The Public and Private MPK*

Matt Lowe
University of Oxford
matt.lowe@economics.ox.ac.uk

Chris Papageorgiou
International Monetary Fund
cpapageorgiou@imf.org

Fidel Perez-Sebastian
University of Alicante
fidel.perez@ua.es

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Abstract

Why doesn't capital flow to developing countries as predicted by the neoclassical model? Is the explanation simply that cross-country marginal productivity of capital (MPK) is equalized, and if so, why? We revisit these issues by unpacking the MPK into its public and private components, since there is good reason to believe that the process of MPK determination is enormously different across the two sectors, especially in developing countries. We do so by calculating MPK schedules for the two sectors in a large sample of advanced and developing countries. The main findings are twofold: using updated investment data shows that the MPK is not only flat but rather slightly positively sloped. More importantly, this finding is mainly driven by the public sector – the public MPK is strongly positively sloped whilst the private MPK is flat. We offer an intepretation of this surprising result and advance new explanations for the Lucas Paradox and the Gourinchas-Jeanne allocation puzzle related to the behavior of the public sector.

JEL Classification: O41, O47

Keywords: Marginal product of public and private capital, public sector inefficiencies, capital flows, the Lucas Paradox, the Gourinchas-Jeanne allocation puzzle.

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1 Introduction

If capital-labor ratios are low in poor countries and returns high as the standard one-sector growth model predicts, why doesn't more capital flow from rich to poor countries? This fundamental question known as the Lucas Paradox, coined after Lucas' (1990) seminal paper, is a focal point for many key areas of economic development; whether the efficacy of aid, the extent of international capital market frictions, or the importance of institutions and complementary factors.

The paradox pre-supposes a downward-sloping financial return to investment in the cross-section of nations. Intuitively, there are only a small set of possible explanations: (i) either the return has been mis-measured, and it is not actually downward-sloping; (ii) the return is downward-sloping but capital movement is restricted by capital market imperfections; or (iii) investors in some way defy standard theories of profit maximization (e.g. there is some home bias which permits returns differentials to persist). Lucas himself posited that the explanation could be that of failing to account for complementary factors to physical capital, such as human capital, resulting in an overstating of the MPK. Lucas placed little credence on the argument of capital market frictions.

The aggregate MPK is the most common measure employed to approximate the return to investment, in an attempt to resolve the paradox. Unfortunately estimating the MPK is no easy task. Several approaches exist: among them, comparison of interest rates across countries, production function estimation, and calibration.[1] Caselli and Feyrer (2007) (CF from hereafter) argue that these approaches have collectively failed at producing reliable and comparable estimates of the cross-country MPK.[2] In a persuasive, yet provocative, contribution to the literature, they present the case for direct MPK estimation using easily accessible macroeconomic data.[3] Their approach assumes competitive markets and imposes no restrictions on production functions other than that of constant returns to scale.

CF's main contribution is that they derive an MPK measure that is more suitable for the purpose of international credit flows. The standard MPK derived from the one-sector growth model is not a good measure of capital returns because it provides output per unit of physical capital invested.

[1] See Banerjee and Duflo (2005) for an extensive review.

[2] According to CF, the comparison of interest rates in developing countries is problematic because markets are heavily distorted, identification in production function estimation presents many caveats, and calibration exercises rely on specific forms of the production function.

[3] Taylor (1998) measures the MPK similarly for Argentina, and Bai *et al.* (2006) use a similar approach to measure the return to capital (both in aggregate and by sector/region) in China, though they use current price data to measure $P_Y Y / P_K K$ rather than real data followed by a price adjustment as in CF.

Multisector models imply that the financial return to investment is better proxied as output per unit of output invested. By making two reasonable adjustments to a naïve measure of the MPK, Lucas Paradox resolved, CF find that the cross-country MPK is roughly flat. Yet, another burning question emerges: why would the cross-country MPK possibly be flat?

In this paper, we attempt to tackle this question and in doing so dig deeper into a resolution to the Lucas Paradox by distinguishing between the public and private MPK.[4] The private and public distinction is important for a host of reasons. First and foremost amongst these is that the theory behind MPK determination is likely to differ significantly between the two sectors. There is much literature elsewhere with results that hinge on the contrasting behavioral idiosyncrasies of public and private agents (e.g., Becker (1957), Fama (1980), Besley and Burgess (2002), Robinson and Torvik (2005)).[5] The empirical evidence in Keefer and Knack (2007) is also consistent with the notion of governments as non-maximizers. To be consistent with MPK equalization, public investment should be highest where the returns are highest. Keefer and Knack find instead that public investment is dramatically higher in countries with low-quality governance and limited political checks and balances. Their interpretation of this result is that governments use public investment as a means for rent-seeking. If the public sector maximizes an entirely different objective function to the private sector, capital allocation and the resulting MPK should be determined differently.

Second, the private and public sectors tend to make different types of investment. The public sector tends to invest where markets fail: where social returns exceed private returns, where the capital is non-rivalrous and non-excludable and where high fixed costs make a natural monopoly a strong possibility. In short, public and private capital should be considered imperfectly substitutable in a country's production function. In this sense, the overall MPK is misleading, whilst the private and public MPKs are more informative.

Third, following Pritchett (2000), the separation between public and private capital is warranted in light of public investment inefficiency. As Pritchett emphasizes, there is no plausible behavioral model by which we would expect public investment to be efficient in the same way that might be expected of private investment. Caselli (2005) echoes this sentiment and argues for the future

[4] This within-country heterogeneity in returns is a key theme in Banerjee and Duflo (2005).

[5] Robinson and Torvik (2005), for example, aim to explain why governments don't act like profit maximizers when it comes to investing. In particular, the model explains the political motivation behind the construction of white elephants. Politicians construct these inefficient projects when they find it difficult to make credible promises to political supporters. The general point of this and other political economy models is that governments are driven more by an electoral motive than by a profit motive.

separation of public and private investment, when appropriate data comes available, in the context of development accounting. In this paper, we use data that makes this separation possible.

Pritchett (2000) and Caselli (2005), among others, thought that data issues would make it near impossible to convincingly estimate the private and public MPK. One main contribution of this paper is to break the impasse and carry out this exercise for the first time. To do this, we employ improved data on the sectoral share of investment from IMF's World Economic Outlook (WEO). This data permits us to estimate the private and public MPK for a broad sample of advanced and developing countries.

Our finding is surprising: the overall MPK is not only flat but rather somewhat positive; most importantly this is driven by the strongly positively sloped public MPK (whilst the private MPK is flat). This finding is subsequently explored by two extensions and a thorough robustness analysis pointing to public sector frictions rather than financial frictions or complementarities to low human capital or TFP as the key constraint to enhancing the MPK and with it, accelerating international capital inflows. This distinct behavior of the public sector promotes new explanations of the Lucas Paradox and the "allociation puzzle" recently advanced by Gourinchas and Jeanne (forthcoming) in which international capital flows more towards developing countries with lower (not higher) productivity growth.

We proceed as follows. Section 2 takes a close look at the primary sources of the data used to disaggregate total capital into its public and private components and discusses the steps followed to calculate the public and private MPK. Section 3 presents and discusses the new trends unravelled from the data disaggregation. Section 4 extends the main analysis in three directions: incorporating inefficiencies in the measurement of the MPK, examining the effects of public and private capital in a three-sector neoclassical growth model, and offering an explanation to the Gourinchas-Jeanne allocation-puzzle. Section 5 reports results from a number of robustness tests applied to the main assumptions made in the construction of the public and private MPK. Section 6 concludes.

2 Data

In this section we show in detail the steps followed to construct the public and private marginal product of capital. Assume that firms produce final output using private capital (K_p), public capital (K_g), and other inputs (X) according to $Y = F(K_p, K_g, X)$. If F displays constant returns to scale over the inputs and there is perfect competition, Euler's homogeneity theorem implies that

the relevant price-corrected MPKs are as follows:

$$MPKP = \beta \frac{P_y Y}{P_k K_p}; \qquad MPKG = \gamma \frac{P_y Y}{P_k K_g}, \tag{1}$$

where β and γ denote the shares of private and public capital in income, respectively.

Our core sample comprises fifty developing and developed countries with public, private and overall MPK data in 2006.[6] We also look at time series data from 1990, with the sample size beginning at fifty-two, but falling to forty-eight across 1990-2009. As in CF, the main constraint on sample size is due to the need for data on the overall capital share taken from Bernanke and Gurkaynak (2001).

We measure the cross-country private and public MPK using current price local currency data from World Development Indicators (WDI), rather than real data from Penn World Tables (PWT) adjusted for relative price differences as in CF. The use of current price local currency data is preferred here since it side-steps any reliance on PPP adjustments and extrapolated ICP data shown to be quite unstable for non-OECD countries (see Johnson *et al.,* 2011). In addition, it has been argued elsewhere (e.g. Knowles, 2001) that investment shares are more accurately measured using local price data, rather than data from PWT. In any case, for our analysis the two approaches yield essentially the same results, as will be seen in Section 5. The data we require are: income shares of public and private capital (β, γ), GDP in current price local currency $(P_y Y)$, public capital $(P_k K_g)$ and private capital $(P_k K_p)$.

Current price local currency data on GDP and investment are taken from WDI. In principle, each capital series could be obtained by using the perpetual inventory method on current price historic investment data, deflated each year by a sector-specific investment deflator. In practice however, only a common investment deflator exists.[7] In applying this common deflator, we are constrained in identifying differences in the relative price of capital faced by the public and private sector. But for the baseline estimation, the public and private MPK are adjusted by the same price ratio.

With current and constant price investment data, the next step is to split these investment

[6] Though we have data for subsequent years until 2010 (sample sizes of 49, 49, 48 and 23 in 2007, 2008, 2009 and 2010, respectively).

[7] This investment deflator is derived from WDI data as 100*(current price local currency gross fixed capital formation/constant price local currency gross fixed capital formation). Missing constant investment data is set equal to the product of constant price GDP and gross fixed capital formation as a proportion of GDP, for countries with available data.

flows into their private and public sector constituents. This split is crucial as it drives the resulting differences in the private and public MPK. To do this disaggregation, we use private investment share data from the World Economic Outlook (WEO), as was done recently in Gupta *et al.* (2011). For the sample of fifty countries in 2006, the mean number of time series observations of the private investment share is thirty-three (ranging from a minimum of twelve to a maximum of forty-nine).[8] Before total investment is disaggregated, the first available observation of the private investment share is extrapolated back to the first year of investment data.

In the absence of any investment data at all prior to 1960, it is necessary to set initial conditions for both the public and private capital stocks. As is common practice (given the notion of a steady-state capital stock), we set the initial condition, K_{j0}, to $I_{j0}/(\mathfrak{g}_j + \delta_{j0})$ where private and public sectors are indexed by $j = p, g$. I_{j0} is current price investment in the first year available, $\mathfrak{g}_j$ is the country- and sector-specific average growth rate of constant price investment over the first twenty years of available data,[9] δ_{j0} is the relevant depreciation rate for the first year of available investment data, with the pattern of depreciation rates taken from Gupta *et al.* (2011).[10] Caselli (2005) shows that sufficiently recent capital measures tend to be insensitive to the exact assumptions made on these initial conditions. Armed with disaggregated investment and deflator data, assumptions on initial conditions and a pattern of depreciation rates, we apply the perpetual inventory method to construct current price capital series for each country as follows:

$$P_{kt}K_{jt} = (1 - \delta_{jt}) \left(\frac{P_{kt}}{P_{kt-1}} \right) P_{kt-1}K_{jt-1} + I_{jt-1}, \tag{2}$$

so that

$$P_{kt}K_{jt} = (1 - \delta)^t \left(\frac{P_{kt}}{P_{k0}} \right) \frac{I_{j0}}{\mathfrak{g}_j + \delta_{j0}} + \sum_{i=1}^{t} (1 - \delta)^{t-i} \left(\frac{P_{kt}}{P_{k0}} \right) I_{ji-1}. \tag{3}$$

The total capital stock is then simply set equal to the sum of the private and public stocks. The

[8] For seven countries (Austria, Denmark, Spain, Greece, Ireland, Jamaica and Sweden) investment share data was missing from the latest WEO. We opted to take the share data from WEO 2003, using forecasted shares for the years 2004-2008.

[9] Since a negative g_j could result in implausibly large or impossibly negative initial conditions, the measure was bounded at zero. For the core sample of fifty countries, this bounding only affected the public capital initial condition for Zambia.

[10] The depreciation rates employed in Gupta *et al.* (2011) are as follows (all 1960-2008): (1) Public sector: 2.5% in LICs, 2.5% rising to 3.4% in MICs and 2.5% rising to 4.3% in Advanced; (2) Private sector: 4.25% in LICs, 4.25% rising to 7.6% in MICs, 4.25% rising to 9.6% in Advanced. We extrapolated the 2008 income- and sector-specific depreciation rates to 2009 and 2010. The underlying empirical and intuitive basis for this pattern of depreciation rates can be found in Arslanalp *et al.* (2010).

capital measures become less sensitive to the initial conditions and investment share extrapolation as t becomes closer to the present. This suggests that time series results have to be interpreted with greater care than the cross-section results in 2006.

Having constructed public and private capital stocks, the remaining specification choice is that for income shares β and γ. Unlike the share of capital in income, these shares cannot be straightforwardly derived from national accounts data. We proceed instead by taking the overall share of reproducible capital, $\beta + \gamma$, to be equal to the share data used by CF (α_k). This share data derives initially from Bernanke and Gurkaynak (2001).[11] CF then make an additional adjustment using wealth data from World Bank (2006) in order to account for natural capital. The result is data on the share of reproducible capital in income, α_k.

Next, we take the composition of this reproducible capital share to be consistent with the results of Gupta et al. (2011); see columns (2) and (3) in Table 6. This approach treats the production function regressions in Gupta et al. (2011) with some confidence. Their approach is to estimate system-GMM panel regressions assuming a Cobb-Douglas production function with skill-adjusted labour, private and public capital as its arguments. Since the estimation is in logs, each coefficient captures the income share of the associated factor input – provided that the identification is credible. Still, we don't take the absolute coefficients for our measurement since the aim is to maintain full country-specificity of the reproducible capital share in income. In addition to this, we place more credence on shares derived from national accounts as opposed to those derived from regression estimates.

With this in mind, we use the results in Gupta *et al.* (2011) to infer only the *relative* income shares of public and private capital for income groups, with $\beta/(\beta + \gamma) = 0.63$ in Middle Income and Advanced economies, and $\beta/(\beta + \gamma) = 0.48$ in Low Income Countries (LICs) (i.e. the relative income share of public capital is lower in richer countries). This is certainly an imperfect approach to measuring income shares since we fail to identify full heterogeneity in relative shares across countries, however, the results of Gollin (2002) provide at least some support that there is no systematic relationship between income levels and factor shares; that is the parameters of the aggregate production function are broadly similar across countries.[12] If this is the case, assuming away full cross-country heterogeneity in relative public to private capital shares should not affect

[11] Bernanke and Gurkaynak (2001) themselves extended an earlier dataset compiled in Gollin (2002).

[12] Important to note that the shares estimated by Gupta et al. (2011) are consistent with constant returns to scale over labor, private capital, and public capital.

our estimates substantively.

3 Public and Private MPK Calculations

With the necessary data at hand we turn to calculating each country's private and public MPK.[13] Table 1 presents baseline summary statistics for 2006, unless stated otherwise. It is reassuring that the only difference between our country sample and that of CF is the loss of Jamaica and Trinidad and Tobago due to a lack of updated investment data covering these countries.

Next we attempt to reproduce CF's main results on the overall MPK using our baseline dataset. Let Y and P_y be the quantity and price of final goods; K and P_k the quantity and price of capital goods; α_w the share of reproducible *plus* natural capital; and α_k the share of reproducible capital. By construction, $\alpha_w > \alpha_k$. CF define the following MPK measures:

$$MPKN = \alpha_w \frac{Y}{K}; \quad MPKL = \alpha_k \frac{Y}{K}; \quad PMPKN = \alpha_w \frac{P_y Y}{P_k K}; \quad PMPKL = \alpha_k \frac{P_y Y}{P_k K}.$$

$MPKN$ is the naïve MPK, while $MPKL$ adjusts the income share of capital to exclude natural capital, and $PMPKN$ controls for the relative price of final goods to capital products. Finally, we arrive at the preferred measure, $PMPKL$, which incorporates natural-capital with relative-output-to-capital-price. Table 2 presents summary statistics of CF's four main MPK measures with increasing sophistication for 1996. CF argue on the basis of the final measure (PMPKL) that the MPK is essentially flat.

CF's results are also illustrated in Figure 1. Fitted lines are added to obtain a better sense of the implied relationship between the MPK measures and income levels. The top-left panel in Figure 1 shows clearly that the naïve MPK implied by the standard neoclassical one-sector model is downward sloping. As we move to the right or down, each of the two adjustments disproportionately reduces the MPK in developing countries, since developing countries tend to have a higher share of natural capital in income and tend to face a higher relative price for capital goods.[14] The preferred MPK measure, $PMPKL$ (bottom-right panel), is actually slightly upward sloping (the fitted line is in fact statistically significant at the one percentage level, though its economic significance could be disputed). CF's main result then suggests that international capital markets do a good job of

[13] Later in the paper, we explore the sensitivity of the results to different assumptions regarding public investment efficiency, factor shares and relative prices.

[14] Hsieh and Klenow (2003) point to the relatively low productivity in capital goods producing sectors in developing countries as a cause of the high relative price.

Table 1: Summary Statistics

Country	Iso	y	Sh#	MPK(96)	MPK	MPKG	MPKP
Algeria	DZA	14560.1	21	0.03	0.05	0.04	0.06
Australia	AUS	75219.6	23	0.08	0.09	0.12	0.08
Austria	AUT	73793.3	40	0.08	0.09	0.20	0.07
Belgium	BEL	77973.8	16	0.08	0.10	0.25	0.07
Bolivia	BOL	7933.45	30	0.05	0.04	0.05	0.03
Botswana	BWA	19477.6	31	0.14	0.16	0.12	0.19
Burundi	BDI	702.85	31	0.01	0.01	0.01	0.02
Canada	CAN	68609.3	32	0.07	0.09	0.17	0.07
Chile	CHL	27516.7	26	0.09	0.11	0.25	0.09
Colombia	COL	17441	42	0.06	0.07	0.06	0.08
Congo, Republic of	COG	5138.94	42	0.02	0.05	0.10	0.04
Costa Rica	CRI	23514.9	20	0.03	0.07	0.10	0.06
Cote d'Ivoire	CIV	3352.81	41	0.03	0.02	0.02	0.02
Denmark	DNK	67132	31	0.08	0.11	0.24	0.08
Ecuador	ECU	14134.6	32	0.03	0.03	0.02	0.04
Egypt	EGY	13872.9	42	0.05	0.05	0.04	0.06
El Salvador	SLV	15734.4	30	0.17	0.16	0.16	0.16
Finland	FIN	65269	12	0.08	0.10	0.17	0.08
France	FRA	68105.4	15	0.08	0.09	0.13	0.08
Greece	GRC	61528.3	40	0.05	0.08	0.07	0.08
Ireland	IRL	75376.3	49	0.11	0.10	0.13	0.09
Israel	ISR	60113.8	27	0.11	0.14	0.27	0.11
Italy	ITA	70881.8	23	0.08	0.10	0.18	0.08
Jamaica	JAM	20282.8	40	0.07			
Japan	JPN	64150.5	31	0.08	0.09	0.09	0.09
Jordan	JOR	14078.7	48	0.09	0.10	0.08	0.11
Korea, Republic of	KOR	48077.8	41	0.1	0.12	0.19	0.09
Malaysia	MYS	25977.6	42	0.06	0.07	0.05	0.10
Mauritius	MUS	19235.3	38	0.12	0.15	0.12	0.18
Mexico	MEX	30136.5	38	0.09	0.14	0.20	0.12
Morocco	MAR	8860.36	41	0.09	0.10	0.19	0.08
Netherlands	NLD	75013.1	31	0.09	0.11	0.16	0.10
New Zealand	NZL	52261.3	26	0.05	0.06	0.06	0.05
Norway	NOR	94797.3	21	0.08	0.13	0.19	0.11
Panama	PAN	18734.6	42	0.06	0.09	0.11	0.08
Paraguay	PRY	7943.12	42	0.09	0.08	0.07	0.08
Peru	PER	13645	42	0.09	0.14	0.21	0.12
Philippines	PHL	6540.46	25	0.09	0.10	0.14	0.09
Portugal	PRT	38554.6	16	0.08	0.08	0.14	0.07
Singapore	SGP	84558.7	32	0.14	0.20	0.25	0.17
South Africa	ZAF	19752.7	40	0.08	0.13	0.19	0.11
Spain	ESP	58428.5	40	0.09	0.10	0.17	0.08
Sri Lanka	LKA	8347.63	34	0.06	0.08	0.14	0.06
Sweden	SWE	70425.8	49	0.07	0.09	0.13	0.08
Switzerland	CHE	64887.2	31	0.06	0.08	0.14	0.06
Trinidad and Tobago	TTO	45789.9	36	0.04			
Tunisia	TUN	15714.4	36	0.07	0.08	0.14	0.07
United Kingdom	GBR	68307.3	32	0.09	0.11	0.15	0.09
United States	USA	84597.9	32	0.1	0.10	0.16	0.09
Uruguay	URY	19200	42	0.12	0.08	0.06	0.10
Venezuela	VEN	20038.2	43	0.05	0.07	0.04	0.12
Zambia	ZMB	3942.16	31	0.02	0.01	0.00	0.01

Note: Iso refers to each country's isocode, y is PPP Real GDP Per Worker from PWT 7, Sh# indicates the number of time series observations of sectoral investment shares, MPK(96) refers to CF's MPK measure for 1996 using PWT data.

Figure 1: Main CF Results

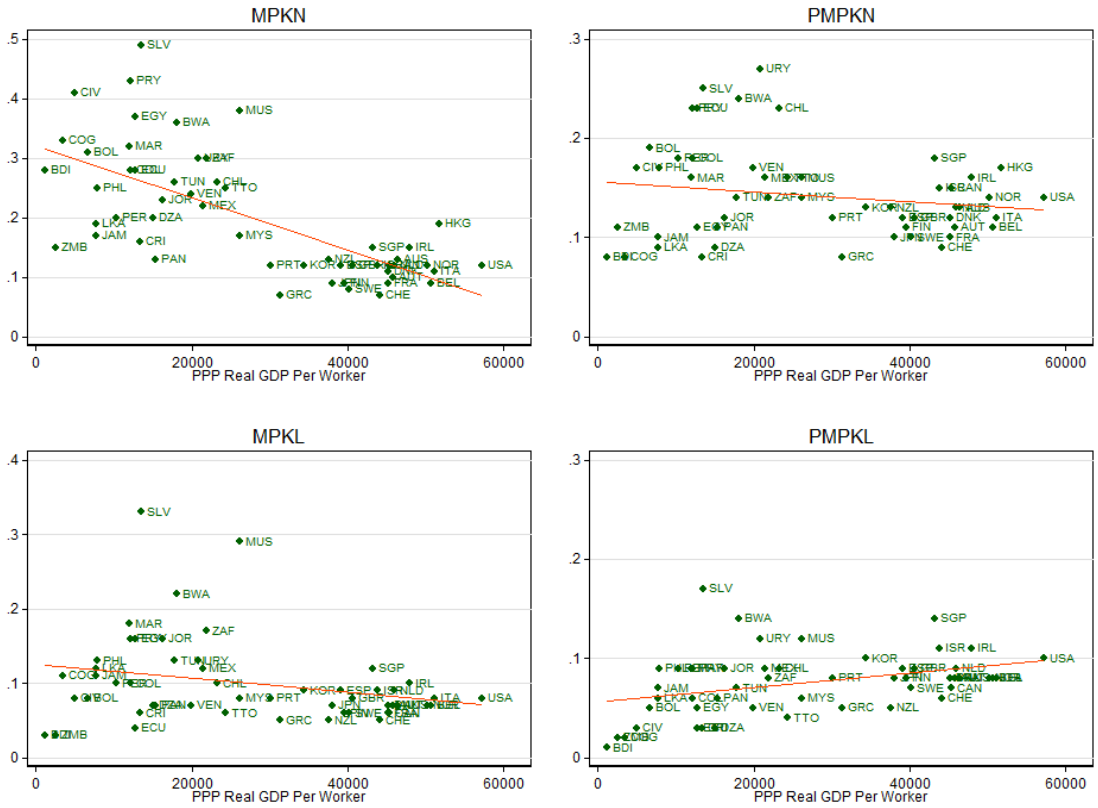


Table 2: Caselli and Feyrer (2007) MPK Measures

Measure	Mean	Std. Dev	Min	Max
MPKN	0.20	0.10	0.07	0.49
PMPKN	0.14	0.05	0.08	0.27
MPKL	0.10	0.06	0.03	0.33
PMPKL	0.08	0.03	0.01	0.17

Table 3: The Composition of Public Investment

Variable	LICs*	MICs†	Advanced
Mean Public Share in Total Investment (2010)	42.6%	29.4%	16.6%
Mean Public Investment as % of GDP (2007)	6.0%	6.9%	3.9%

Source: World Economic Outlook, Penn World Tables

*LICs: low income countries

†MICs: middle income countries

allocating capital efficiently across countries, and that there are no downward financial frictions in capital movements.[15] Provocative as it is, there is, in our view, not much cause to argue with the result presented in CF. Both adjustments are reasonable and make intuitive sense. Whilst the individual country MPK estimates could be challenged on the basis of data, the overall shape of the MPK schedule is quite robust.[16]

Closer inspection of the charts demonstrates that this result obtains mostly from CF's adjustments affecting developing, not advanced economies. Focusing our attention on advanced economies, with Portugal (PRT) the poorest of this group, we can see that the naïve MPK measure ($MPKN$) is slightly increasing even without the two adjustments made in CF. The main finding of a non-decreasing MPK obtains from the impact of the adjustments on developing economies. Before the adjustment, there is no clear relationship between the return and income in developing nations, whereas after it a clear non-negative relationship is unravelled.

The core analysis in the remainder of the paper focuses on shedding light on these intriguing results by turning attention to the distinction between private and public capital. Put differently, the analysis will attempt to unpack the results found by CF by examining the role of the public sector in capital allocation. Our key motivation stems from the observed variation of public investment across nations. Specifically, Table 3 and Figure 2 show that the public sector plays a disproportionately large role in investment in developing countries compared to advanced economies.[17] Therefore disaggregating the MPK into private and public may have important implications for the slope of

[15] For example, as CF show, the misallocation of capital implies an overall efficiency loss of only 0.1% of global GDP.

[16] Having said that, other adjustments can be suggested which in principle have the ability to overturn the result of a flat MPK. Chirinko and Mallick (2008) draw attention to the role played by adjustment costs, finding that a large MPK differential re-emerges once adjustment costs are accounted for.

[17] The relationship is flat when public investment as a percentage of GDP is considered because of two opposing forces: whilst public investment as a proportion of overall investment falls in income, investment as a proportion of GDP rises in income.

Figure 2: The Composition of Investment

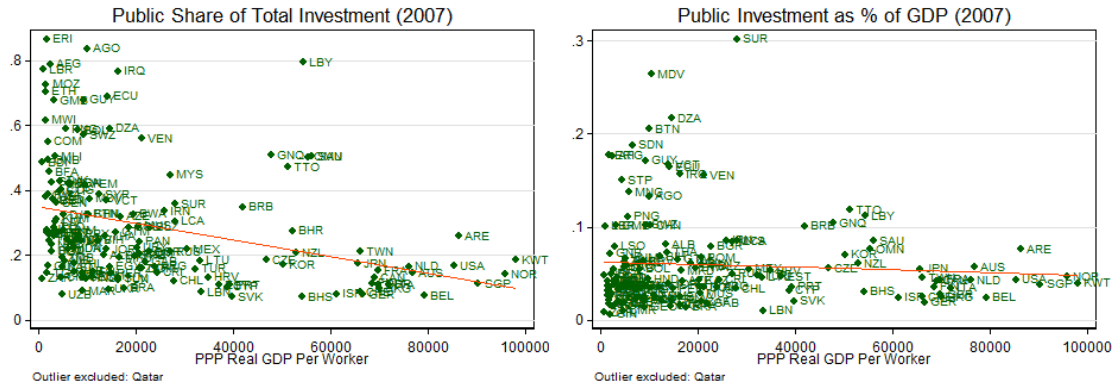


Table 4: Current Price Public and Private MPK

Measure	Year	Mean	Std. Dev	Min	Max
$MPKG$	1996	0.116	0.067	0.005	0.302
$MPKP$	1996	0.081	0.042	0.015	0.202
$MPKG/MPKP$	1996	1.432	1.595	0.333	1.495
$MPKG$	2006	0.130	0.069	0.005	0.265
$MPKP$	2006	0.085	0.037	0.014	0.193
$MPKG/MPKP$	2006	1.529	1.865	0.357	1.373

the overall MPK.

As explained in Section 2, our approach is to measure the cross-country MPK (overall, public and private) using current price data on income and capital along with income share data. Using current price data, we can estimate the MPK schedule for the exact same sample as CF, for the year 1996. This exercise is performed in Figure 3, which shows that the current price approach yields essentially the same overall MPK as CF, and that little has changed over the 10-year period 1996-2006. The advanced economies remain bunched closely around a financial rate of return of ten percent while the developing nations have a similar mean but greater variation, with rates of return from below one to sixteen percent.

Charts contained in Figure 4 show the public MPK ($MPKG$), its private counterpart ($MPKP$), and their ratio ($MPKG/MPKP$) for 1996 and 2006. Table 4 shows respective summary statistics. What jumps out is the distinctly different schedules between public and private MPKs.

More specifically, three observations are particularly notable. First and most important, the

Figure 3: CF Results with Current Price Data

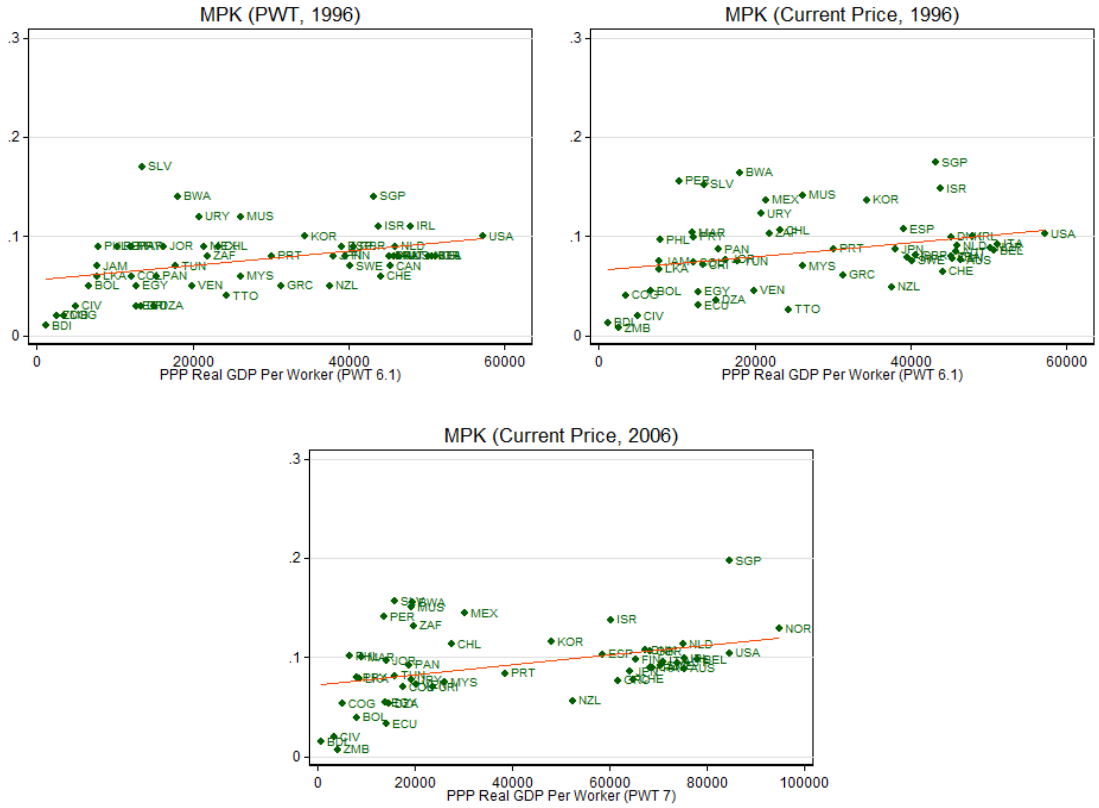
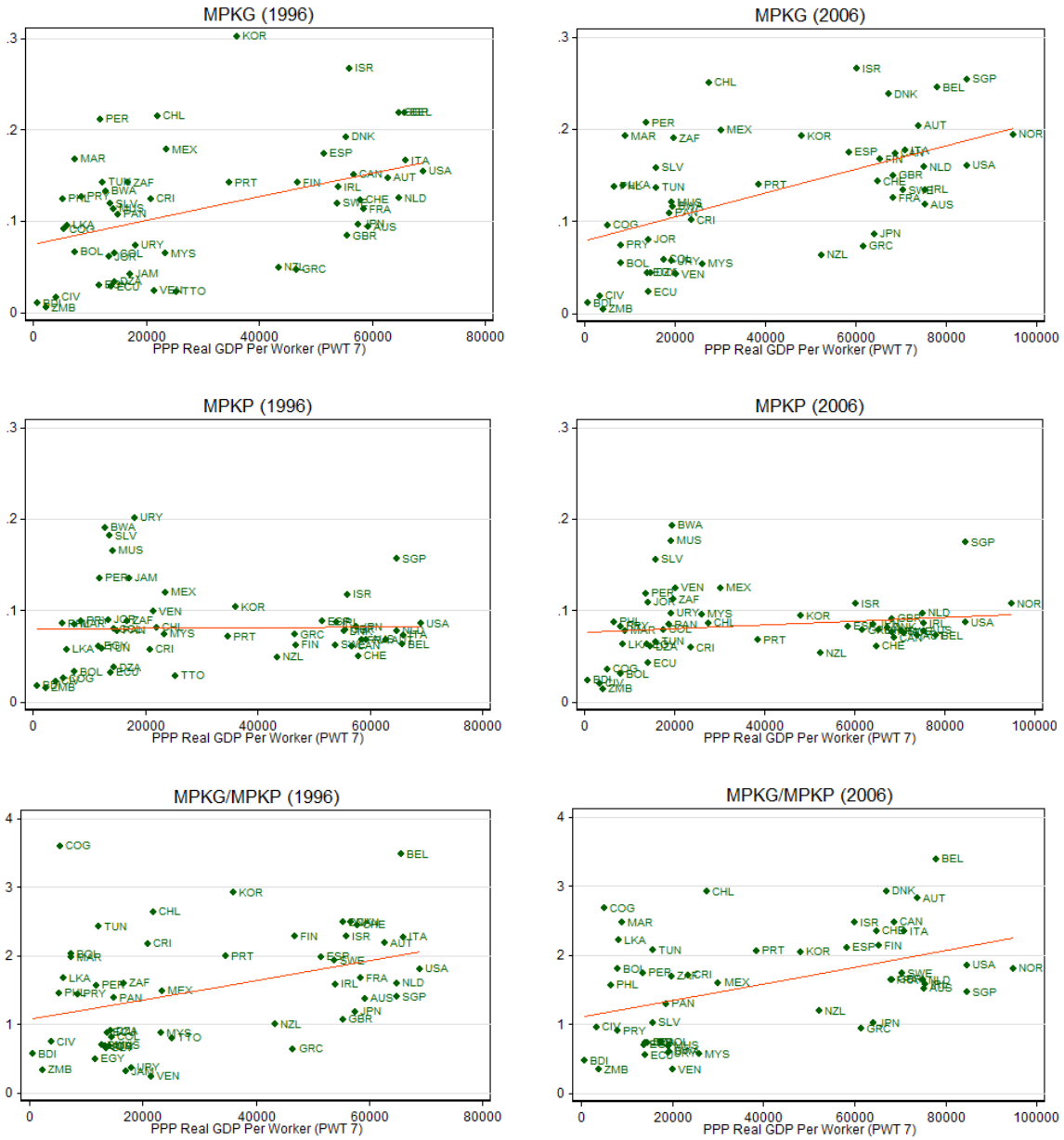


Figure 4: Public and Private MPKs



public MPK is upward sloping whereas the private MPK is flat. The fitted lines for the $MPKG$ measure (first row) are highly significant, whereas the ones for the $MPKP$ measure (second row) are insignificant. In fact, the evidence here suggests that it is the returns in the public sector which make CF's preferred overall MPK schedule flat or slightly upward sloping. Once the public and private components of capital are separated, the return to investment relevant for markets, that is, the private MPK, suggest neither downward nor upward rigidities to international capital flows. An upward sloping public MPK, on the other hand, fits with political economy stories such as Robinson and Torvik (2005) and Keefer and Knack (2007) of public sector ineffciencies.

Second, there is greater variation in the public MPK. This indicates that the most significant loss in world GDP may be due to the misallocation of public capital, not private capital.[18]

Third, there is an interesting pattern amongst the advanced economies: the private MPKs are extremely similar, the public MPKs are much more dispersed, and the mean public MPK is higher. According to this, the graphs potentially tell another story: private capital is allocated efficiently in advanced economies, but inefficiently in poor countries; public capital is allocated inefficiently everywhere.

Efficiency requires not only that marginal returns are equalized across countries, but also across sectors. The ratio of the public to the private return, appearing in the third row of Figure 4, gives information about how countries deviate from this cross-sector equalization. The natural interpretation is that a ratio below one reflects a government that overinvests in public capital, whereas a number above one suggests underinvestment. Few nations show values around one – the degree of dispersion is indeed high. In 2006, 48 percent of developing countries (13 out of 27 LICs and MICs) provide a ratio above one, making the case for underinvestment in public capital. The developing country sample is then fairly evenly split between over and underinvestment in public capital, within-country, according to this measure. Governments in advanced economies, in contrast, appear consistently to accumulate too little public capital. Greece is the only exception, and shows signs of overinvestment. Underinvestment in advanced economies may hide a provision of 'public' capital by the private sector, something more difficult to argue for developing economies.

[18] We show this to be the case more formally in Section 5.

Figure 5: Mean Value and Dispersion Time series

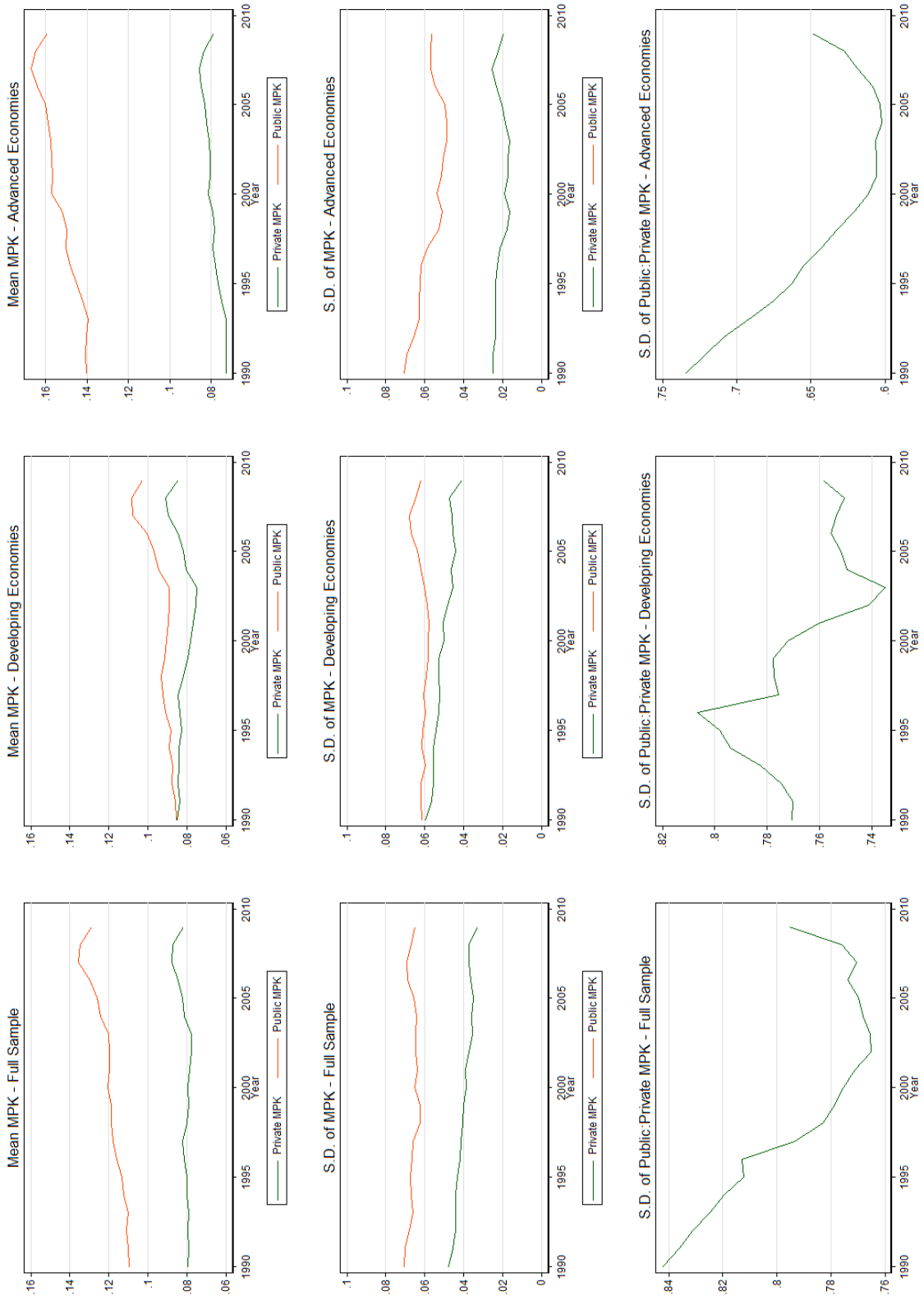


Figure 5 contains the temporal evolution from 1990 to 2009 of the mean values of the public and private returns to capital (first row), their standard deviation (second row), and the standard deviation of the ratio of public to private MPK (third row). These results should be interpreted with care given the greater sensitivity to initial conditions as we go back in time. The standard deviation of each of the MPKs reflects efficiency in the distribution of resources across countries, whereas the dispersion of the MPK ratio tells us about differences in the degree of under/overinvestment in public capital. To some extent, this dispersion may reflect the magnitude of divergence in political views towards public participation in investment across countries. Focusing on the first row, the annual means, public and private, have increased since 1990 in the full sample (left chart). The increase is stronger for public capital in all country groups. The rise in the private MPK is, on the other hand, evident in advanced nations (right chart), but not in developing economies (middle panel). The trend in the developed-world private MPK is most likely due to technical change, whereas the divergence between the two MPKs can be due to several factors such as a decrease in the relative inefficiency of the public sector and an increase in the private provision of public capital; further research is needed here.

The annual standard deviation of the MPK is more closely related to the concept of capital misallocation. In particular, a falling variation suggests more efficient allocation of capital worldwide. The second row in Figure 5 shows that private capital is persistently allocated more efficiently across countries than public capital – a result which may reflect the purer profit-maximizing incentives of private agents, compared with those in government. The Figure also suggests that private capital has become more efficiently allocated across nations since 1990, whilst public capital has not. This result is driven by developing countries (middle panel); in this group we see that, in 1990, the standard deviation of the private and public MPK was roughly equal, but there is divergence over the subsequent two decades. The left chart suggests the opposite in advanced economies – the standard deviation of the public MPK falls whilst that of the private MPK does not. Though in 2009, the dispersion of the private MPK remains much smaller than that of the public MPK.

The left panel in the third row shows a decrease in the standard deviation of the relative MPK until about 2003, and a rise after that date. It suggests that governments converged in the degree of underinvestment of infrastructure until 2003 and then diverged. For the developing world (middle panel), there is also divergence in underinvestment policies until 1996. Divergence can be due, for example, to differences in the degree of privatization of public capital.

Table 5: PIMI-adjusting and Infrastructure

Period: 2001-2005	Infrastructure Quantity*	Infrastructure Quality*
Public Capital/GDP	0.1205	−0.0712
PIMI-adjusted Public Capital/GDP	0.5596	0.5573
N	70	47

*Infrastructure Quantity and Infrastructure Quality are from Calderón and Servén (2008).

4 Extensions

In this section we introduce three extensions to our baseline analysis. First, we try to correct public capital stocks for possible inefficiencies in public investment by using a recently developed measure by Dabla-Norris *et al.* (2011). Public investment inefficiencies are notorious in several developing and emerging economies, therefore incorporating them into our analysis is potentially important. Second, in the context of a partial equilibrium multisector neoclassical growth model that incorporates public and private capital, we explore conditions under which the public and private MPK can obtain the differential schedules obtained by the empirical analysis. In addition, the model allows for public investment inefficiency and examines how such a public sector distortion may affect the core results of the neoclassical economy.

4.1 Incorporating Inefficiencies in Public Investment and Capital Formation

Pritchett (2000) and Caselli (2005) correctly argue that in many countries only a fraction of the actual accounting cost of investment passes into the value of the public capital stock. It is then the case that the public capital stock suffers from an upwards bias measurement problem when the perpetual inventory method is applied to past investment flows. In our case that would imply that the MPK schedules could also be biased – perhaps the public MPK is not upward sloping after all. By overstating the public capital stock in developing countries where public investment efficiency is lower, the public MPK is understated. Here we carry out an efficiency adjustment to the public capital stock measures by using a newly constructed measure, the Public Investment Management Index (PIMI), as our inefficiency proxy. This is the approach also taken in Gupta *et al.* (2011) where the overall PIMI score (averaged across its four sub-components) is normalized to lie between zero and one, and subsequently used as the efficiency parameter in the capital accumulation equation.

Using the Dabla-Norris *et al.* (2011) data, correlations in Table 5 suggest that the PIMI-adjusted public capital stock is a better proxy for actual public capital than the unadjusted measure. The

unadjusted measure of public capital (as a percent of GDP) is only weakly positively correlated with infrastructure quantity and actually negatively correlated with quality. The PIMI-adjusted measure on the other hand has a fairly strong positive correlation with both. As shown in Dabla-Norris *et al.* (2011), the PIMI possesses a lot of attractive features and is a good first proxy of public inefficiencies; however, it is also only an ordinal measure. Subsequent results using this approach should therefore be interpreted with care.

To obtain the efficiency-adjusted public capital stock ($\bar{K}_{gt}$), we alter the method of Gupta *et al.* (2011) slightly by focusing only on the two components of the PIMI most closely related to investment efficiency – project appraisal and selection.[19] These two components are summed for each country and normalized to lie between zero and one, resulting in a time-invariant efficiency measure ξ. The construction of the public capital stock becomes:

$$P_{kt}\bar{K}_{gt} = (1-\delta_{gt})\left(\frac{P_{kt}}{P_{kt-1}}\right)P_{kt-1}\bar{K}_{gt-1} + \xi I_{gt}, \tag{4}$$

so that

$$P_{kt}\bar{K}_{gt} = (1-\delta)^t\left(\frac{P_{kt}}{P_{k0}}\right)\frac{\xi I_{j0}}{\mathfrak{g}_g + \delta_{g0}} + \sum_{i=1}^{t}(1-\delta)^{t-i}\left(\frac{P_{kt}}{P_{k0}}\right)\xi I_{gi}, \tag{5}$$

which (because of time-invariance) implies the straightforward adjustment

$$P_{kt}\bar{K}_{gt} = \xi P_{kt}K_{gt}. \tag{6}$$

Our assumptions here differ from Gupta *et al.* (2011) as in that paper they assume efficiency equal to one prior to 1960 – in a sense, inefficiency only 'kicks in' from the 1960s. Furthermore, we assume that efficiency equals one in advanced economies, that is, their public capital stock is not adjusted.[20] To estimate the public MPK, we employ different estimates of the public capital income share from the regressions in Gupta *et al.* (2011) which use an efficiency-adjusted measure – this is their Table 6, columns (5) and (6).[21] The private share in total capital income is assumed to be 0.66 in MICs and advanced economies; 0.68 in LICs.

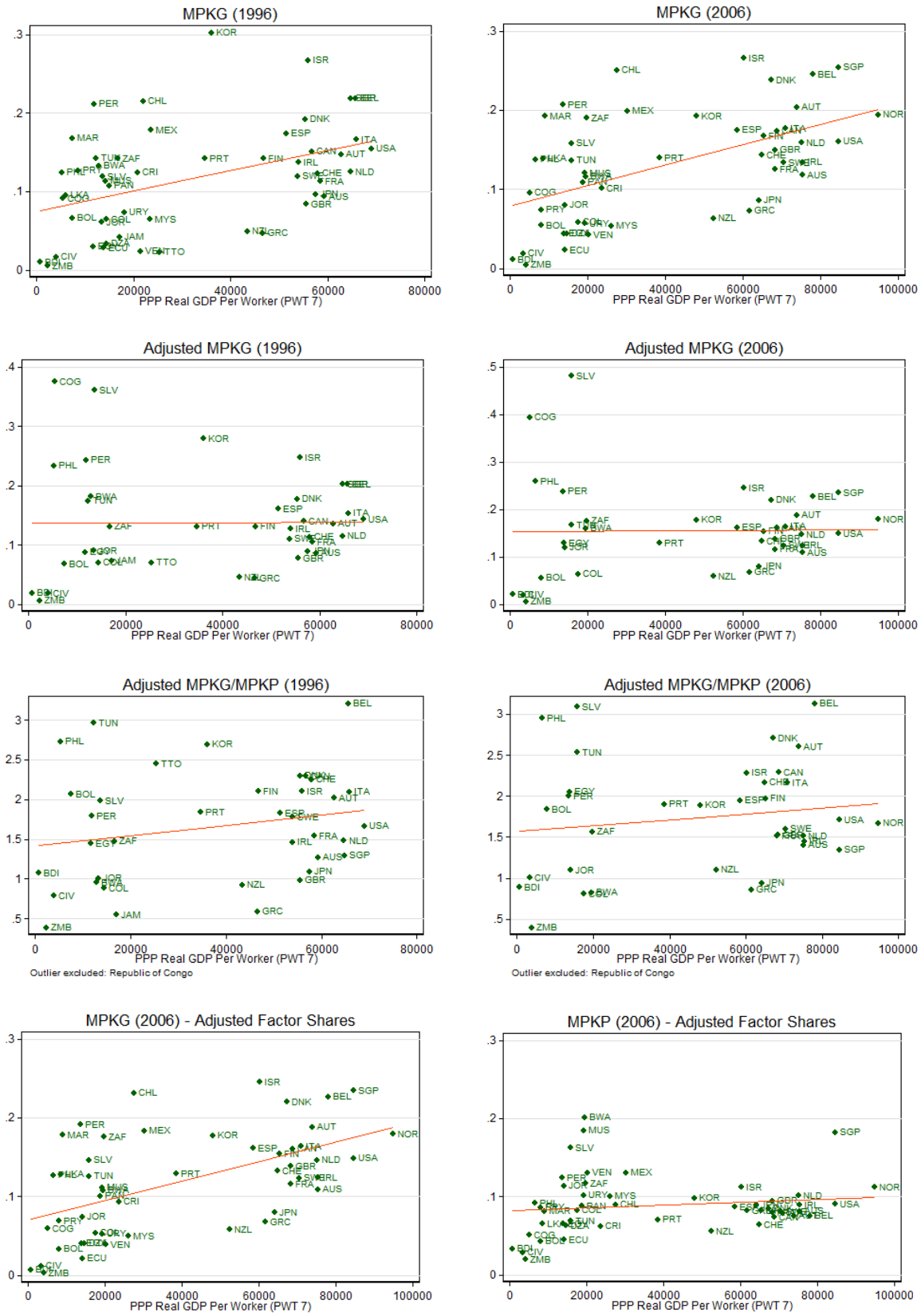
Figure 6 compares the public MPK measured before ($MPKG$) to the PIMI-adjusted measure ($eMPKG$). The use of PIMI data causes a drop in the sample size from fifty to thirty-seven countries. The result, for both 1996 and 2006, is a potential resolution of the upward-sloping

[19] The other two components are implementation and evaluation.

[20] There is no PIMI data available for advanced economies – but it is notable that the most developed countries in the PIMI sample tend to have high scores.

[21] Recall that they take into account all four components comprising the PIMI when adjusting capital stocks.

Figure 6: Adjusted Public MPK



public MPK. However, these suggestive results demand careful interpretation. Upon introducing the concept of imperfect public investment efficiency, the measure of interest changes. Under the standard assumption of perfect efficiency (i.e. $\xi = 1$ in the capital accumulation equation), the price-corrected MPK reflects well the returns to investment. Once we consider $\xi < 1$, there is a disconnect between investment flows and capital accumulation. Assuming that firms take prices as given, the correct measure of the returns to public investment is now

$$MPIG_t = \frac{P_{yt}}{P_{kt}} \frac{\delta Y_t}{\delta K_t} \frac{\delta \left(P_{kt} K_t\right)}{\delta I_t} = MPKG_t \cdot \xi_t = \eta \frac{P_{yt} Y_t}{P_{kt} \bar{K}_{gt}} \cdot \xi_t, \tag{7}$$

which we call here $MPIG$, the marginal product of public investment. In expression (7), η represents the efficiency-adjusted public capital share.

It is crucial to notice that $\delta(P_{kt}K_t)/\delta I_t$ depends only on efficiency at time t, whereas $\delta Y_t/\delta K_t$ is a function of the full history of efficiency (though with declining weight as we go further into the past). Under the assumptions of *constant* efficiency and same factor shares ($\eta = \gamma$), the $MPIG$ is in fact identical to the un-adjusted $MPKG$ (first row, Figure 6) – this comes as the result of an exact offset with ξ cancelling out. If the factor shares are estimated differently when we take into account public investment efficiency (which is the case here), the $MPIG$ is reflected by the $MPKG$ measured using η rather than γ (fourth row, first column).[22] Low historic efficiency will imply a smaller capital stock today and a correspondingly higher $MPKG$ (as we see in the second row of Figure 6), but this is offset by the low present-day public investment efficiency. The purpose of all this is to show that the result of an upward-sloping return to public investment across countries is robust to the introduction of inefficiency in public investment, provided the inefficiency is either constant or at least that present-day efficiency is a close proxy for 'historic efficiency'.

Even if the $MPKG$ schedule is the most useful for understanding actual public investment returns, the $eMPKG$ schedule may still have a useful interpretation. In some sense it hints at the returns to public investment possible if public investment efficiency in developing countries was brought up to the level of advanced economies, even leaving the greater relative price of capital in developing countries unchanged. From a policy perspective, there seem to be two implications for bringing public returns in developing countries in line with those in advanced economies: reform public investment efficiency, and tackle the higher relative price of capital goods.

[22] The private MPK should also be adjusted accordingly using the efficiency-adjusted factor shares. This is done in the fourth row, second column. There are no qualitative differences to the earlier private MPK schedule.

Figure 7: Dispersion in the adjusted and non-adjusted $MPKG$

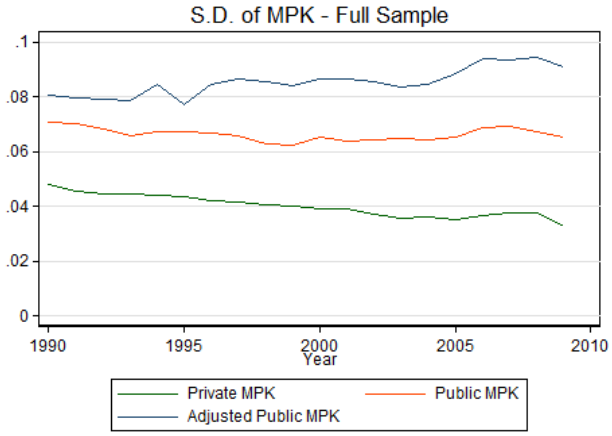


Figure 8:

Returning to the adjusted public capital results, Figure 8 shows the time series dispersion exercise repeated with the addition of the efficiency-adjusted public MPK, only for those countries with PIMI data, including advanced economies. The efficiency adjustment gives no new meaningful time variation since the PIMI is time-invariant. The interesting result is that the efficiency adjustment does not overturn the initial observation that the variation in the public MPK is significantly higher than the variation in the private MPK, as one might expect. The efficiency-adjustment only reinforces this conclusion along with the finding that the private MPK variance has fallen since the 1990s whilst the variance of the public MPK has not.[23]

4.2 A Three-sector Model with Private and Public Capital

Results in previous sections leave some open questions. Can other public sector inefficiencies affect our MPK measures? Why does the public MPK schedule slope up? We now present a simple framework that explores these issues. The model is close to the standard neoclassical multisector framework in CF, but contains more structure.

[23] Whilst the ξ-adjusted public MPK is based on a smaller sample (non-Advanced economies without PIMI data are dropped), we would expect this to make the standard deviation smaller, not larger. If anything, the graph understates the difference in variation by using non-comparable samples. Of course, the analysis can be repeated for the common sample of countries.

4.2.1 Production

Eliminate for simplicity time subcripts. The economy produces three final goods: a consumption product (Y_c); and two types of investment products – one for the private sector (Y_m) and the other for the public sector (Y_s). The three goods are manufactured by private firms. The government simply finances some of the production.

Firms in sector j employ private capital (K_{pj}), efficiency-adjusted public capital ($\bar{K}_{gj}$) and other factors (X_j) as inputs. The three goods are manufactured under constant returns to scale and perfect competition according to

$$Y_c = A_c K_{pc}^{\beta} \bar{K}_{gc}^{\gamma} X_c^{1-\beta-\gamma}, \tag{8}$$

$$Y_m = A_m K_{pm}^{\beta} \bar{K}_{gm}^{\gamma} X_m^{1-\beta-\gamma}, \tag{9}$$

$$Y_s = A_s K_{ps}^{\beta} \bar{K}_{gs}^{\gamma} X_s^{1-\beta-\gamma}. \tag{10}$$

Input elasticities are such that $\beta, \gamma \in (0,1)$ and $\beta + \gamma < 1$. Employing results in Herrendorf and Valentinyi (2008), we assume that all sectors display the same input intensities. Total factor productivity (TFP) in private and public investment-goods production are related. In particular, we suppose that $A_s = \varphi A_m$, where $\varphi \in (0,1]$; that is, firms may not be as efficient when they produce for the public sector. The TFP parameters A_c and A_m are assumed to grow exogenously at rate $\mathfrak{g}$.

The idea behind expressions (9) and (10) is that the public and private sectors invest systematically in different types of capital that are complements in the production function. In fact, there is some capital that the public sector is more willing to invest in; historically, for example, the public sector has been instrumental in the provision of transportation networks or sanitation in many nations.

As mentioned above, production can be financed either by private agents to increase firms' stocks or by the public sector to provide infrastructure to the economy. The motion equations for capital are given by:

$$P_k \dot{K}_p = I_p - \delta P_k K_p, \text{ with } I_p = P_k Y_m \tag{11}$$

$$P_s \dot{\bar{K}}_g = \xi I_g - \delta P_s \bar{K}_g, \text{ with } \xi I_g = P_s Y_s, \tag{12}$$

where $\bar{K}_g = \bar{K}_{gc} + \bar{K}_{gm} + \bar{K}_{gs}$, and $K_p = K_{pc} + K_{pm} + K_{ps}$. Expressions (11) and (12) are the continuous-time version of motions (2) and (4), taking into account that the price of public capital (P_s) can differ from the one of private capital (P_k).

As in the previous section, the coefficient ξ is a measure of government inefficiency in channeling funds to investment in line with Agénor (2010). Following the same steps as in the derivation of expression (6), it is straightforward that (12) implies that the public-capital stock corrected for inefficiencies ($\bar{K}_g$) and the one not corrected (K_g) maintain the relationship:

$$P_s \bar{K}_g = \xi P_k K_g. \tag{13}$$

Let us consider that firms pay an interest rate r to private savers for the capital borrowed ($P_k K_{pj}$) to construct their capital, a price τ (net of depreciation) for the use of public infrastructure, like airport fees and taxes, and a rate w to each unit of other inputs hired. Profit maximization in production sector $j \in \{c, m, s\}$ implies the following FOCs for capital and other inputs:

$$r = \left(\frac{P_j}{P_k}\right) \frac{\partial Y_j}{\partial K_{pj}} - \delta, \tag{14}$$

$$\tau = \left(\frac{P_j}{P_s}\right) \frac{\partial Y_j}{\partial \bar{K}_{gj}} - \delta, \tag{15}$$

and

$$w = P_j \frac{\partial Y_j}{\partial X_{gj}}, \tag{16}$$

where P_c represents the price of the consumption good.

It is easy to show that expressions (14) to (16) imply that capital-labor ratios need to be equalized across sectors, that the relative prices of goods are exclusively pinned down by the relative TFPs, and that the private-to-public capital ratio depends on input elasticities and prices. Mathematically,

$$\frac{K_{pc}}{L_c} = \frac{K_{pm}}{L_m} = \frac{K_{ps}}{L_s} = \frac{K_p}{L}, \tag{17}$$

$$\frac{\bar{K}_{gc}}{L_c} = \frac{\bar{K}_{gm}}{L_m} = \frac{\bar{K}_{gs}}{L_s} = \frac{\bar{K}_g}{L}, \tag{18}$$

$$\frac{P_c}{P_k} = \frac{A_m}{A_c}, \tag{19}$$

$$\frac{P_s}{P_k} = \frac{1}{\varphi}, \tag{20}$$

and

$$\frac{K_{pc}}{\bar{K}_{gc}} = \frac{K_{pm}}{\bar{K}_{gm}} = \frac{K_{ps}}{\bar{K}_{gs}} = \frac{\beta}{\gamma} \frac{\tau + \delta}{r + \delta}, \tag{21}$$

where

$$L_c + L_m + L_s = L, \tag{22}$$

$$K_{pc} + K_{pm} + K_{ps} = K_p, \text{ and } \bar{K}_{gc} + \bar{K}_{gm} + \bar{K}_{gs} = \bar{K}_g. \tag{23}$$

The total amount of other resources X is assumed to grow at rate n.

Expression (20) implies that the relative price of public infrastructure is affected by inefficiencies related to the relative TFP. Taking this into account, we can use equality (13) to get

$$\bar{K}_g = \xi\varphi K_g. \tag{24}$$

Inefficiencies reduce the amount of resources that end up being public capital in real terms.

4.2.2 Efficiency Adjusted MPKs

The MPK measures that we used to proxy the return to private and public capital investment are contained in expression (1). In terms of our model, GDP in the numerator of the last expression equals

$$P_y Y = P_c Y_c + P_k Y_m + P_s Y_s. \tag{25}$$

The issue that we explore in this section is whether these MPK measures continue being a good proxy for the return to investment once inefficiencies are taken into account.

Given that neither ξ nor φ affect the private sector return, the measure $MPKP$ still captures the financial return to private investment. For the public sector, however, the marginal product of capital $MPKG$ does no longer give the relevant financial return to investment. As argued above, this return now equals the efficiency-adjusted marginal product of investment, expression (7); although we need to substitute P_s for P_k in (7) since the two prices may differ because of φ. The proxy $MPIG$ becomes:

$$MPIG = \frac{P_y}{P_s}\frac{\partial Y}{\partial \bar{K}_g}\frac{\partial\left(P_s\bar{K}_g\right)}{\partial I_g}.$$

Which using expressions (12), (20) and (24) can be written as

$$MPIG = \frac{P_y}{P_s}\frac{\partial Y}{\partial \bar{K}_g}\xi = \frac{P_y}{\frac{P_k}{\varphi}}\left(\gamma\frac{Y}{\xi\varphi K_g}\right)\xi = MPKG.$$

Therefore, neither ξ nor φ, as long as they are constant, matter for the calculation.

We already explained in the previous section the intuition for the absence of impact of ξ. For the TFP inefficiency φ, the intuition is similar: the parameter φ affects the stock of public capital, and also its price; both affect the value of the MPK in opposite directions, offsetting each other. Also common to both inefficiencies is that their effect on the capital stock is a function of the

full history of efficiency, whereas their other (offsetting) effect depends only on efficiency at time t. Nevertheless, there is an important difference between the two: unlike for the investment inefficiency ξ, the neutrality finding for the TFP inefficiency φ depends on the Cobb-Douglas form adopted by the model. Finally, before moving to our next task, it is important to recall that, if capital shares depended on the amount of capital, as it is the case in production function estimation, these shares would be different depending on whether or not capital stocks were efficiency corrected.

4.2.3 The Different Behavior of MPKP and MPKG

Next, we look at the price-corrected MPK proxy constructed by CF ($PMPKL$) using the total capital stock. It is easy to show that this measure is simply a weighted average of the public and private MPKs. In particular,

$$PMPKL = \frac{P_j}{P_k}\left(\frac{K_p}{K}\frac{\partial Y_j}{\partial K_{pj}} + \frac{K_g}{K}\frac{\partial Y_j}{\partial K_{gj}}\right), \tag{26}$$

with $K = K_p + K_g$. The equality must hold for all j. Focusing on the consumption-goods production activity, we can expand (26) using (17), (22) and (23) to obtain

$$PMPKL = \frac{K_p}{K}\beta\frac{P_cY_c}{\frac{L_c}{L}P_kK_p} + \frac{K_g}{K}\gamma\frac{P_cY_c}{\frac{L_c}{L}P_kK_g} = (\beta+\gamma)\frac{P_cY_c}{P_kK\frac{L_c}{L}}.$$

Which employing the value of consumption-goods production implicit in (29) (see below) delivers

$$PMPKL = (\beta+\gamma)\frac{P_yY}{P_kK}. \tag{27}$$

It provides a direct measure of the MPK that can be obtained using the physical capital share in income to approach $\beta+\gamma$, GDP, and the non-adjusted capital stock. The key prediction of the multisector framework that CF exploit is that the financially-relevant MPK depends on the relative price of final-to-capital goods, P_y/P_k.

Equality (27) is, however, a good proxy only if resources are efficiently allocated between capital types. To see this, we need to compare $PMPKL$ to the financial return to private investment ($MPKP$), which in our model is the right measure of the market return. Focusing again on the c sector,

$$MPKP_c = \beta\frac{P_cY_c}{P_kK_{pc}}. \tag{28}$$

Employing expressions (8), (9), (17) to (20), (22) and (23), we can rewrite (25) as

$$P_yY = P_cY_c\,\frac{L}{L_c}. \tag{29}$$

This and (21) make (23) become

$$MPKP = \beta \frac{P_y Y}{P_k K_p} = \left(\beta + \gamma \frac{r+\delta}{\tau+\delta}\right) \frac{P_y Y}{P_k K}. \tag{30}$$

Comparing $PMPKL$ and $MPKP$, they differ because input prices play a role in the latter measure. In fact, when payments to both types of capital are the same, that is, the public sector charges a fee for the use of public infrastructure equal to the market return ($\tau = r$), $MPKP$ equals $MPKG$, and $PMPKL$ and $MPKP$ coincide.

The two prices can, however, differ at least for two reasons. First, government's inefficiencies. Their effect is that the public sector needs to borrow more than private firms to obtain the same amount of physical capital; and therefore, pay a larger price for each unit borrowed. Second, the government may think that the return to public investment differs from the one of private investment, and want to subsidize the use of K_g. This can be due to political reasons, if the public sector wants to signal its capacity to increase people's welfare; but also to economic factors, if the government perceives possible *big-push* effects from increasing public infrastructure and economic activity.

Our last task is trying to explain why the public marginal product of capital slopes up with income per capita in the cross-section of nations. According to the model, expressions (1), (20) and (21) imply that the ratio public-to-private MPK is given by

$$\frac{MPKG}{MPKP} = \frac{\gamma \frac{P_y Y}{P_s K_g}}{\beta \frac{P_y Y}{P_k K_p}} = \frac{\gamma}{\beta} \frac{P_k}{P_s} \frac{K_p}{K_g} = \frac{\gamma}{\beta} \varphi \frac{\beta(\tau+\delta)}{\varphi\gamma(r+\delta)};$$

that is,

$$\frac{MPKG}{MPKP} = \frac{\tau+\delta}{r+\delta}. \tag{31}$$

The empirical evidence that we have found suggests that financial markets do a good job at equalizing private-sector returns across nations. Equality (31), therefore, says that to explain why the public-to-private MPK ratio slopes up, we need to explain why the user cost of public infrastrucure increases with development.

4.3 Gourinchas-Jeanne Allocation Puzzle

In neoclassical theory, countries with faster productivity growth should invest more, and attract more foreign capital. But data shows that amongst developing countries this is not true – if

anything, capital seems to flow more to countries that invest and grow less. Gourinchas and Jeanne (forthcoming; GJ thereafter) who uncover this surprising fact call it the "allocation puzzle."

In their introductory section GJ assert, according to neoclassical theory, that: "If investment and capital flows were driven primarily by changes in domestic productivity, [...], countries that invest more should receive more capital from abroad." Against, this neoclassical model implication these authors present data from 66 developing economies that show a distinct negative relationship between capital flows and investment-to-GDP ratio (I/GDP), thus giving rise to the "allocation puzzle." While the Lucas Paradox is about the small magnitude of capital inflows to developing countries the allocation puzzle is about the allocation of the already small size of capital flows across developing countries.

GJ present one possible explanation for this puzzle: wedges affecting returns to savings and investment. But the saving wedge has to be important; that is savings has to be more strongly positively correlated with productivity growth than investment. The paper then builds a case for the difference between savings and investment (capital outflows) in developing countries. In this subsection we briefly consider whether our results on public and private MPK can shed more light onto this puzzle.

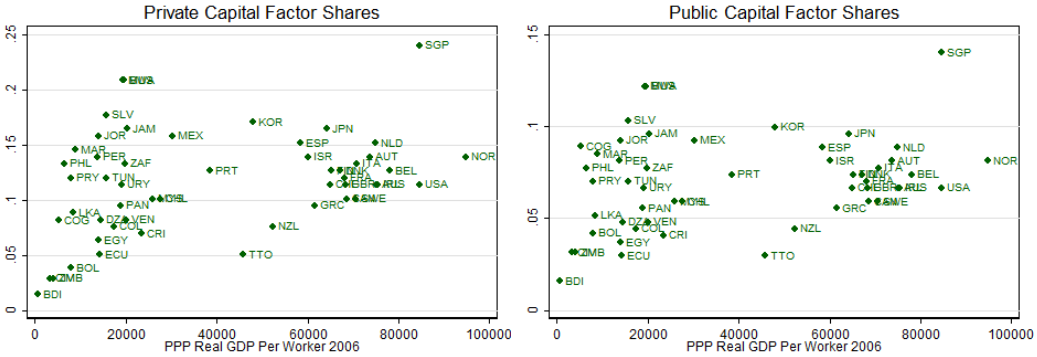
The main finding in this paper, that MPKG and therefore returns to public investment is suppressed in developing countries, could offer a complementary explanation of this puzzle. Specifically, if countries with low TFP growth also tend to be countries where the government has few checks and balances and uses public investment for rent-seeking, for example, it could be that there is public overinvestment. To put it in more extreme terms, corrupt authorities in developing economies may easily resort to inefficient overinvestment by taking advantage of their sovereignty status that allows them to more easily borrow from international capital markets (than private firms) and often to secure large amounts of foreign aid. While GJ have shown that the allocation puzzle remains even after netting foreign aid out of their capital inflows measure, it is notable that it becomes substantially weaker - that is there is now a flat relationship between the aid-ajdusted capital and investment. This could indicate that along with GJ's investmnet-savings wedge explanation there is also a public sector story that could refocus the question to: why does capital flows to governments whose productivity and returns to public investment are so low? Examining this question is certainly worthy of future research that would require looking further into the connection between public sector productivity and disaggregated capital flows to the public and private sectors.

5 Robustness

In this section we examine the robustness and validity of several assumptions in the baseline analysis of Section 3.

5.1 Income Shares

Our approach to income shares is to take the overall share of reproducible capital from national accounts data (adjusted for natural capital and the under-estimation of labour income in small firms) and split it using production function regression estimates of the relative output elasticities of private and public capital. The resulting public and private shares for our maximum sample of fifty-two countries are plotted below.



The mean private capital share in income is 0.12, whilst the mean public capital share is 0.07. The mean overall share of reproducible capital is 0.19 – this may seem low given the usual national accounts estimates being around 0.3 or 0.4, but it can be explained by the natural capital adjustment: prior to this adjustment, the mean capital share is 0.35.

One question for these capital share measures is whether they are consistent with other estimates of the output elasticity of capital from the production function regression literature. A useful reference point is given by Bom and Ligthart (2010) who carry out a meta-analysis on 67 studies estimating the private output elasticity of public capital using the production function approach. Even given much variation across the studies, they find the average true output elasticity of public capital to be positive and significant – giving support for the implicit assumption throughout this paper that public capital is productive and should appear in the production function.

More specifically, after correcting for linear publication bias, the unconditional average output elasticity of public capital is found to be 0.146. This is double the mean public capital share in our sample, though it tells us nothing about the relationship of the public capital share with income. Having said that, had we applied our public-private split to the capital share before the adjustment for natural capital, the mean public capital share would be 0.13. Our estimates of the public capital share are then consistent with the production function approach once we take into account the adjustment for natural capital here which is omitted in production function studies. Though many of the studies in Bom and Ligthart's sample are for the US or other advanced economies (and so not completely applicable to the estimates in this paper), the one study which focusses on LICs (Dessus and Herrera (2000)) yields a similar output elasticity of 0.13.

Bom and Ligthart note that the conditional output elasticity of public capital in the benchmark specification, 0.165, implies a public MPK for the US of 28.8-32.6 percent in 2001. Our preferred estimate (using current price local currency data) is 16.9 percent – similarly implying under-investment in public capital by the US, but smaller because of the smaller capital share we calculate.

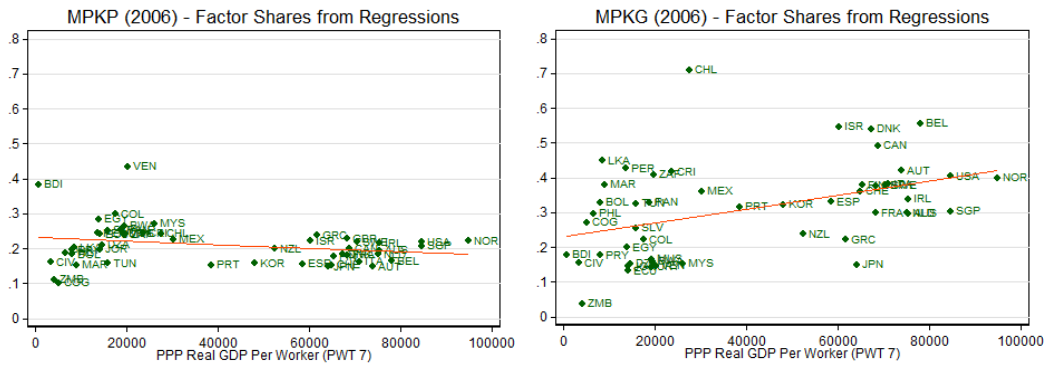
Arslanalp *et al.* (2010) provide an additional set of relevant empirical results – they estimate the impact of public capital on economic growth for OECD and non-OECD countries during 1960-2001, again using a production function approach. Consistent with the general finding of Bom and Ligthart, the results show a positive elasticity of output with respect to public capital. Building on this, they find that the elasticity depends on the income level of countries – the elasticity is stronger for OECD countries. They speculate that this is due to institutional factors. Regardless of the reason, this fits our data on public capital shares in which there is a positive association between the share and income. On the other hand, for non-OECD countries, the elasticity of output with respect to public capital is only significant after controlling for the initial level of public capital. The interpretation of this result is not obvious, but in effect contributes to the rejection of the notion of a constant output elasticity with respect to public capital.

The next important question is whether other studies corroborate the result we take from Gupta *et al.* (2011) that the public and private output elasticity is similar in LICs, but that the private output elasticity is larger than the public elasticity in developed economies. Arslanalp *et al.* (2010) find that private capital has a higher output elasticity than public capital in all models for both the OECD and non-OECD sample. However, contrary to the results we use from Gupta *et al.*, in their

standard model the difference between the public and private output elasticities is only statistically significant for non-OECD countries. Taking these results literally, the private and public capital output elasticities are essentially equivalent in OECD countries, but the public capital elasticity is lower in non-OECD countries. Applying this to our own MPK measurement would actually make the public MPK *more* upward-sloping and the private MPK *more* flat.

It is also critical for our approach to MPK measurement to test for constant returns to scale in all factors. Arslanalp *et al.* cannot reject the null hypothesis of constant returns to scale (in all factors) in their standard model; however, constant returns to scale is rejected for non-OECD countries. When estimating over five-year intervals though, constant returns to scale cannot be rejected.

As another robustness check here, we see how our results change if we apply the regression estimates for β and γ directly, ignoring national accounts estimates for $\beta+\gamma$, and at the loss of full heterogeneity in factor shares.[24] This check is appropriate because Gupta *et al.* (2011) estimates are consistent with constant returns over production factors, including public capital. Turning again to columns (2) and (3) in Table 6 of Gupta *et al.*, for LICs we set $\beta = 0.231$ and $\gamma = 0.253$, whilst for middle-income and advanced economies we have $\beta = 0.286$ and $\gamma = 0.167$. The results are shown for the core sample of fifty countries in 2006:



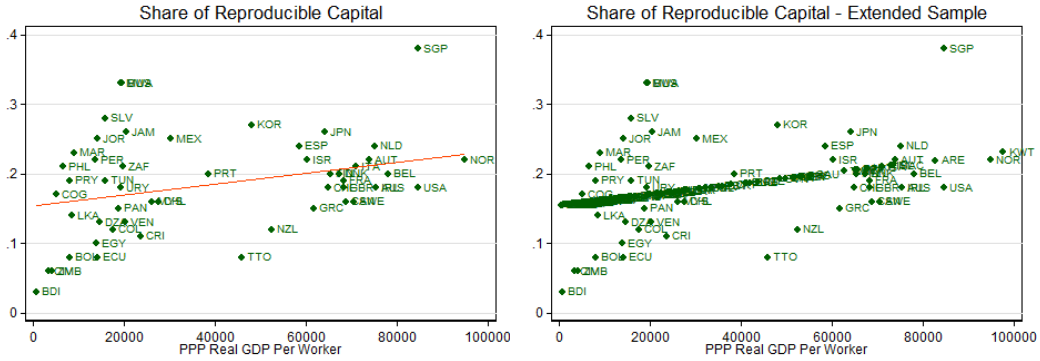
As is to be expected, this approach yields higher estimates for the MPKs all round – the private MPK looks roughly equalised at around 20 percent (though there are two notable outliers), whilst most public MPKs lie between 10 and 50 percent. These estimates seem implausibly high, showing the advantage of using national accounts data to get at capital shares instead of regression

[24] We thank Steve Bond for this suggestion.

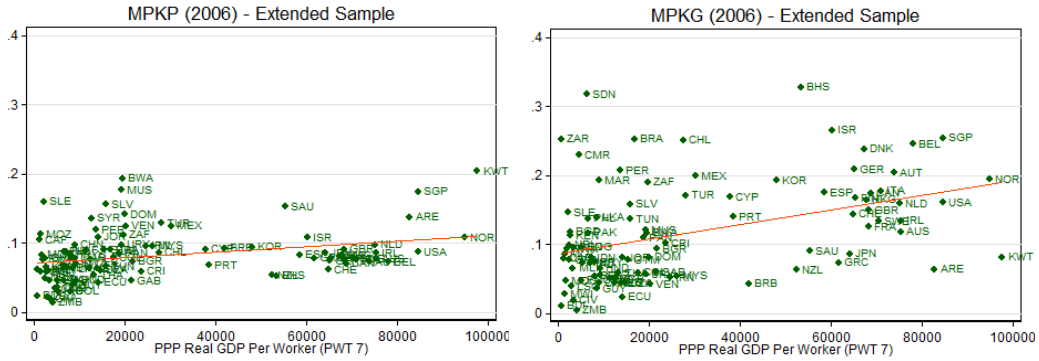
estimates. Still, taking these plots at face value, we find now that the private MPK is slightly downward-sloping (fitted line is negative and significant at 10 percent) whilst once again the public MPK is upward-sloping (fitted line is positive and significant at 1 percent).

5.2 Extending the Sample

The sample of fifty countries in 2006 only includes five LICs (Burundi, Bolivia, Côte d'Ivoire, Republic of Congo and Zambia). The major data constraint is the share of reproducible capital in income – it is only available for fifty-two countries. Further work will aim to extend the dataset constructed by Bernanke and Gurkaynak (2001) by turning to the latest national accounts data. For now, we try a first shot at extending the dataset by plotting a linear fit of α_k on PPP Real GDP Per Worker in 2006, and setting α_k equal to the linear prediction for countries with missing data. The linear fit is as follows:



With the extended sample, the public and private MPK in 2006 can be re-plotted to see if the main results still stand. The sample size increases from 50 to 133 countries – but some of these countries have suspect capital stock data. We restrict the sample to countries with at least 12 observations of the private share of investment and at least 31 observations of the investment deflator. With 12 and 31 being respectively the lowest number of private share and deflator observations in the core sample of fifty, these conditions restrict the sample to countries with comparable data quality to the original sample. The restricted sample includes 95 countries, of which 26 are LICs. The graphs that follow show the private and public MPK for this sample in 2006.



The results for the extended sample are roughly equivalent to the earlier results. There is more heterogeneity in the public MPK than the private MPK, and the public MPK is more positively sloped. The public MPK fitted line remains positive and significant at 1 percent, as is the fitted line for the private MPK, though the slope is much smaller (as is evident in the graphs). Extending the sample has resulted in an increase in precision of the fitted line – with this larger sample, it is no longer the case that public sector behaviour alone explains the upward slope of the overall MPK (though it still provides a partial explanation).

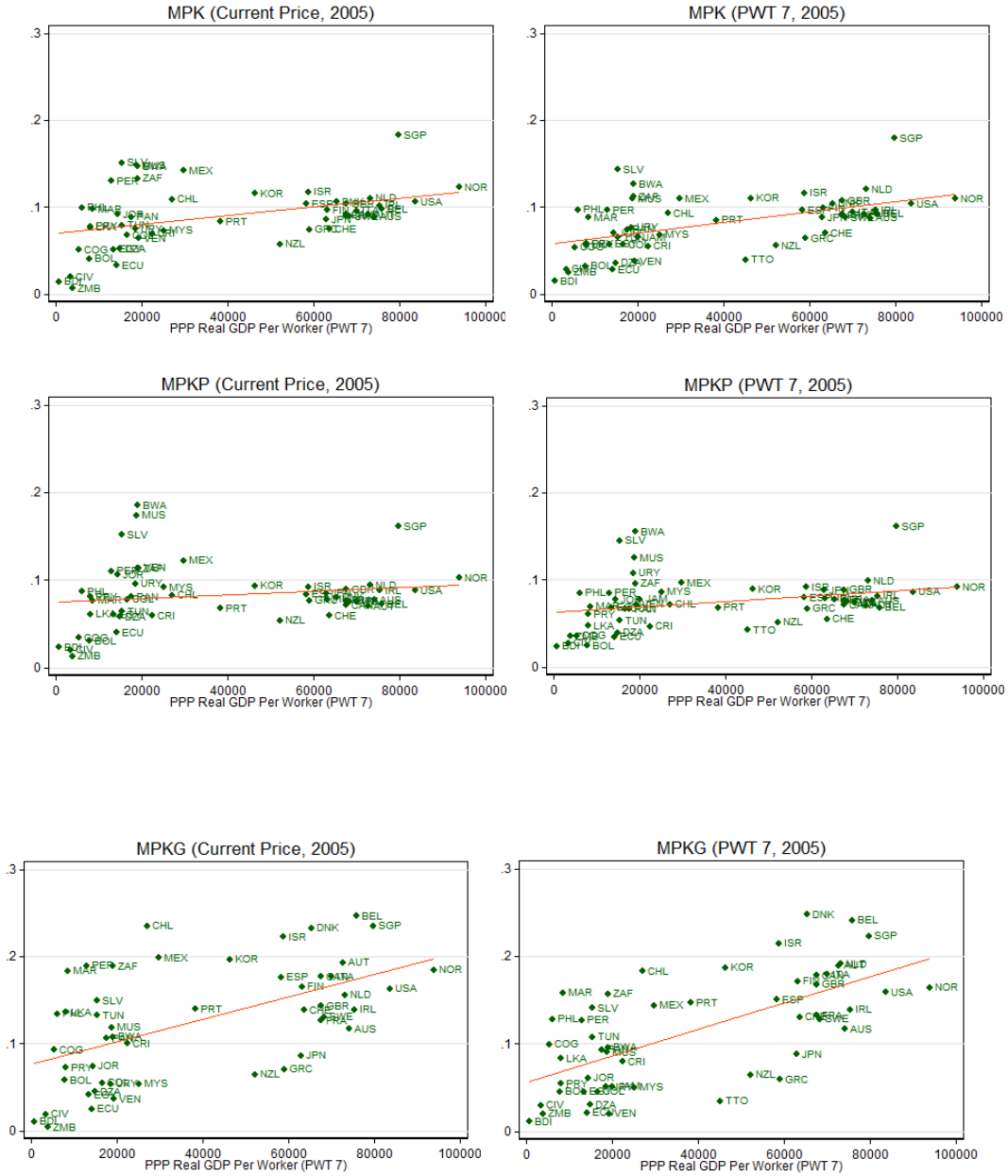
5.3 Using PWT 7.0

As a further robustness check, and to use in subsequent deadweight loss calculations, we re-calculate our measures of the private, public and overall MPK using real investment flows from PWT 7.0. The MPK measures are constructed exactly as before except for these differences: (i) Y is constant price PPP-converted GDP;[25] (ii) the price-adjustment is done by multiplying by the relative price of final goods to investment goods;[26] and (iii) the capital stock measures used are *real* measures – the perpetual inventory method is applied to PWT 7.0 investment flows[27] without needing to adjust using the investment deflator.

We show graphs here comparing MPK schedules in 2005 using PWT and current price data. The year 2005 is used to correspond with the most recent ICP reference year. The PWT 7.0 data permits two additions to the sample – Jamaica and Trinidad and Tobago. The graphs show

[25] Calculated as rgdpl*pop (using PWT 7 variable names).
[26] Which is p/pi in PWT 7.
[27] Calculated as rgdpl*pop*ki/100, then disaggregated into private and public using WEO investment share data.

no obvious differences when using the real measures, though the fitted line for the private MPK schedule using PWT data is positive and significant at 5 percent.



5.4 Deadweight Loss Calculations

Until now we have looked only at the standard deviation of the MPK as a proxy for the efficiency loss from capital misallocation. A more direct measure is the deadweight loss, which we define here,

as in CF, as

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

where Y_i^* is counterfactual GDP with capital (public, private or overall) efficiently allocated. The greatest asset of this measure here is that we can start to quantify the relative losses from public versus private capital misallocation. The calculations extend the approach of CF to account for complementarity of public and private capital in the production function.

We abstract from changes in aggregate capital and assume Cobb-Douglas technology. Each country i has production function,

$$Y_i = Z_i^{\varphi_i} K_{pi}^{\beta_i} K_{gi}^{\gamma_i} (X_i L_i)^{1-\varphi_i-\beta_i-\gamma_i},$$

where Z_i is natural capital and X_i is a measure of labour-augmenting technology. Profit-maximization and price-taking ensure that the following conditions hold for each country i:

$$\begin{aligned}
\frac{P_i}{P_{K_p}} \beta_i Z_i^{\varphi_i} K_{pi}^{\beta_i - 1} K_{gi}^{\gamma_i} (X_i L_i)^{1-\varphi_i-\beta_i-\gamma_i} &= MPKP_i, \\
\frac{P_i}{P_{Kg}} \gamma_i Z_i^{\varphi_i} K_{pi}^{\beta_i} K_{gi}^{\gamma_i - 1} (X_i L_i)^{1-\varphi_i-\beta_i-\gamma_i} &= MPKG_i.
\end{aligned}$$

In the counterfactual case where the returns to private and public capital (separately) are equalised across countries, we have that

$$\begin{aligned}
\frac{P_i}{P_{K_p}} \beta_i Z_i^{\varphi_i} (K_{pi}^*)^{\beta_i - 1} K_{gi}^{\gamma_i} (X_i L_i)^{1-\varphi_i-\beta_i-\gamma_i} &= MPKP^*, \\
\frac{P_i}{P_{Kg}} \gamma_i Z_i^{\varphi_i} K_{pi}^{\beta_i} (K_{gi}^*)^{\gamma_i - 1} (X_i L_i)^{1-\varphi_i-\beta_i-\gamma_i} &= MPKG^*.
\end{aligned}$$

These conditions can be manipulated to show that the counterfactual capital stocks can be calculated as

$$\begin{aligned}
K_{pi}^* &= \left(\frac{MPKP_i}{MPKP^*} \right)^{\frac{1}{1-\beta_i}} K_{pi}, \\
K_{gi}^* &= \left(\frac{MPKG_i}{MPKG^*} \right)^{\frac{1}{1-\gamma_i}} K_{gi}.
\end{aligned}$$

$MPKP^*$and $MPKG^*$ are however unknown. To solve for these, we require an additional resource constraint – we impose that the aggregate counterfactual private/public capital stock is equal to the existing aggregate stocks:

$$\begin{aligned}\sum K_{pi}^* &= \sum K_{pi} = \sum \left(\frac{MPKP_i}{MPKP^*}\right)^{\frac{1}{1-\beta_i}} K_{pi}, \\ \sum K_{gi}^* &= \sum K_{gi} = \sum \left(\frac{MPKG_i}{MPKG^*}\right)^{\frac{1}{1-\gamma_i}} K_{gi}.\end{aligned}$$

We solve for $MPKP^*$ and $MPKG^*$ to an accuracy of four significant figures. Once we know the counterfactual equalised MPKs, it is straightforward to find counterfactual capital stocks country-by-country. Counterfactual income with private capital efficiently allocated is then simply

$$Y_i^* = Y_i \left(\frac{K_{pi}^*}{K_{pi}}\right)^{\beta_i},$$

or with efficient allocation of public capital it is

$$Y_i^* = Y_i \left(\frac{K_{gi}^*}{K_{gi}}\right)^{\gamma_i}.$$

The deadweight loss measure is then calculated as the overall percentage increase in income from capital reallocation. Since the calculations in this section require comparable capital measures across countries, we revert to our real capital measures using PWT 7.0 data, rather than the current price local currency measures used for our preferred measures of the MPK. To be consistent, we also utilize the MPK measures derived from PWT data.

Recalling that CF find the deadweight loss to be 0.1 percent of income in 1996 using PWT 6.1 data, we find a comparable result using our approach to capital stock construction (which differs slightly to CF in its initial conditions and depreciation rates assumed) – we find the deadweight loss to be 0.054 percent of GDP. Using the latest PWT 7.0 data on the same country sample however, we find the deadweight loss for the same year to be 0.31 percent of income – the update to the data itself yields an update to the deadweight loss.

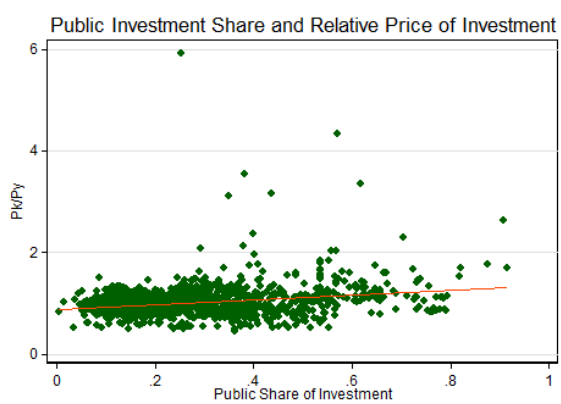
Our interest is more in finding the deadweight loss by sector, for two reasons. Firstly, the figure of 0.1 percent (or 0.31 percent) could understate the actual deadweight loss if public and private capital are complements in the production function – the simplest intuition is that a completely flat overall MPK schedule (deadweight loss of zero) could conceal an upward-sloping public MPK

offset by a downward-sloping private MPK (positive deadweight loss in each sector). Secondly, we are interested in quantifying the difference in efficiency losses between the sectors.

The calculations confirm our priors. In 2005, using PWT 7.0 data, the overall deadweight loss is again 0.31 percent. Once we disaggregate capital, we find the deadweight loss in the private sector (assuming the allocation of public capital unchanged) to be only 0.12 percent, whilst the loss from public capital misallocation is 0.54 percent, almost five times greater. In addition, to be most comparable with the idea of an 'overall deadweight loss', we calculate the overall gain to income of first re-allocating private capital efficiently, and then re-allocating public capital efficiently (given the new incomes and $MPKG$s implied by the re-allocation of private capital). The overall gain is 0.67 percent – over twice as much as the estimate found when considering aggregate capital.[28]

5.5 Price Disaggregation

One issue with the baseline analysis is that we implicitly assume (by using a common investment deflator) the price of public and private investment to be equal. This is a sensible first approach since there does not exist investment deflator data disaggregated by sector (public and private). One simple check on this assumption is to plot the public share of investment against the relative price of investment from PWT. A positive association may imply that the public sector pays more for investment goods than the private sector (though this would not be the only explanation). If there is no correlation, the assumption of a common price of investment seems more reasonable. For the sample of fifty, the plot is shown below (where we use data in all time periods):



[28] This is in fact a lower bound on the deadweight loss since there would be further 'second-order' gains from iterating and continuing to re-allocate private and public capital optimally until both are efficiently allocated though a brief attempt at re-optimisation suggests that these 'second-order' gains are small.

Clearly there are a handful of outliers, but the mass of points does show a positive association, and the fitted line is positive and significant at 1 percent. The relative price of investment tends to be higher in countries/years where the public sector share in total investment is higher. This is not conclusive (it can be shown that this association could still be consistent with the price of private investment being higher than that of public investment), but it suggests exploration of the robustness of our results to different assumptions on prices.

One robustness check we can try is to split the price ourselves, using some proxy for the relative price of public to private investment goods. This may affect our baseline results to the extent that, for example, the public sector in developing countries pays more for investment goods relative to the private sector.

A first effort at this is to assume that $P_{k_p}/P_{k_g}$is proxied well by P_C/P_G (the relative price of consumption to government consumption, from PWT 7.0). In principle we would like to know that these two are highly correlated – but it is not obvious how to do this given that P_{k_p}/P_{k_g} is not observed. Still, the intuition would be that the same behaviour driving the public/private consumption price differences drives investment price differences.

Recall that our MPK measures are

$$MPKP = \beta \frac{P_y Y}{P_k K_p}; \qquad MPKG = \gamma \frac{P_y Y}{P_k K_g}.$$

Define $a = \frac{I_p}{I}$, the *real* share of private investment in total investment. The adjustment we want to make is $MPKP' = MPKP * \frac{P_k}{P_{k_p}}$ and $MPKG' = MPKG * \frac{P_k}{P_{k_g}}$, where

$$\begin{aligned} \frac{P_k}{P_{k_p}} &= \frac{P_G}{P_C}\frac{P_k}{P_{k_g}} = \frac{P_G}{P_C}\frac{aP_{k_p} + (1-a)P_{k_g}}{P_{k_g}} \\ &= a + (1-a)\frac{P_G}{P_C}. \end{aligned}$$

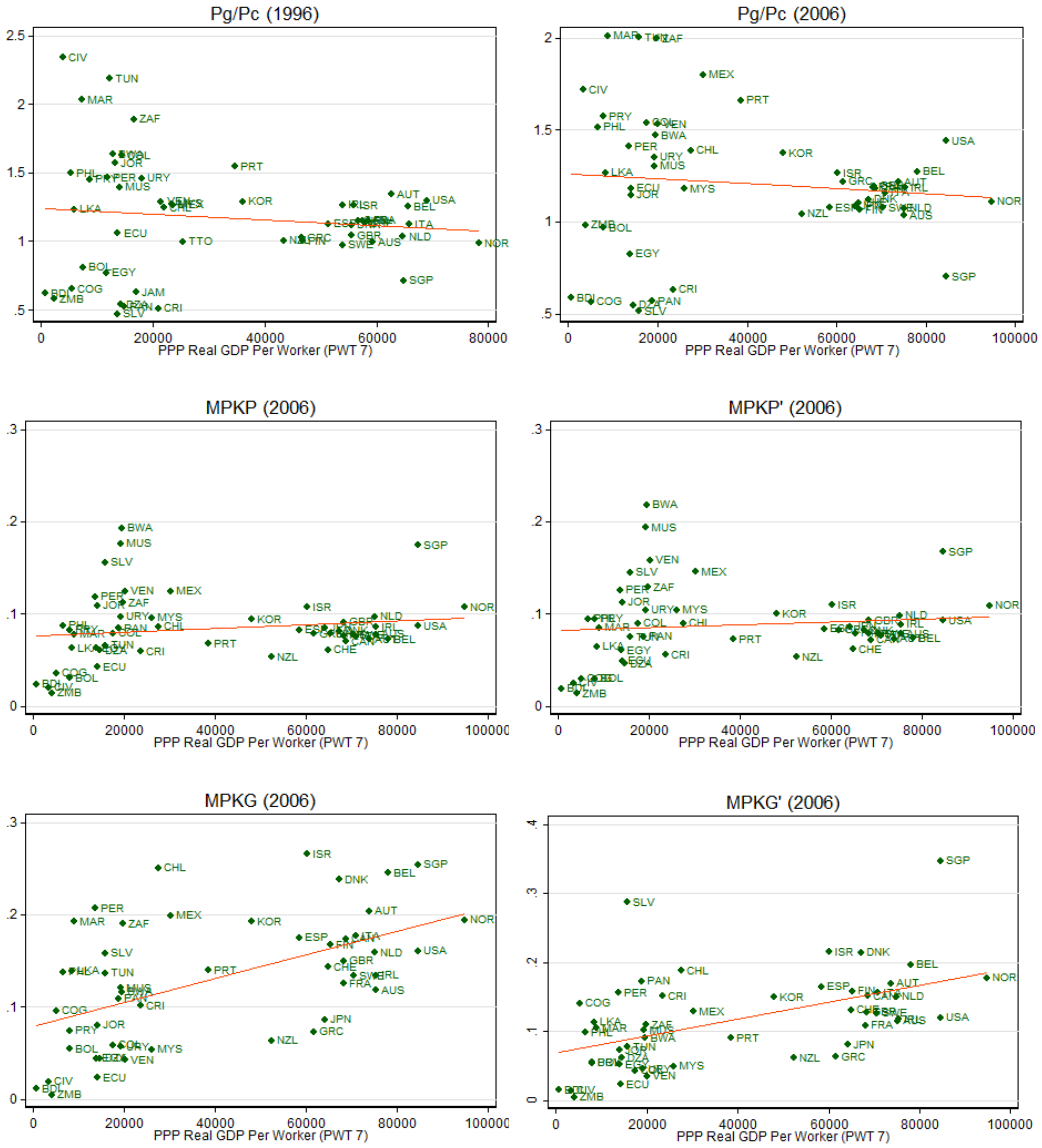
By similar rearranging,

$$\frac{P_k}{P_{kg}} = a\frac{P_C}{P_G} + 1 - a.$$

Therefore, the adjustment to make is

$$\begin{aligned} MPKP' &= MPKP * \left(a + (1-a)\frac{P_G}{P_C}\right), \\ MPKG' &= MPKG * \left(a\frac{P_C}{P_G} + (1-a)\right). \end{aligned}$$

This shows clearly that the adjustment depends on both the private:public consumption price ratio, as well as the private share in investment. Whilst a is not observed, we have WEO data on the private investment share of overall investment as the best approximation. The graphs below show the relative consumption price data and the result of the adjustment in 1996 and 2006.



Briefly, if anything, P_G/P_C is downward-sloping – suggesting that the prices spent on consumption by governments in poor countries are relatively higher. Applying this to investment prices, the implication is that our results our even stronger – the public MPK is even lower in poor countries

because we have so far been understating the price of investment goods by using the common deflator. Having said that, the adjusted MPKs are not much changed visually.[29] The fitted lines are as before – insignificant for MPKP', positive and significant for MPKG'.

6 Conclusion

In their influential work Caselli and Feyrer (2007) deliver an intriguing result: after appropriately adjusting the share and relative price of capital, the overall MPK is shown to be broadly the same across a large group of advanced and developing economies, casting doubt on the international capital frictions explanation of the Lucas Paradox. Motivated by the extensively documented and remarkable differences between public and private sector incentives, especially in developing countries, we have attempted in this paper to unpack the overall MPK into its public and private components.

First, we have used the most recent data from WDI, WEO and PWT 7.0, and consistent with recent independent work by Francesco Caselli, we have shown that the cross country schedule of the total MPK is not only flat but rather rather somewhat positively (and significantly) sloped. Second and most important, we have shown that the main driver of the overall MPK schedule is the strongly positively sloped public MPK in developing countries, whilst the private MPK is found to be flat. This surprising finding is subsequently explored by three extensions and a thorough robustness analysis.

In particular, we extended the analysis to incorporate a recently developed index of public investment management inefficiency in our measurement of public capital. While our application of this index is certainly not ideal, modifying public capital for public investment inefficiencies is hugely important as originally argued by Pritchett (2000). Whilst the adjustment suggests a flat public MPK, we show that the measure of interest, the marginal product of investment, is still proxied well by the unadjusted MPK, provided public investment efficiency is roughly constant. We also examine the effects of public and private capital in the context of a three-sector neoclassical growth model. The model is useful as a first attempt to build structure that incorporates differential MPKs and in understanding the causes of an upward sloping public MPK.

A large number of detailed and thorough robustness tests to the various assumptions made in the construction of public and private MPK have shown that our baseline findings are robust.

[29] Note: the graph for MPKG' has a different scale, up to 0.4, to include Singapore.

Whilst we encourage further work on robustness, extending the sample and improving the quality of the estimates, we have shown clearly that aggregate estimates can provide a very good start in this line of research and that existing aggregate datasets are adequate for taking on the task. Still, such aggregate estimates should be compared against micro evidence which are as crucially important in understanding the pattern of capital flows.

Our findings lend a new set of explanations to the Lucas Paradox, placing public sector idiosyncrasies center stage. The data supports our intuition – public agents act differently to private agents in the context of investment decisions. The result is a vastly different cross-country variation in the marginal product of capital across the two sectors. Our interpretation has emphasized the possibility of overinvestment by governments in developing countries facing few checks and balances and driven by an electoral motive. In contrast, the data points toward *under*investment in advanced economies – perhaps because of greater political pressure for a laissez-faire approach or due to inreasing private participation in typically public investment ventures. Still, the interpretation we suggest should be further explored.

Taking these claims seriously, there are clearly implications for the role of foreign aid in building capital stocks. Importantly, donors should have realistic expectations and reject the notion that aid (for investment) will have high returns purely because of a chronic lack of capital in low income countries. Our results suggest that returns to public investment are actually lower in LICs than in advanced economies. This is by no means an argument to reduce aid flows, but suggests the need for a shift in emphasis. In particular, there is renewed impetus for 'investing in investing' (to use the terms of Collier (2010)) – channeling aid towards institutional reforms in order to bring down the high relative cost of capital and to raise public investment efficiency. In some sense this is akin to "Big Push" arguments for aid, whilst remaining within the confines of the neoclassical framework.

Beyond this, our approach suggests a refinement of the outlook on aid presented in Caselli and Feyrer (2007). CF presented a skeptical view on aid, concluding that greater flows of aid would only be displaced by capital outflows, given the flat MPK. Our disaggregation brings an alternative view. Based on our findings, the provision of foreign aid is not strongly growth enhancing but could rather facilitate inefficient overinvestment by the public sector, since aid is less accountable to returns than private sources of finance. However, given imperfect substitutability between private and public capital in the production function, this overinvestment leads not to capital outflows, but *inflows* of

private capital, since the greater stock of public capital raises the returns to private capital.

We started out on this research with one particular prior: that with careful measurement, the financial return to public capital would be found to be relatively high in developing countries reflecting the large needs in education and infrastructure, to name a few. We were stunningly wrong. It may be fitting to close with a story of Tanzania's ability to attract foreign capital. Taking a walk in the busy streets of Dar es Salaam, the capital city, one is impressed by the vibrant private economic activity, entrepreneurship and the many bank branches (local and multinational) scattered across town. One gets the favorable impression that, although at embryonic stages, the private sector operates under close proximity to "market" conditions. A look at public goods (e.g. rail roads and ports) and the provision of public services (e.g. power generation) signals clear deficiencies. Experts correctly insist on the major progress, including in the public sector, that Tanzania has been through over the last two decades as captured by the country's seven percent average GDP growth. But by all accounts this progress is not sustainable unless capital starts to flow inwards from abroad. This paper points to public sector frictions rather than financial frictions or complementarities to low human capital or TFP as the key constraint to enhancing the MPK and with it, accelerating international capital inflows.

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