij}}{P_k} \alpha_i Z_{ij}^{\beta_{ij}} (K_{ij}^*)^{\alpha_i - 1} (X_{ij} L_{ij})^{1-\alpha_i-\beta_{ij}} = PMPK^*. \tag{5}$$

Dividing (5) by (4) we have

$$K_{ij}^* = \left(\frac{PMPK_i}{PMPK^*} \right)^{\frac{1}{1-\alpha_i}} K_{ij},$$

[20]For the remainder of this section, expressions relating to $PMPK$ equalization can be simplified to expressions for MPK equalization by assuming $P_k = P_y$. Calculations will be performed for both cases.

which shows that capital increases or decreases by the same proportion in each sector.

Earlier we made the conjecture that all adjustment to the equalization of $PMPK$s was through the capital stock, and not through reallocations of labor or natural capital. Under this conjecture, since the amount of capital per worker changes by the same factor in each sector, the marginal products of labor and natural capital must do the same. Hence, even if labor is not a specific factor, as long as its allocation across sectors depends on *relative* wages, there will be no reshuffling of workers across sectors.[21] The same is true of natural capital.

We can now aggregate the sectorial capital stocks to the country level:

$$K_i^* = \sum_j K_{ij}^* = \sum_j \left(\frac{PMPK_i}{PMPK^*}\right)^{\frac{1}{1-\alpha_i}} K_{ij} = \left(\frac{PMPK_i}{PMPK^*}\right)^{\frac{1}{1-\alpha_i}} K_i \tag{6}$$

In order to close the model we need to impose a resource constraint. The resource constraint is that the world sum of counter-factual capital stocks is equal to the existing world endowment of reproducible capital, or

$$\sum K_i^* = \sum K_i = \left(\frac{PMPK_i}{PMPK^*}\right)^{\frac{1}{1-\alpha_i}} K_i. \tag{7}$$

Taking the values for $PMPK_i$ calculated in the previous section, the only unknown in (7) is $PMPK^*$, which can be solved for with a simple non-linear numerical routine. To recap, $PMPK^*$ is the common world rate of return to capital that would prevail if the existing world capital stock were allocated optimally.[22]

3.1 Counterfactual Capital Stocks

With the counterfactual world rate of return, $PMPK^*$, at hand we can use equation (6) to back out each country's assigned capital stock when rates of return are equalized. As with our initial MPK calculations, four variations are calculated. The base version, labeled $MPKN$, is calculated under the assumption that $P_k = P_y$ and uses the total share of capital, not correcting for natural capital (i.e. it sets $\beta_{ij} = 0$). $MPKL$

[21] In particular, our experiment is consistent with wage equalization across sectors, but also with models in which inter-sectoral migration frictions imply fixed proportional wedges among different sectors' wages.

[22] Removing the frictions that prevent $PMPK$ equalization would almost certainly also lead to an increase in the world aggregate capital stock. Our calculations clearly abstract from this additional benefit, and are therefore a lower bound on the welfare cost of such frictions.

is calculated using the share of reproducible capital rather than the share of total capital. $PMPKN$ allows for differences in prices. $PMPKL$ includes both the price adjustment and the natural capital adjustment. Figure 2 plots the resulting counterfactual distributions of capital-labor ratios against the actual distribution. The solid lines are 45-degree lines. Table 3 summarizes the change in capital labor ratios under the various calculations for poor and rich countries.

Not surprisingly, under the naive MPK calculation, most developing countries would be recipients of capital and the developed economies would be senders. The magnitude of the changes in capital-labor ratios under this scenario are fairly spectacular, with the average developing country experiencing almost a 300 percent increase. In the average rich country the capital-labor ratio falls by 13 percent. These figures remain in the same ball park when weighted by population. The average developing country worker experiences a still sizable 206 percent increase in his capital endowment. The average rich-country worker loses 19 percent of his capital allotment. The scatter plots show that despite this substantial amount of reallocation, many developing countries would still have less physical-capital per worker, reflecting their lower average efficiency levels (as reflected in the X_{ij}s). Similarly, some of the rich countries are capital recipients.

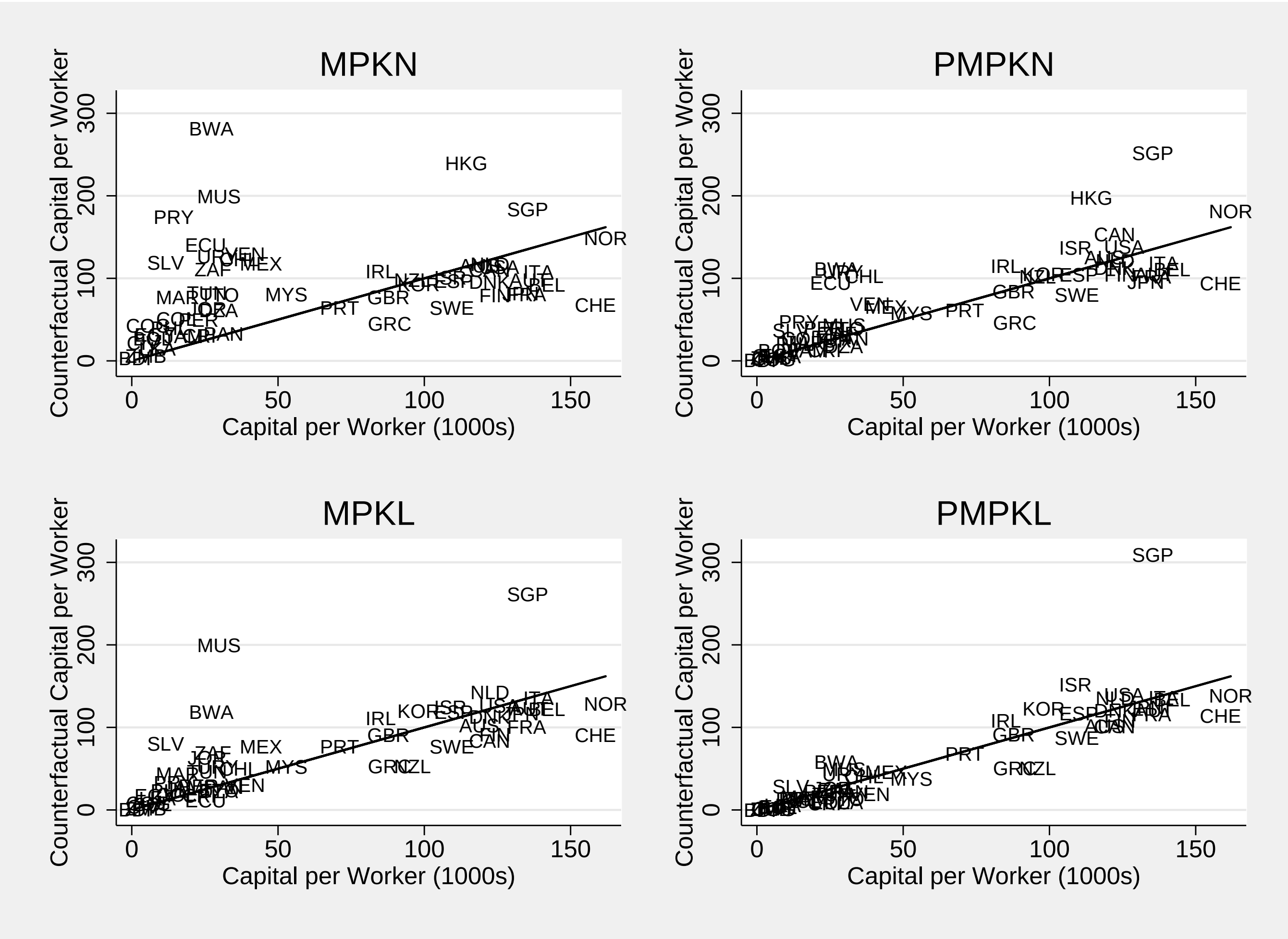
However when we correct the MPK for the natural capital share and relative prices once again rich-poor differences are dramatically reduced. Either the price adjustment or the natural capital adjustment taken alone reduces the averaged weighted gain in the capital stock to about 50% in the poor countries while the rich countries lose about 5% of their capital stock. With both corrections in place the poor countries actually lose capital to the rich countries.

3.2 Counterfactual Output

The effect on output of our counter-factual reallocation of the capital stock is easily calculated. Substituting K^*_{ij} into the production function (3), we get

$$Y^*_{ij} = Z^{\beta_{ij}}_{ij}(K^*_{ij})^{\alpha_i}(X_{ij}L_{ij})^{1-\alpha_i-\beta_{ij}} = \left(\frac{PMPK^*}{PMPK_i}\right)^{\frac{\alpha_i}{1-\alpha_i}} Y_{ij}.$$

Figure 2: Counterfactual Capital per Worker with Equalized Returns to Capital



Notes: see Figure 1

Table 3: Average Changes in Equilibrium Capital Stocks under MPK Equalization

	Unweighted		Weighted by Population	
	Rich Countries	Poor Countries	Rich Countries	Poor Countries
$MPKN$	-12.9%	274.5%	-19.3%	205.8%
$MPKL$	-6.2%	86.6%	-5.6%	59.3%
$PMPKN$	0.1%	71.8%	-4.9%	52.0%
$PMPKL$	0.6%	-10.6%	1.4%	-14.5%

Notes: see Table 2

Since all sectorial outputs go up by the same proportion, aggregate output also goes up by the same proportion, and we have

$$Y_i^* = \left(\frac{PMPK^*}{PMPK_i}\right)^{\frac{\alpha_i}{1-\alpha_i}} Y_i.$$

Hence, plugging values for α_i, $PMPK_i$ and $PMPK^*$ we can back out the counterfactual values of each country's GDP under our various MPK equalization counterfactuals. These values are plotted in Figure 3, again together with a 45-degree line. Table 4 summarizes the change in output per worker under the various calculations.

Changes in output in our counterfactual world are obviously consistent with the result for capital-labor ratios. For our naive MPK measure, developing countries tend to experience increases in GDP, and rich countries declines. The average developing country experiences a 77 percent gain, while the average developed country only "loses" 3 percent. These numbers fall dramatically when adjustments are made for relative capital prices and natural capital, with increases of less than 25% in both cases. For the scenario with both adjustments, average output in the two groups is essentially unchanged.

3.3 Dead Weight Losses

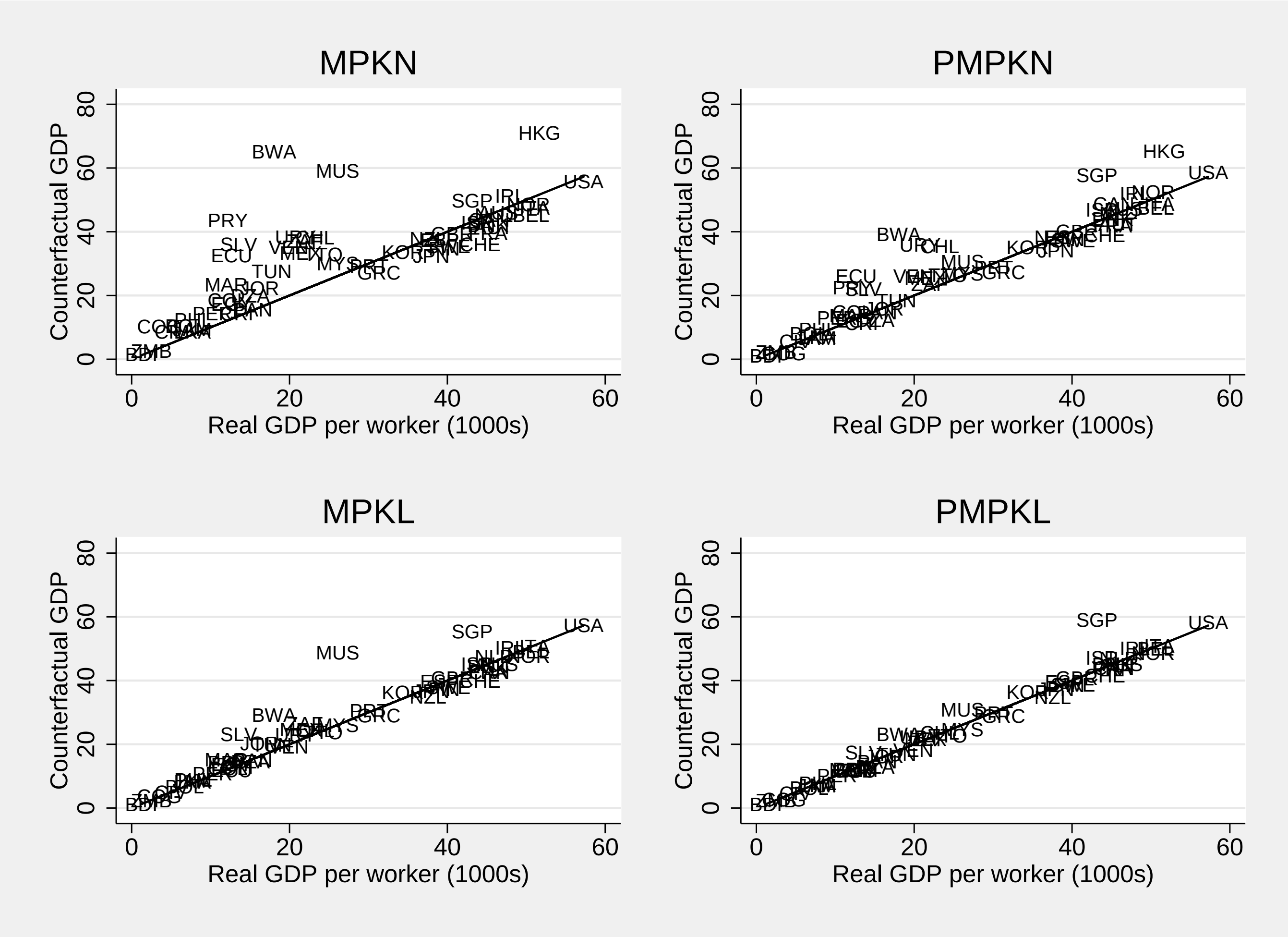
To provide a comprehensive summary measure of the deadweight loss from the failure of MPKs to equalize across countries we compute the percentage difference between world output in the counterfactual case and actual world output, or

$$\frac{\sum_i (Y_i^* - Y_i)}{\sum Y_i}.$$

This can be calculated for each of our measures of the marginal product. Table 5 summarizes this calculation for our four calculation methods.

For the naive MPK calculation, the result is in the order of 0.03, or world output would increase by 3 percent if we redistributed physical capital so as to equalize the MPK. This number is large. To put it in perspective, consider that the 28 developing countries in our sample account for 12 percent of the aggregate GDP of the sample. This result implies that the deadweight loss from inefficient allocation of capital is in the order of one quarter of the aggregate (and hence also per capita) income of developing countries.

Figure 3: Counterfactual Output with Equalized Returns to Capital



Notes: see Figure 1

Table 4: Average Changes in Equilibrium Output per Worker under MPK Equalization

	Unweighted		Weighted by Population	
	Rich Countries	Poor Countries	Rich Countries	Poor Countries
$MPKN$	-3.0%	76.7%	-5.5%	58.2%
$MPKL$	-0.7%	16.8%	-1.0%	10.4%
$PMPKN$	1.1%	24.7%	-1.0%	17.4%
$PMPKL$	0.7%	0.0%	0.4%	-2.4%

Notes: see Table 2