WP/14/73

IMF Working Paper

Public Investment, Public Finance, and Growth: The Impact of Distortionary Taxation, Recurrent Costs, and Incomplete Appropriability

Christopher Adam and David Bevan

INTERNATIONAL MONETARY FUND

 WP/14/73

IMF Working Paper

Strategy, Policy, and Review Department

Public Investment, Public Finance, and Growth: The Impact of Distortionary Taxation, Recurrent Costs, and Incomplete Appropriability[1]

Prepared by Christopher Adam and David Bevan

Authorized for distribution by Catherine Pattillo and Andrew Berg

April 2014

Abstract

Effective public investment requires governments to address the "recurrent cost problem" to ensure operations and maintenance (O&M) expenditures are sufficient to sustain the flow of productive public capital services to private factors of production. Building on the model of Buffie et al (2012), this paper explores the macroeconomic implications of this recurrent cost problem and its resolution in a context that recognizes that taxation is distortionary. The model is also used to examine stylized fiscal reforms including the replacement of a distortionary output tax with a uniform consumption tax and budgetary reforms that restore O&M expenditures to their efficient levels. These experiments are stylized but clearly demonstrate the material consequences of the tax and public expenditure structures for growth and debt sustainability in low-income countries.

JEL Classification Numbers: E60, E62, O11, O23
Keywords: economic growth; public investment; tax reform; recurrent costs; operations and maintenance

Author's E-Mail Address:christopher.adam@economics.ox.ac.uk

[1] This working paper is part of a research project on macroeconomic policy in low-income countries supported by the U.K.'s Department for International Development. This working paper should not be reported as representing the views of the IMF or of DFID. We are grateful to Andy Berg and Catherine Pattillo for inviting us to participate in the project and to Ed Buffie, Andy Berg, Catherine Pattillo, Rafael Portillo and Luis-Felipe Zanna for sharing the original model code for Buffie et al. (2012). We thank them as well as Steve O'Connell, Andrew Warner and Adrian Peralta for helpful comments on earlier presentations of the paper.

Contents **Page**

1 Introduction

In the last decade, investment in public infrastructure capital has come to be seen as central to any sustained growth strategy in developed and developing countries alike. But an important part of the reality for many low-income countries is that, even as governments and donors prioritize new infrastructure investment projects, the existing public capital stock is degrading more rapidly than it ought to and is contributing less to economic growth than its *ex ante* potential would suggest. Hence closing the 'infrastructure gap' entails more than simply increasing public investment rates. What matters for growth is the sustained flow of productive capital services that the public capital stock provides to private factors of production, which in turn requires that the capital stock is efficiently operated and maintained. Efficient operations and maintenance (O&M) expenditures can be very substantial per dollar of installed capital, and it is very common for actual expenditures to fall well below these efficient levels. Capital accumulation needs to be accompanied by action to address this problem of deficient O&M expenditures. This 'recurrent cost problem' emerges from weaknesses in public budgeting and expenditure implementation systems – themselves often exacerbated by the separation of responsibilities for investment and O&M expenditures – combined with a political economy that results in O&M expenditures being the first to be pared back in times of fiscal pressure, and that favours new capital formation, whether funded by governments or by donors, over the maintenance and operation of the existing capital stocks.The endless list of "rehabilitation" projects for roads and other public infrastructure on the World Bank's loan book bears witness to the tendency for neglected maintenance expenditures to be capitalized through 'new build' projects.[1] [2]

The purpose of this paper is to explore the macroeconomic implications of this recurrent cost problem, in a context recognizing that taxation is distortionary and imposes deadweight burdens on the private sector. In doing so we extend the model developed by Buffie *et al* (2012) to study the macroeconomic and fiscal effects of public investment surges in low-income countries. What turns recurrent costs into a budgetary issue is that, for a substantial share of public investment, it is only possible to recover a part of the ongoing recurrent expenditure requirements for O&M directly from users. This may be due to the intrinsic nature of the public investment, or may reflect

[1] For example, the World Bank's Africa Infrastructure Country Diagnostic (AICD) programme estimate that "...on average, about 30 percent of the infrastructure assets of a typical African country need rehabilitation...[reflecting]...a legacy of underfunding maintenance" (Foster and Briceno-Garmendia, 2010).

[2] There is a substantial and long-standing literature on the recurrent cost problem. An important and fairly early example is Heller (1974). See also Gray and Martens (1983), who may have coined the phrase. Rioja (2003) provides a theoretical treatment of the problem of maintenance expenditures, while Sunderland's (2007) history of the British 'Crown Agents' describes how late colonial administrations sought to use sinking funds and the services of the Crown Agents to try to prevent the recurrent cost problem from emerging.

political economy considerations, but in either case it has the consequence that not only does the initial capital cost of any additional investment have to be financed, but also much of the ongoing increase in recurrent spending. While some share of public investment may be financed by grants and concessional debt, at the margin, fiscal balance is satisfied by some mixture of non-concessional external borrowing, domestic borrowing, adjustment to taxes, and, possibly, economizing on O&M expenditures. Domestic taxation is distortionary and exerts a deadweight loss; in other words, raising a dollar of government revenue imposes more than a dollar of cost on the private sector. Estimates of the size of this excess burden relative to the revenue generated vary widely, but values in the range 20%-50% are common, so the 'marginal cost of public funds' (MCF) might be in the range 1.2-1.5 (see for example Auriol and Warlters, (2012). In the Buffie *et al* model, all tax revenue is raised from a uniform consumption tax, and labour is supplied inelastically. In these circumstances, the tax operates like a lump sum tax and is non-distortionary provided the tax rate is constant. If the tax rate changes over time, there is a distortion to inter-temporal consumption choices, but this is second order.

In a more disaggregated setting, distortionary taxation could arise from a tax structure with a variety of different tax rates and tax bases, coupled with widespread exemptions. However, the present model is highly aggregated, and the simplest device to represent distortionary structures is to replace the consumption tax with a uniform output tax, or equivalently an income tax where labour and capital incomes are taxed at the same rate. This is the approach followed, for example, by Barro (1990) and Barro and Sala-i-Matin (1992), and is the procedure adopted here.[3] Since an output tax is a proxy for the more complicated structures that give rise to distortions in practice, it is natural to wonder what level of MCF it might imply. For the calibration values in the base case of Table 1 below, the MCF imposed by an output tax at the rate of 17% would be the relatively low value of 1.13. However, the MCF schedule rises steeply for higher tax rates.[4] At a rate of 30%, for example, it would be 1.76. For the consumption tax, of course, the MCF is exactly 1 for all

[3] In other work we disaggregate the tax system to allow for consumption taxes to vary across goods and to introduce separate taxation of labour and capital income.

[4] One reason for the relatively low MCF in our treatment is that the tax system converts revenue collections from firms and households dollar-for-dollar into government revenue. An alternative, considered by Berg *et al* (2014) amongst others, is to assume some 'transmission loss' in the process of remitting tax collections to government, such that the MCF for distortionary taxes would increase for any given level of government revenue collection. This transmission loss could be treated as a pure loss (an 'iceberg' technology) or as a lump-sum transfer of rents back to households. This mechanism may be important for country-specific calibrations of the model but does not add specific insights in the context of the stylized calibration used here.

values of the tax rate.[5] In this paper all the simulations are duplicated for the two polar cases of pure consumption and output taxation.[6]

To illustrate the recurrent cost problem and how it interacts with the tax regime and debt financing decisions, we simulate the model under a range of configurations. Our benchmark policy experiment consists of a permanent increase in the rate of public investment, from 6 percent to 9 percent of GDP per annum. The first set of experiments establishes the macroeconomic properties of the model economy under alternative characterizations of the tax regime – the polar cases of a consumption tax and a uniform output tax – and where public investment and O&M provision may fall short of their fully efficient levels. The second set of experiments explores the macroeconomic consequences of fiscal reforms, including both a tax reform entailing the replacement of the output tax with a uniform consumption tax and budgetary reforms that see previously deficient O&M expenditures increased to their efficient levels. We examine these reforms in isolation and in the context of a public investment surge.

These initial experiments are conducted holding borrowing, both domestic and external, concessional and non-concessional, on its initial steady-state trajectory, allowing us to focus on the comparative steady-state properties of the economy under broadly comparable debt burdens. In the final set of simulations we turn our attention to the dynamic behaviour of the economy under alternative debt-financing strategies.

Although these experiments are stylized and are based on a representative rather than country-specific calibration of the model they clearly demonstrate the material consequences of the tax and public expenditure structures for growth and debt sustainability in low-income countries and the potentially large social returns to fiscal reforms and to the institutional arrangements for the budgeting and implementation of O&M expenditures.

Since this paper is focused on modifications to a well-articulated existing model, it is necessary to begin by summarizing the existing model, and this is done in the next section. Section 3 then introduces the two model extensions. The output tax needs only a brief discussion, since the alteration to the model equations is minimal, though the consequences are profound. The section then moves on to consider operations and maintenance expenditures and how they are inserted into the model, which requires a much more extended discussion. Section 4 discusses calibration issues which the model extension needs to resolve, and the issue of the feasibility of investment surges, given fiscal constraints. Section 5 presents the simulation results from the perspective of

[5]Values of the MCF are computed within the model by making a very small increase in the tax rate from the initial calibrated value, reducing the (lump-sum) transfer sufficiently to maintain budget balance, and re-solving the model. Then the ratio of the amount of the reduction in total private disposable income to the increased amount of tax revenue gives the MCF.

[6]It would be straightforward to run a mixture of the two, but it seems better to highlight the polar cases.

comparative statics, both for investment surges and the various policy reforms. Section 6 looks at dynamic perspectives, and section 7 concludes.

2 A stripped-down version of the Buffie et al model

The framework utilized by Buffie *et al* is the standard two-sector model of a small open economy, where the country produces a traded good q_x and a non-traded good q_n from private capital k, labour L, and government-supplied infrastructure z. In addition to these domestically produced goods, agents can import a traded good for consumption c_m and machines m_m which can be combined with the non-traded good to produce factories (private capital) and infrastructure (public capital). All quantity variables except labour are detrended by $(1+g)^t$, where g is the exogenous long-run growth rate of real GDP. The model abstracts from money and all nominal rigidities, but includes taxation (a uniform consumption tax) and a lump-sum transfer from government to private agents, as well as grants, remittances and a variety of forms of public and private debt.

Since the present paper extends this model, it is helpful first to summarize it. However, it has a number of features which are neglected here. These include two types of sector-specific externalities in production, adjustment costs incurred in changing the private capital stock, portfolio adjustment costs associated with foreign liabilities, absorptive capacity constraints associated with public investment, and also provision for natural resource rents. Shorn of these elaborations, the stripped-down model is summarized in the rest of this section, starting with the specification of technology.

2.1 Firms

2.1.1 Technology

In each sector $j = n, x$, the representative firm uses a Cobb-Douglas technology to convert labour $L_{j,t}$, private capital $k_{j,t-1}$, and "effectively productive" infrastructure z^e_{t-1}, which is a public good, into output:

$$q_{x,t} = a_x (z^e_{t-1})^{\psi_x} (k_{x,t-1})^{\alpha_x} (L_{x,t})^{1-\alpha_x} \tag{2.1}$$

$$q_{n,t} = a_n (z^e_{t-1})^{\psi_n} (k_{n,t-1})^{\alpha_n} (L_{n,t})^{1-\alpha_n} \tag{2.2}$$

where the a_j are sector-specific productivities.

Factories and infrastructure are built by combining imported machines and a non-traded input (e.g., construction) in fixed proportions, determined by a_k and a_z respectively.[7] The supply prices of private capital and infrastructure are thus:

$$P_{k,t} = (1 - a_k)P_{m,t} + a_k P_{n,t} \tag{2.3}$$

$$P_{z,t} = (1 - a_z)P_{m,t} + a_z P_{n,t} \tag{2.4}$$

where P_n is the (relative) price of the non-traded good and P_m is the (relative) price of imported machinery.

2.1.2 Factor demands

Competitive profit-maximizing firms equate the marginal value product of each input to its factor price. This yields the input demand equations:

$$P_{n,t}(1 - \alpha_n)\frac{q_{n,t}}{L_{n,t}} = w_t \tag{2.5}$$

$$P_{x,t}(1 - \alpha_x)\frac{q_{x,t}}{L_{x,t}} = w_t \tag{2.6}$$

$$P_{n,t}\alpha_n \frac{q_{n,t}}{k_{n,t-1}} = r_{n,t} \tag{2.7}$$

$$P_{x,t}\alpha_x \frac{q_{x,t}}{k_{x,t-1}} = r_{x,t} \tag{2.8}$$

where w is the wage and r_j is the rental earned by capital in sector j. Labour is intersectorally mobile, so the same wage appears in (2.5) and (2.6). Capital is sector-specific, and in the presence of adjustment costs r_x may differ from r_n along the transition path. After adjustment is complete and k_x and k_n have settled at their equilibrium levels, the rentals are equal. When adjustment costs are suppressed, as here, the rentals are equal even during the transition.

[7] The approach in Buffie *et al* is slightly different from this, and has the consequence that these supply prices are not equal to 1 at calibration, as ensured by the present procedure. There are no material consequences of this change.

2.2 Consumers

There are two types of private agents, savers and non-savers, with the former and the latter distinguished by the superscripts s and h respectively. Labour supply of savers is fixed at L^s while that of non-savers is $L^h = aL^s$ with $a > 0$. The two types of agent consume the domestic traded good $c^i_{x,t}$, the foreign traded good $c^i_{m,t}$, and the domestic non-traded good $c^i_{n,t}$ for $i = s, h$. These goods are combined into a CES basket:

$$c^i_t = \left[\rho_x^{\frac{1}{\epsilon}}(c^i_{x,t})^{\frac{\epsilon-1}{\epsilon}} + \rho_m^{\frac{1}{\epsilon}}(c^i_{m,t})^{\frac{\epsilon-1}{\epsilon}} + \rho_n^{\frac{1}{\epsilon}}(c^i_{n,t})^{\frac{\epsilon-1}{\epsilon}}\right]^{\frac{\epsilon}{\epsilon-1}} \tag{2.9}$$

for $i = s, h$ where ρ_x, ρ_m, and ρ_n are CES distribution parameters with $\rho_x + \rho_m + \rho_n = 1$, and ϵ is the intra-temporal elasticity of substitution.

The (relative) CPI associated with the basket (2.9) is:

$$P_t = \left[\rho_x P_{x,t}^{1-\epsilon} + \rho_m P_{m,t}^{1-\epsilon} + \rho_n P_{n,t}^{1-\epsilon}\right]^{\frac{1}{1-\epsilon}}$$

while the demand functions for each good can be expressed as:

$$c^i_{j,t} = \rho_j \left(\frac{P_{j,t}}{P_t}\right)^{-\epsilon} c^i_t$$

for $j = x, m, n$ and $i = s, h$.

Savers can invest quantities i_x and i_n in private capital that depreciates at the rate δ, pay user fees charged for infrastructure services according to μz^e, can buy domestic bonds b - which cannot be bought in any market by foreigners - and face a real interest rate r.[8] They solve the inter-temporal problem:

$$Max \sum_{t=0}^{\infty} \beta^t \frac{(c^s_t)^{1-1/\tau}}{1-1/\tau}$$

subject to:

$$\begin{aligned} b^s_t &= r_{x,t}k^s_{x,t-1} + r_{n,t}k^s_{n,t-1} + w_t L^s_t + \frac{R_t}{1+a} + \frac{T_t}{1+a} \\ &+1 + r_{t-1}b^s_{t-1} - P_{k,t}\left(i^s_{x,t} + i^s_{n,t}\right) - P_t c^s_t(1+h_t) - \mu z^e_{t-1} \end{aligned} \tag{2.10}$$

$$(1+g)k^s_{x,t} = i^s_{x,t} + (1-\delta)k^s_{x,t-1} \tag{2.11}$$

and:

$$(1+g)k^s_{n,t} = i^s_{n,t} + (1-\delta)k^s_{n,t-1} \tag{2.12}$$

[8] The full model also permits them to contract foreign debt, but this feature is suppressed here.

where $\beta = 1/\left[(1+\varrho)(1+g)^{(1-\tau)/\tau}\right]$ is the discount factor; ϱ is the pure time preference rate; τ is the inter-temporal elasticity of substitution; δ is the depreciation rate; R are remittances; T are (net) government transfers; h denotes the consumption value added tax (VAT). Remittances and transfers are proportional to the agent's share in aggregate employment. Observe that the trend growth rate appears in each of (2.10), (2.11), and (2.12), reflecting the fact that some variables are dated at t and others at $t-1$.[9]

The choice variables in the optimization problem are:

$$c_t^s = c_{t+1}^s \left(\beta \frac{1+r_t}{1+g} \frac{P_t}{P_{t+1}} \frac{1+h_t}{1+h_{t+1}}\right)^{-\tau} \tag{2.13}$$

$$\frac{r_{x,t+1}}{P_{k,t+1}} + 1 - \delta = (1+r_t)\frac{P_{k,t}}{P_{k,t+1}} \tag{2.14}$$

$$\frac{r_{n,t+1}}{P_{k,t+1}} + 1 - \delta = (1+r_t)\frac{P_{k,t}}{P_{k,t+1}} \tag{2.15}$$

Equation (2.13) is an Euler equation in which the slope of the consumption path depends on the interest rate adjusted for trend growth and on changes in the VAT. The other two equations are arbitrage conditions, requiring the rate of return on capital in each sector to equal the interest rate.

Non-savers have the same utility function as that of savers and consume all of their income from wages, remittances, and transfers each period. The non-saver's budget constraint then reads:

$$(1+h_t)P_t c_t^h = w_t L^h + \frac{a}{1+a}(R_t + T_t) \tag{2.16}$$

These hand-to-mouth consumers are a realistic feature of the model and their inclusion breaks Ricardian equivalence.

Households are aggregated over $i = s, h$, so that $x_t = x_t^s + x_t^h$ for $x_t = c_t, c_{l,t}, L_t, b_t, i_{j,t}, k_{j,t}$, and the sub-indices $l = x, n, m$ and $j = x, n$. Note that $b_t^h = i_{j,t}^h = k_{j,t}^h = 0$ for $j = x, n$.

[9] In Buffie *et al*, the domestic bond is indexed to the (relative) price level. However, this is a very ambiguous concept, and the bonds are treated here as un-indexed.

2.3 The Government

2.3.1 Infrastructure, public investment and efficiency

The model allows for inefficiencies in public capital creation. Public investment i_z produces additional infrastructure z according to:

$$(1+g)z_t = (1-\delta)z_{t-1} + i_{z,t} \tag{2.17}$$

but some of the newly built infrastructure may not be economically valuable, since effectively productive capital z_t^e, which is actually used in technologies (2.1) and (2.2), evolves according to :

$$z_t^e = \bar{s}\bar{z} + s(z_t - \bar{z}) \tag{2.18}$$

where $\bar{s}, s \in [0,1]$ are parameters of efficiency at and off steady state, and $\bar{z}$ is public capital at the (initial) steady state.

Combining equations (2.17) and (2.18) yields:

$$(1+g)z_t^e = (1-\delta)z_{t-1}^e + s(i_{z,t} - \bar{i_z}) + \bar{s}\bar{i_z} \tag{2.19}$$

where $i_z = (\delta + g)\bar{z}$ is public investment at the (initial) steady state. When $s < 1$, this specification makes clear that one dollar of additional public investment $(i_{z,t} - \bar{i_z})$ does not translate into one dollar of effectively productive capital (z_t^e). Citing empirical estimates, the core simulations reported in Buffie et al set $s = \bar{s} = 0.6$, and the same assumption is adopted here.

2.3.2 Fiscal adjustment and the public sector budget constraint

The government spends on transfers, debt service, and infrastructure investment. It collects revenue from the consumption VAT and from user fees for infrastructure services, expressed as a fixed fraction of recurrent costs, which are restricted to depreciation of effective capital at initial prices, that is $\mu = f\delta P_{z0}$. When revenues fall short of expenditures, the resulting deficit is financed through domestic borrowing $\Delta b_t = b_t - b_{t-1}$, external concessional borrowing $\Delta d_t = d_t - d_{t-1}$, or external commercial borrowing $\Delta d_{c,t} = d_{c,t} - d_{c,t-1}$. Hence:

$$\begin{aligned}\Delta b_t + \Delta d_{c,t} + \Delta d_t &= \frac{r_{t-1} - g}{1+g} b_{t-1} + \frac{r_{d,t-i} - g}{1+g} d_{t-1} \\ &+ \frac{r_{dc,t-1} - g}{1+g} d_{c,t-1} + P_{z,t} i_{z,t} + T_t - h_t P_t c_t - G_t - \mu z_{t-1}^e\end{aligned} \tag{2.20}$$

where G denotes grants, and r_d and r_{dc} are the real interest rates (in dollars) on concessional and commercial loans. The interest rate on concessional loans is assumed to be constant $r_{d,t} = r_d$, while the interest rate on external commercial debt incorporates a risk premium that depends on the deviations of the external public debt to GDP ratio $ed_t = \frac{d_t + d_{c,t}}{y_t}$ from its (initial) steady state value $\bar{ed} = \frac{\bar{d} + \bar{dc}}{\bar{y}}$, where $y_t = P_{x,t}q_{x,t} + P_{n.t}q_{n,t}$ is GDP. That is,

$$r_{dc,t} = r^f + \upsilon_g e^{\eta_g \left(ed_t - \bar{ed} \right)} \tag{2.21}$$

where r^f is a risk-free world interest rate. If $\upsilon_g > 0$ and $\eta_g = 0$, this specification provides for an exogenous risk premium that does not depend on the level of public debt; if both are positive, the premium is increasing in the external debt to GDP ratio.

Policy makers accept all concessional loans proffered by official creditors. The borrowing and amortization schedule for these loans is fixed exogenously. Given the paths for public investment and concessional borrowing, the fiscal gap before policy adjustment (GAP_t)can be defined as:

$$\begin{gathered} GAP_t = \frac{1 + r_d}{1 + g} d_{t-1} - d_t + \frac{r_{dc,t-1} - g}{1 + g} dc_{t-1} + \frac{r_{t-1} - g}{1 + g} b_{t-1} \\ + P_{z,t} i_{z,t} + T_0 - h_0 P_t c_t - G_t - \mu z^e_{t-1} \end{gathered} \tag{2.22}$$

GAP_t corresponds to expenditures (including interest payments) less revenues and concessional borrowing, when transfers and taxes are kept at their initial levels T_0 and h_0 respectively. Using this definition, the government budget constraint (2.20) can be rewritten as:

$$GAP_t = \Delta b_t + \Delta d_{c,t} + (h_t - h_0) P_t c_t - (T_t - T_0) \tag{2.23}$$

In other words, given the investment programme, in the short- to medium-term, this gap can be covered by some mixture of domestic and external commercial borrowing, tax adjustments, and transfer adjustments.

Debt sustainability requires, however, that the VAT and transfers eventually adjust to cover the entire gap. Policy makers divide the burden of adjustment between transfer cuts and tax increases, setting targets as follows:

$$h_t^{target} = h_0 + (1 - \lambda) \frac{GAP_t}{P_t c_t} \tag{2.24}$$

$$T_t^{target} = T_0 - \lambda GAP_t \tag{2.25}$$

where $0 \leq \lambda \leq 1$ is a policy parameter that splits the fiscal adjustment between taxes and transfers. Given these targets, reaction functions are defined as:

$$h_t = Min\left\{h_t^r, h^u\right\} \tag{2.26}$$

$$T_t = Max\left\{T_t^r, T^l\right\} \tag{2.27}$$

where h^u is a ceiling for taxes, T^l is a floor for transfers, and h_t^r and T_t^r are determined by the fiscal rules:

$$h_t^r = h_{t-1} + \lambda_1(h_t^{target} - h_{t-1}) + \lambda_2 \frac{(x_{t-1} - x^{target})}{y_t} \tag{2.28}$$

$$T_t^r = T_{t-1} + \lambda_3(T_t^{target} - T_{t-1}) - \lambda_4(x_{t-1} - x_t^{target}) \tag{2.29}$$

with $\lambda_1, \lambda_2, \lambda_3, \lambda_4 > 0$ and $x = b$ or d_c, depending on whether the rules respond to domestic or external commercial debt. The target for debt x^{target} is given exogenously.

Given the targets, the reaction functions defined in (2.26) - (2.29) together with the budget constraint (2.23) reflect the fact that rapid fiscal adjustment is painful. Tax increases or expenditure cuts must be phased in gradually ($\lambda_1 > 0$, $\lambda_3 > 0$). On the other hand, policy responds to the debt overruns that this may induce ($\lambda_3 > 0$, $\lambda_4 > 0$).

2.4 Market-clearing conditions and external debt accumulation

Flexible wages and prices ensure that demand continuously equals supply in the labour market:

$$L_x + L_n = L \tag{2.30}$$

where the labour supply $L = L^s + L^h$ is fixed.

Aggregating over both types of consumers, and taking into account private and public investment, the demand for non-tradables is:

$$q_{n,t} = \rho_n \left(\frac{P_{n,t}}{P_t}\right)^{-\epsilon} c_t + a_k(i_{x,t} + i_{n,t}) + a_z i_{z,t} \tag{2.31}$$

Finally, consolidating public and private sector budget constraints yields the accounting identity that growth in the country's net foreign debt equals the difference between national spending and national income:

$$d_t - d_{t-1} + d_{c,t} - d_{c,t-1} = \frac{r_d - g}{1+g} d_{t-1} + \frac{r_{dc,t-1} - g}{1+g} d_{c,t-1}$$
$$+ P_{z,t} i_{z,t} + P_{k,t}(i_{x,t} + i_{n,t}) + P_t c_t - P_{n,t} q_{n,t} - P_{x,t} q_{x,t} - R_t - G_t \tag{2.32}$$

3 Introducing output taxation and operations and maintenance expenditures

3.1 Output taxation

Private and public budget constraints, and the fiscal adjustment rules, need to be adjusted for the switch in tax instrument, but in very obvious ways. More significant is the impact on factor demands. Firms still equate the (private) marginal value product of each input to its factor price. However, the output tax, designated by the rate θ, drives a wedge between the private and social values:

$$P_{n,t}(1-\alpha_n)\frac{q_{n,t}}{L_{n,t}}(1-\theta_t) = w_t \tag{3.1}$$

$$P_{x,t}(1-\alpha_x)\frac{q_{x,t}}{L_{x,t}}(1-\theta_t) = w_t \tag{3.2}$$

$$P_{n,t}\alpha_n\frac{q_{n,t}}{k_{n,t-1}}(1-\theta_t) = r_{n,t} \tag{3.3}$$

$$P_{x,t}\alpha_x\frac{q_{x,t}}{k_{x,t-1}}(1-\theta_t) = r_{x,t} \tag{3.4}$$

The real wage is substantially reduced, but consumer purchases from this reduced wage no longer attract consumption tax. There are no consequences for labour supply, since that is fixed. The situation is very different for private capital, however. For given steady state r, determined in the model by savers' preference parameters over the infinite horizon, and unaffected by the switch in tax instrument, the output capital ratio must rise by $1/(1-\theta)$, which requires a sharp fall in private capital stocks relative to what would have been held under a consumption tax. This implies a substantial reduction in GDP and in consumption.

3.2 Operations and maintenance expenditures

Apart from the use of resources and the need to finance this, operations and maintenance expenditures affect the model in two ways. Deficient maintenance expenditure leads to an increase in the rate at which the public capital stock depreciates through time while deficient operations expenditure reduces the flow of output produced by the current stock of public capital. Both effects can be temporary: a return to 'full' maintenance and operations expenditures restores the (technical minimum) depreciation rate and the full flow of output respectively.[10]

We distinguish between three different notions of public capital: notional capital (z); installed capital (z^i); and effective (or effectively productive) capital (z^e). The distinction between notional and installed capital mirrors Buffie *et al*, with inefficiencies in public capital formation meaning that one unit of notional capital investment generates $s \leq 1$ units of installed capital. Hence $z^i = s.z$.[11]

Installed capital depreciates at a rate determined by the level of maintenance expenditure. The depreciation rate (of installed capital) is defined as

$$\delta_z^i = \delta_z \left[1 + (1 - \gamma_m)\beta_\delta\right] \tag{3.5}$$

where $0 < \gamma_m \leq 1$ is the ratio of actual to efficient maintenance expenditure and $\beta_\delta \geq 0$ is a measure of excess depreciation. Thus the rate of depreciation is bounded between δ_z when maintenance is at its efficient level and $\delta_z(1 + \beta_\delta)$ when maintenance is neglected entirely. The accelerated loss of installed capital during a period when maintenance is inadequate is permanent; however, if maintenance expenditure is subsequently improved, following such an episode, the depreciation rate on the remaining capital falls back to a lower level.

Effective capital is defined as $z^e = \gamma_p z^i$ where $0 < \gamma_p \leq 1$ is the ratio of actual to efficient operations expenditure.[12] For simplicity, these operations and maintenance requirements are treated as being kinked at the efficient level; while there is an immediate loss involved when either γ is allowed to fall below 1, there is no corresponding gain if either is set greater than 1. Such excess expenditure would just be wasted. Both operations and maintenance expenditures can be modeled as involving labour inputs, or use of traded and non traded goods, or some combination of the two. In this note, we focus mainly on the polar case where O&M exclusively involves goods, but we also illustrate the (fairly considerable) difference in behaviour under the alternative polar case

[10] This is of course a simplifying assumption: in practice, the capital stock may be so degraded as a result of deficient maintenance expenditures that it is simply not possible to restore it to 'full' efficiency without rebuilding afresh.

[11] Note that z^i here corresponds to Buffie *et al* 's z^e.

[12] It might seem more plausible to model this relation as linear rather than proportional but, for lack of evidence, it seems best to stick with the simpler formulation.

exclusively involving labour inputs. In the goods case, it is assumed that the composition of traded and non-traded goods is fixed, and is the same as the initial composition of domestic absorption. Thus, an increase in the level of O&M as a share of total absorption leaves the initial price vectors undisturbed. The quantities of this composite good are then defined respectively as $q_{p,t}z^i_{t-1}$and $q_{m,t}z^i_{t-1}$where $q_{j,t} = \gamma_{j,t}\overline{q}_j$ for $j = p, m$ and $\bar{q_j}$ is a measure of 'efficient' O&M goods expenditures per unit of installed capital. Similarly, in the polar case of labour inputs, these are defined respectively as $l_{p,t}z^i_{t-1}$and $l_{m,t}z^i_{t-1}$where $l_{j,t} = \gamma_{j,t}\overline{l_j}$ for $j = p, m$ and $\overline{l_j}$ is a measure of 'efficient' O&M labour inputs per unit of installed capital. These efficient values could be calibrated on the basis of Heller's 'r-coefficients', which are estimates of the required annual recurrent expenditure in dollars per dollar of installed capital.[13]

We are aware of no quantitative evidence on the scale of the losses inflicted by inadequate O&M, so the assumptions made here are necessarily speculative. However, we believe that these are quite conservative. In the simulations reported below, the measure of excess depreciation, β, is set equal to one. This implies that the depreciation rate would only double, for example from 5% to 10%, even if maintenance were abandoned entirely. As regards operational expenditures, the proportionality assumption again seems conservative. These expenditures are composites, and the components are likely to be required in fixed proportions, or at least to be poor substitutes. Since inadequate spending is itself inefficient, it seems most unlikely that the reduction would be allocated optimally between these components.[14]

It is necessary to consider how these O&M costs relate to the definition of GDP. It might seem natural to consider operations expenditures, for example, as intermediate goods, necessary in providing the final services of public capital. However, the present model is a pure value-added model, with no provision for intermediates; and conventional national accounting tends to value these activities at cost and treat them as part of GDP. Accordingly, that is the practice adopted here. In the polar goods case, GDP is still defined as $Y = P_xQ_x + P_nQ_n$. The introduction of positive O&M costs then reduces the amount of Y that is available for private consumption, public and private investment, and net exports. Where at least part of O&M expenditures are on labour

[13]See Heller (1991). His estimates are highly dependent on the type of public capital involved, with the coefficients covering the huge range between 1% and 72%; the lower values are characteristic of economic infrastructure, the higher ones of social infrastructure. Concentrating on maintenance only, for economic infrastructure, Fay and Yepes (2003) estimate values of 2% for electricity generation, rail and road; 3% for water and sanitation; and 8% for mobile and mainline telephones. They stress that these are estimates of the minimum expenditure to ensure the integrity of the system, not of the higher levels that would be efficient. Even so, these magnitudes imply that required expenditures on maintenance of existing capital are typically slightly larger than expenditures on new investment.

[14]For example, a health clinic may receive inadequate supplies of medicines, even when it is adequately staffed with medical personnel. This is likely to reduce services more than proportionally to the reduction in the operational budget. It would be straightforward to model this relationship by treating operations as a Leontief relationship between labour inputs and goods expenditures.

inputs, the definition of GDP becomes $Y = P_x Q_x + P_n Q_n + w(l_m + l_p)z^i$. When labour inputs to O&M are positive, this reduces the amount of the given labour force that is available for production of the two goods.

An important point to note is that it is not assumed that the prior or indeed final equilibrium of the economy is characterized by efficient O&M. As a consequence of inadequate budget planning and implementation, exacerbated by the separation of responsibilities for investment decisions and for O&M, there often is a substantial deficit in the latter from efficient levels.[15] The problem may of course be temporarily worsened during an investment surge if that leads to fiscal difficulties; on the other hand, a programme of reforms to public financial management may yield a sustained improvement in the relationship. The present model is designed to permit all these possibilities to be explored.

Adding in depreciation and debt-financing costs the full cost of public investment is given as

$$\left[P_{om,t}(q_{p,t} + q_{m,t}) + (\delta^i_{z,t} + r^g_t)P_{z,t}/s\right] z^i_{t-1} \tag{3.6}$$

where $P_{om,t} = a_{om}P_{n,t} + (1 - a_{om,t})P_{m,t}$ is the composite price of operations and maintenance. This polar case where O&M consists only of goods expenditure is used for illustration.[16] The first two terms are the recurrent cash costs of operations and maintenance; the third and fourth terms correspond to the depreciation and financing costs per unit of installed capital, where r^g_t is the marginal cost of government (non-concessional) borrowing, recognizing that a unit of installed capital costs P_z/s to replace. Treating the financing cost as equivalent to the cost of borrowing may seem over-simplified; it appears to imply that financing is by means of a perpetuity. However, it is a more robust approach than that, and this is spelled out in Appendix II.

Finally, we define the user-cost recovery rate as:

$$\mu_t = \left[P_{om,t}(f_{p,t}q_{p,t} + f_{m,t}q_{m,t}) + (f_{d,t}\delta^i_{z,t} + f_{r,t}r_t)P_{z,t}/s\right] z^i_{t-1} \tag{3.7}$$

where $0 < f_j \leq 1$ for $j = p, m, d, r$ are the recovery rates for each financing component. The reason for distinguishing these rates is that the financing components have very different perceptual properties, and are most unlikely to be treated as an aggregate in budget decisions. In the calculations reported below, it is assumed that there may be some cost recovery (on an equal

[15] Rioja (2003) models the issue, and suggests that it would often be efficient to divert available finance from new investment to increased maintenance of the existing stock. There appears to be less hard numerical evidence in respect of operations expenditures, but anecdotal evidence as to its common inadequacy abounds.

[16] The labour case is similar, where the relevant price is the wage; in the mixed case, of course, two prices have to be tracked.

basis) for O&M expenditure, but not for the other two categories of cost. That reflects the likely budget operations in many public finance systems.

4 Calibration issues

The calibration of our model largely mirrors that of Buffie *et al* and is summarized in Appendix I. The introduction of distortionary taxation and the possibility of inefficient O&M expenditures, however, requires some modification to the calibration process.

4.1 Distortions in the initial steady states

The original model is set up so that, for any new set of choice parameters (the initial consumption tax rate, for example), the calibration adjusts various model elasticities and factor inputs to be consistent with an initial GDP of 100, and for the wage and (most) initial prices to be unity. While this is convenient for many purposes, it has the disadvantage that the production structure of the economy varies between experiments: by altering factor inputs, the calibrated productivity parameters in the production functions (a_x and a_n), and the elasticity of output with respect to public capital (ψ_x and ψ_n) adjust. It is therefore difficult to compare like with like. In this paper, since much of the focus is on the impact of various distortions on the outcomes, a different calibration procedure is required to make it possible to explore the consequences of reforms which reduce these distortions. The one adopted here is to use the existing procedure to calibrate the 'undistorted' case where there is a consumption tax and O&M expenditures are at their efficient levels.[17] In that case, the production parameters are set to yield an initial GDP of 100. These parameters are then locked down, and calibrations in the various comparable distorted cases (output tax, and/or inefficient O&M) are conditional on these structural parameters, which include the production elasticities and the labour force, but not the capital stocks, which are of course contingent on the distortions. As is to be expected, initial GDP is less than 100 in the distorted cases, the more so for more pervasive distortions. Just how far below 100 is a measure of the costs of the distortion.

4.2 Efficient O&M expenditures

Since the model is used to examine the consequences of inadequate operations and maintenance expenditures, it is important to ensure that the 'efficient' levels are just that; if the calibration sets either of the $\overline{q}_j$ or $\overline{l}_j$ too high, a reduction would be budget enhancing. It is necessary that they

[17] This case is undistorted in a rather restricted sense, since it still has the distortion arising from the inefficient public capital formation process on which the original paper focused.

satisfy the condition that the budget does deteriorate when inadequate O&M provision is made. To keep matters simple, suppose that all steady state comparisons involve the same level of effective public capital, so if O&M is inadequate, higher gross investment is required.

Then for the inadequate maintenance case, it is straightforward to show that the budget deteriorates provided:

$$\beta_\delta \delta_z (1 - f_d) P_z / s > (1 - f_m) P_{om} \overline{q}_m.$$

This condition could fail to be satisfied if $f_d \gg f_m$,which seems highly unlikely, or if β_δ is very small. Note that there is a further welfare loss arising from higher user charges levied on the private sector. In the absence of cost recovery, or if the two recovery rates are the same, and public investment is efficient ($s = 1$), the condition reduces at calibration in the undistorted case ($P_z = P_{om} = 1$) to:

$$\beta_\delta \delta_z > \overline{q}_m \tag{4.1}$$

For the inadequate operation case, the budget deteriorates provided:

$$(\delta_z + g) P_z / s > P_{om} \overline{q}_p$$

Under the same simplifying assumptions as before, this reduces to:

$$(\delta_z + g) > \overline{q}_p \tag{4.2}$$

Cost recovery doesn't enter the story here, because user charges can only be levied on services provided, and keeping effective capital at the same level means no change in user charges. Provided the two simpler versions of the conditions are satisfied, they will necessarily also be satisfied in the presence of inefficient investment ($s < 1$) if $P_{om}/P_z \leq 1$, for the plausible case where $f_m \geq f_d$.[18]

4.3 Policy rules

Here we follow the design in the original paper, except that with certain exceptions, detailed in the text, the procedure has been to lock government transfers and aid at their initial level, so that all fiscal adjustments on the path must come from other components which could, in principle, include temporary or permanent changes in the adequacy of O&M expenditures as well as adjustments to the level of cost-recovery. The principal experiment we examine is an increase in public investment which is raised from 6 percent to 9 percent of initial GDP. Throughout most of the paper we assume

[18] The simulations presented below assume equality of the non-tradable weight in the price of capital goods and operations and maintenance ($a_z = a_{om}$) so that $P_{om}/P_z = 1$.

that this increase is financed through domestic taxation – allowing us to explore the properties of alternative tax regimes – but we also allow for the investment surge to be debt-financed where the gross (additional) public investment profile is matched exactly by non-concessional external borrowing, but in some fixed proportion. Hence it might be set to cover none, half, or all of the investment spending at each date in the surge, with the balance financed by some combination of tax and domestic debt. Concessional external debt is held constant throughout.

5 Simulation results: comparative statics

5.1 Public investment, deficient O&M and alternative tax regimes

Tables 1 to 3 describe the key features of the model in the context of a public investment surge. Here we confine our attention to the steady state properties of the model and limit our attention to programmes in which public investment is financed exclusively from domestic taxation; in the dynamic runs examined later we provide for external and domestic bond financing.[19] In all cases, the comparison is between an initial steady state where public investment is stationary at 6% of GDP, and one where it has been raised by 50% of that level, i.e. by 3% of initial GDP, but to a level below 9% of final GDP, given the induced growth in the latter. Features that are common to all the tables are the private cost of capital, at 10% per annum; and the steady state inefficiency in public capital creation ($\bar{s} = 0.6$ throughout). Public and private capital depreciate at 5% per annum, though the depreciation of the public infrastructure capital will rise if maintenance expenditure is inadequate. The social return to public infrastructure capital in the undistorted initial steady state is set to 25% and the initial social return to public investment is 13%. The derivation of these calibration parameters is described in Appendix III.

Table 1, which describes base cases and is analogous to the base case in the original paper (Buffie *et al.,* 2012, Table 3), compares outcomes under a set of runs for the consumption tax and a corresponding set for the output tax. The latter is set at an initial rate of 17 per cent, to reflect a typical ratio of tax revenue to GDP in low-income countries. Given the parametrization of the original model, a consumption tax at a rate of 20 per cent generates broadly similar revenue. Any difference in initial revenue yield is taken up by a compensating variation in the lump-sum transfer

[19] An alternative strategy would entail maintaining taxes and borrowing fixed at their initial values and financing the increased public investment by reducing other component of public expenditure. The model used here is, however, not well suited to examining this case. Other than O&M expenditures, no government services are produced so that all non-O&M recurrent expenditures consist of lump-sum non-distortionary transfers to households. In macroeconomic terms, therefore, an expenditure-switching strategy that sees transfers reduced is equivalent, across steady states, to one in which the investment surge is financed by increasing the uniform consumption tax. The alternative of financing public investment by scaling back O&M expenditures will have features similar to an extreme version of the case we analyse in Table 3 below.

from government to households.[20] The financing of the investment surge is entirely via changes in the relevant tax rate, with the transfer held fixed and no change in borrowing, either domestic or external. Efficient operations expenditures and efficient maintenance expenditures are both equal to 2.5 cents per dollar of installed public capital, so that O&M outgoings are 5 cents per dollar. For the present, it is assumed that no cost recovery takes place.

Column (1) describes the effect of the investment surge in the 'undistorted' case. Public investment crowds-in private investment, which rises by \$1.78 for each \$1 of public investment. GDP increases by 14.6% between steady states in a broadly balanced fashion; the real exchange rate appreciates by just over 2% between steady states. Real product wages increase by 15%; combined with the higher level of public capital, this causes the budgetary cost of O&M to rise to 3.6% of (current) GDP which, in turn, requires an increase in the consumption tax rate of just over 3%. Thus far – excepting the O&M expenditure – the results exactly mirror Buffie *et al.*

Introducing O&M inefficiencies has a marked effect on the initial steady state *level* of GDP. Relative to the efficient level of 100%, $\gamma_m = 0.8$ lowers initial GDP by more than 7 percentage points, $\gamma_p = 0.8$ lowers it by more than 10 points, and $\gamma_m = \gamma_p = 0.8$ by more than 17 points [columns (2) to (4)]. Conditional on these differences in the initial level of GDP, however, the response to the investment surge is broadly similar, with output and consumption growing by more or less the same amount.

Also interesting is the comparison between the consumption tax and output tax. Consider first the comparison between columns (1) and (5). Here, even with efficient O&M expenditures, initial GDP is more than 19 percent lower when the economy operates under an output tax regime , the damage being caused by the sharp reduction in equilibrium private capital induced by the tax. Moreover, between steady states the distortionary tax reduces the growth in GDP and consumption in response to the investment surge, again due to the lower rate of private capital accumulation (the crowding-in of private capital is only 60 percent of that achieved under the consumption tax). And while in both the consumption and output tax cases, real GDP rises very slightly further in the final steady state as O&M distortions become more severe – by 14.61% in column 4, as opposed to 14.59% in column 1 in the case of the consumption tax and by 12.97% in column 8 as opposed to 12.54% in column 5 in the output tax case – these higher growth rates are from lower initial starting points (at which the initial return to public investment is correspondingly higher).

[20] In principle, the transfer could be held constant between tax regimes in order to calibrate the initial consumption tax. Given the non-distortionary properties of the consumption tax in the steady state, the model's behaviour is invariant to this choice.

TABLE 1: *Long run effects of scaling-up public investment by 3% of initial GDP.*

Efficient O&M costs at 5 cents per $ of installed public capital in undistorted baseline;

Private cost of capital 10%; $s = 0.6$; No cost recovery.

	Consumption Tax				*Output Tax*			
Maintenance expenditure efficiency (γ_m)	1.0	0.8	1.0	0.8	1.0	0.8	1.0	0.8
Operations expenditure efficiency (γ_p)	1.0	1.0	0.8	0.8	1.0	1.0	0.8	0.8
Initial (final) GDP	100	92.92	89.19	82.87	80.86	75.12	72.09	66.97
	114.59	106.49	102.21	94.98	90.99	84.77	81.21	75.64
Initial k_x (% of undistorted level)	100	92.00	87.80	80.77	63.82	58.70	55.99	51.49
Initial k_n (% of undistorted level)	100	92.74	88.94	82.47	66.08	61.24	58.71	54.40
Initial z_e (% of undistorted level)	100	80.53	71.35	57.46	80.86	65.10	57.67	46.43
Final consumption tax rate (initial = 20%)	23.14	22.74	23.00	22.62	-	-	-	-
Final output tax rate (initial = 17%)	-	-	-	-	19.04	18.73	18.93	18.63
Initial (final) product wage (in price of x)	1.0	0.93	0.89	0.83	0.67	0.62	0.60	0.55
	1.15	1.07	1.02	0.95	0.74	0.69	0.66	0.61
Initial (final) O&M cost (% current GDP)	2.77	2.17	2.51	1.95	2.85	2.24	2.59	2.01
	3.59	2.81	3.26	2.52	3.78	2.95	3.42	2.64
Transfer (% of initial GDP)	11.38	12.05	11.62	12.25	12.01	12.59	12.21	12.76
Increase in effective public capital (%) [1]	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00
Crowding In	1.78	2.04	2.21	2.53	0.96	1.18	1.22	1.50
Real GDP [1]	14.59	14.60	14.60	14.61	12.53	12.85	12.65	12.96
Real consumption [1]	10.26	10.55	10.38	10.65	8.46	9.05	8.68	9.24
Real exchange rate [1]	-2.22	-2.25	-2.26	-2.29	-1.63	-1.78	-1.71	-1.84
Initial social return to public investment (%)	13.00	15.39	13.11	15.46	12.33	14.61	12.43	14.68
Final social return	8.22	9.91	8.37	10.04	7.37	8.99	7.54	9.13
Initial social return to public capital (%)	25.00	30.15	24.68	29.77	23.88	28.85	23.55	28.47
Final social return	17.03	21.01	16.79	20.73	15.62	19.48	15.41	19.23

Note: [1] Percentage change between steady states.

The direct costs of financing the investment surge plus the additional fiscal burden of O&M expenditures raise the consumption tax rate by between 2.6 and 3.1 percentage points and the output tax rate between 1.6 and 2.0 percentage points. This difference reflects two factors, the first of which is the stronger real exchange rate appreciation under the consumption tax, which raises the fiscal cost of public investment, P_z, (and the cost of associated operations and maintenance expenditures through the appreciation of P_{om}), other things equal. The second effect is that the growth of the tax base for the output tax, namely GDP, is more rapid than is the growth of the base for the consumption tax, namely consumption itself. The required increase in the output tax rate is therefore less than that for the consumption tax.

TABLE 2: *Alternative representations of O&M expenditures.*

All settings as Table 1 *except* characterization of O&M costs.

	Consumption Tax				*Output Tax*			
Maintenance expenditure efficiency (γ_m)	1.0	0.8	1.0	0.8	1.0	0.8	1.0	0.8
Operations expenditure efficiency (γ_p)	1.0	1.0	0.8	0.8	1.0	1.0	0.8	0.8
O&M in GDP units								
Final consumption tax rate (initial = 20%)	23.12	22.73	22.98	22.61	-	-	-	-
Final output tax rate (initial = 17%)	-	-	-	-	19.03	18.71	18.91	18.62
Initial (final) product wage (in price of x)	1.00	0.93	0.89	0.83	0.67	0.62	0.60	0.55
	1.15	1.07	1.02	0.95	0.74	0.69	0.66	0.61
Initial (final) O&M cost (% current GDP)	2.77	2.17	2.51	1.95	2.85	2.24	2.59	2.01
	3.59	2.81	3.26	2.52	3.78	2.95	3.42	2.64
O&M in labour only								
Final consumption tax rate (initial = 20%)	24.22	23.40	23.65	22.98	-	-	-	-
Final output tax rate (initial = 17%)	-	-	-	-	19.10	18.70	18.83	18.49
Initial (final) product wage (in price of x)	1.00	0.93	0.89	0.83	0.67	0.62	0.60	0.56
	1.15	1.07	1.03	0.96	0.74	0.69	0.66	0.62
Initial (final) O&M cost (% current GDP)	2.77	2.01	2.23	1.60	1.85	1.35	1.49	1.07
	4.21	3.05	3.38	2.42	2.75	2.00	2.21	1.59

These results are for the case where O&M expenditures are measured in units of GDP. As discussed in Section 3 above, an alternative characterization is to represent O&M purely as a call on labour inputs. Table 2 compares the two cases. Assuming labour-only O&M costs alters both the initial calibration and, more importantly, the response of the economy between steady states. The differences are particularly marked between tax regimes. For the consumption tax case, except in the undistorted baseline (column 1), the initial budgetary cost is slightly lower because the real wage falls in the distorted economy. This drop in the initial cost is much more more marked in the output tax because the real wage is markedly lower, relative to the undistorted baseline. As a result, the initial O&M cost may be up to 1% of GDP lower when characterized as labour only.[21]

An equally large difference emerges following the investment pulse. In the case of the consumption tax, the budgetary increase is larger when O&M costs are labour only. The reason is that the

[21] In order to keep the tax rate constant across characterizations of O&M costs, we allow any differences in cost to be accommodated by changes in the initial level of net government transfers (which are then held constant between steady states).

public investment surge and associated crowding in of private capital drives up the product wage and hence the O&M wage bill. By contrast, the rise in the output tax rate in columns 5-8 is much the same in the two cases, and on average the increase is somewhat lower. This is because two opposing effects are more or less neutralizing each other. One is the rise in the wage following the the investment surge, as before. The other is the fact that the output tax drives the initial product wage down, so that the rise is from a much reduced base. Indeed, the initial product wage is reduced sharply (by a third). This is partially because the product wage is reduced directly by the tax, and partially because it is reduced indirectly by the fall in the private capital stock, lowering the pre-tax marginal product of labour. These effects are exacerbated by O&M inefficiency. The reduction in the public sector wage bill is most marked in the most distorted cases, which is why the increase in required tax revenue is reduced for these.[22]

Finally in this section we examine the long-run effects of a public investment surge that is not matched by a commensurate increase in O&M expenditures. To avoid repetition, we take as our baseline the output tax case where O&M expenditures are initially at 80% of their efficient levels ($\gamma_m = \gamma_p = 0.8$) which corresponds to column (8) of Table 1. Public investment is increased by 3% of initial GDP as before but the provision against the additional installed public capital is insufficient to maintain overall O&M at its baseline rate when spread across the new higher installed capital. Specifically, we calibrate this short-fall such that when one or both of O&M are deficient, the 'marginal γ' is only half its infra-marginal rate. The effective or average values of γs are the weighted average of 0.8 and 0.4, with the weight reflecting the relative size of the addition to the installed capital stock: given the scale of the investment surge this bring the relevant γs to 0.67 in the deficient cases. Under our calibration the budgetary costs of cutting either operations or maintenance expenditures are equivalent *ex ante*. When neither O&M rise proportionally with public investment, growth in output falls sharply, from 13.0% to only 1.9% between steady states. As columns (2) and (3) of the table indicate, deficient operations expenditure account for the greater share of the damage; here the *effective* public capital stock grows by only 25% between steady states compared to the baseline of 50%, whereas when maintenance is deficient (at the same *ex ante* fiscal cost) the effective capital stock grows by 37.8%.[23] In all cases, however, paring back O&M is a false economy with the steady-state tax rate between 0.2 and 1.5 percentage points above that required when baseline O&M levels are maintained. In the extreme (not reported in the table),

[22]The patterns of the results presented here are broadly invariant to assumptions about the initial social rate of return to public capital and the associated social return to public investment, elevated or depressed according to these assumptions of higher and lower productivity respectively. These results are available on request.

[23]This difference reflects, of course, the parameterization chosen in our calibration: if deficient maintenance expenditures were punished by a sharper increase in the depreciation rate in 3.5, for example, the gap between the two cases would diminish.

if the investment surge was 'capital only', with O&M expenditures tethered to the initial capital stock, output would actually contract. This is because, while the additional public capital formation must be financed, the absence of operations expenditure means it generates no additional flow of infrastructure services to augment private factors. Output contracts by about 9.4% and the tax rate rises to 22.1% under the ouput tax; and even when the fiscal regime is characterized by a uniform consumption tax, output falls by 5.1% and the tax rate rises from 20% to 25.6%.

TABLE 3: *Public investment with deficient O&M.*

Output tax case only;Baseline settings as Table 1, column (8) (O&M at 80% of efficient level) Public investment increases by 3% initial GDP.				
Final average expenditure efficiency M(γ_m)	0.8	0.8	0.67	0.67
Final average expenditure efficiency O (γ_p)	0.8	0.67	0.8	0.67
Final output tax rate (initial = 17%)	18.63	19.89	18.80	20.09
Final O&M cost (% GDP, initial = 2.01%)	2.64	2.62	2.30	2.26
Increase in effective public capital (%) [1]	50.00	25.00	37.75	14.79
Product wage growth (%)	10.90	1.81	7.30	-1.19
Crowding In	1.50	0.38	1.34	-0.89
Real GDP [1]	12.96	5.03	9.60	1.88
Real consumption [1]	9.24	1.18	6.21	-1.64
Real exchange rate [1]	-1.84	-0.25	-1.26	-0.36
Final social return to public investment (initial = 14.68%)	9.13	7.98	9.61	8.38
Final social return to public capital (initial = 28.47%)	19.23	16.98	20.80	18.41

Note: [1] Percentage change between steady states.

5.2 Fiscal reforms: O&M rehabilitation and tax reform

Tables 4 and 5 examine the implications of a set of fiscal reform packages. In Table 4 we explore reform combinations consisting of reforms which reverse latent inefficiencies in the level of operations and maintenance expenditures, or both, and which may be combined with reform of the tax regime.[24] The tax reform experiment is a radical one and consists of the complete replacement of the distortionary output tax with the non-distortionary (across steady states) consumption tax. Given the extremely parsimonious representation of the tax system in the model, this reform does not relate directly to actual practice but can be thought of as reflecting elements of the tax reforms across many low income countries in the 1990s and early 2000s that saw highly distortionary elements

[24]Here we restrict our attention to the case where O&M is modeled as a direct claim on GDP.

of tax regimes eliminated and replace by valued-added taxes (see Kloeden, 2011, and Keen, 2012). The present treatment can be thought of as providing an upper bound on the gain from reform. The reference case for this table and the next is the distorted baseline in which both O&M are at only 80% efficiency, there is no cost recovery on (additional) public investment and the economy operates under an output tax. This is the case reported in Table 1, column 8. Columns (1) to (3) consider 'operations-only', 'maintenance-only' and 'combined' O&M reforms while retaining the initial tax regime. Columns (4) to (6) repeat these experiments in combination with a tax reform. Throughout we assume that fiscal reforms can be implemented at no resource cost.

Table 5 then runs these same fiscal reforms with the public investment surge discussed in Table 1 and allows for this to be accompanied by an improvement in the efficiency of public investment. So, again starting from the baseline of Table 1, column 8, the consequences of an improved-efficiency public investment surge, combined with reforms to O&M and an accompanying tax reform, are explored.

TABLE 4: *Fiscal reforms.*

Baseline settings as Table 1, column (8); no public investment.

	Output Tax				*Tax Reform*				
Final maintenance efficiency (γ_m)	1.0	0.8	1.0	1.0	0.8	1.0	0.8	1.0	1.0
Final operations efficiency (γ_p)	0.8	1.0	1.0	1.0	0.8	0.8	1.0	1.0	1.0
Final cost recovery (% of O&M costs)	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.00	0.50
Real GDP growth[1]	5.22	8.98	14.61	16.07	29.19	35.54	39.23	46.08	46.08
Real consumption[1]	4.83	9.13	14.38	15.70	23.89	29.68	33.87	40.16	40.16
Investment crowding-in	2.55	2.96	2.64	3.20	-	42.47	27.64	17.21	17.21
Real exchange rate	-1.0	-1.83	-2.78	-3.30	-10.32	-11.11	-11.54	-12.32	-12.32
Effective public capital[1]	15.38	25.00	44.23	44.23	0.00	15.38	25.00	44.23	44.23
Final product wage (initial = 0.55)	0.58	0.61	0.65	0.67	1.01	1.07	1.10	1.15	1.15
Final O&M cost (% GDP, initial = 2.01%)	2.46	2.06	2.50	2.46	1.48	1.83	1.54	1.88	1.88
Final output tax rate (%)	16.68	15.75	15.49	14.04	0.00	0.00	0.00	0.00	0.00
Final consumption tax rate (%)	0.00	0.00	0.00	0.00	16.52	16.34	15.53	15.39	14.17
Final social return to public investment (%)	13.45	16.67	15.23	15.59	22.94	20.91	25.28	23.02	23.02

Note: [1] Percentage change between steady states.

Starting from an initial position where both operations and maintenance are 20% below their efficient level and the economy operates under an output tax, reforms that restore efficient levels of spending in both generates an increase in real output of around 15% between steady states. Although the budget must bear higher O&M costs, absolutely and as a proportion of GDP, the efficiency gains accruing to the enhanced stock of effective public capital crowds-in private investment and allows these higher budgetary costs to be financed at a lower rate of output tax (recall that in Table 4 there is no increase in the net public investment rate, so that the measured increase in effective public capital entirely reflects efficiency gains: bringing both O&M to their efficient levels raises the effective public capital stock by 44%). The effects are more or less additive between improving operations and improving maintenance expenditures, although the returns to improving operations efficiency has a larger marginal impact on economic performance. Clearly the mechanisms differ, with improved efficiency of operations enhancing the productivity of the entire capital stock and improved efficiency of maintenance altering the depreciation rate henceforth for any given level of efficiency. That the operations effect dominates here is simply a reflection of the uncertainties of our calibration: our estimates of the rate at which deficient maintenance expenditure accelerates the depreciation of public capital and of the elasticity of the effectiveness of the installed capital stock to operations expenditures are highly speculative.

When accompanied by a wholesale tax reform, the output and welfare gains are even more substantial. Aggregate consumption rises by almost 24% across steady states as a result of a deficit neutral tax reform, and by 40% if this is accompanied by reforms to O&M spending that operate on the intensive margin of public capital. The mechanism for output growth is the very substantial increase in private investment across steady states induced by the removal of tax on output: in the case where tax reform is accompanied by O&M reforms, for example, the capital stock in the exportable sector rises by 132% between steady steady states and that in the non-tradable sector by 106%. The surge in absorption drives up real product wages, measured in terms of the tradable good, very sharply (from 0.55 to 1.15 in the comprehensive reform case shown in column 8) although the effect on real consumption wages will be somewhat dampened by the sharp appreciation of the real exchange rate, which in this instance is approximately 12% above its initial steady-state value.

TABLE 5: *Fiscal reforms with public investment.*

Baseline settings as Table 1, column (8); public investment increased by 3% of GDP								
	Output Tax				*Tax Reform*			
Final maintenance efficiency (γ_m)	0.8	0.8	1.0	1.0	0.8	0.8	1.0	1.0
Final operations efficiency (γ_p)	0.8	0.8	1.0	1.0	0.8	0.8	1.0	1.0
Efficiency of public investment	0.6	1.0	1.0	1.0	0.6	1.0	1.0	1.0
Cost recovery (on new investment)	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.50
Real GDP growth[1]	12.97	21.83	41.67	43.45	48.07	58.39	81.98	81.98
Real consumption growth [1]	9.25	17.90	37.00	38.63	38.35	48.21	70.51	70.51
Investment crowding-in	1.50	1.75	1.70	1.87	15.65	10.67	6.40	6.40
Real exchange rate	-1.85	-3.39	–6.29	-6.79	-12.53	-13.61	-15.79	-15.79
Effective public capital[1]	50.00	83.33	177.24	177.24	50.00	83.33	177.24	177.24
Final product wage (initial = 0.55)	0.61	0.67	0.80	0.82	1.16	1.25	1.44	1.44
Final O&M cost (% GDP, initial = 2.01%)	2.64	2.98	3.82	3.77	1.92	2.19	2.85	2.85
Final output tax rate (%)	18.62	17.72	16.40	14.98	0.00	0.00	0.00	0.00
Final consumption tax rate (%)	0.00	0.00	0.00	0.00	18.38	17.71	16.74	14.81

Note: [1] Percentage change between steady states.

The fiscal consequences of reform are highly attractive. The restoration of efficient O&M allows for a modest decline in the steady-state output tax rates, from 17% to 15.49%, and by a further 1.5% if user fees cover half of the O&M costs associated with public capital formation and operation. In the case of a tax reform, the growth effects are sufficiently powerful to ensure both that the O&M cost share in GDP falls and that the consumption tax rate required to balance the budget settles at around 15.4%. In other words the economy can achieve a lower rate of tax on a narrower tax base. In this case too, of course, a measure of cost recovery lowers the consumption tax rate although in contrast to the output tax rate, the substitution of (lump-sum) cost recovery for the non-distortionary consumption tax does not otherwise alter the equilibrium outcome.

The powerfully welfare-enhancing effects of fiscal reform are reinforced when combined with a public investment surge, as shown in Table 5. As Buffie *et al* show in the context of a non-distortionary tax, improvements in the efficiency of public investment - so that the quantity of installed public capital realized per unit of investment is increased – can sharply increase growth, by a factor of almost three, and drive down the required tax rate.[25] A similar but more muted effect occurs in a distortionary tax regime considered here – output less than doubles between columns 1 and 2 of Table 5 while the required output tax rate increases. But when investment efficiencies

[25] Buffie *et al.*, 2012, Table 3

are harnessed with broader fiscal reforms the crowding-in effect is sufficiently strong that the public investment surge can be financed with *lower* output tax rates and by *much lower* consumption tax rates in the case of an investment-cum-tax-reform programme.

6 Debt financing

The analysis in the previous section assumes the public investment surge is entirely tax-financed. The next step is to examine how external and/or domestic debt financing may substitute for tax financing. Table 6 reports the comparative steady-state outcomes under three financing arrangements, separately for the two tax regimes, while Figures 1 and 2 illustrate elements of the dynamic adjustment between the steady states. The first three columns of Table 6 (and Figure 1) describe the economy operating under a consumption tax and the second three (and Figure 2) the outcome for the output tax. In each case the first column corresponds to the tax-only results from Table 1, in which domestic debt is held at a constant share of (initial) GDP. In the second column, the investment costs are fully financed by non-concessional borrowing, and in the final column the investment costs are borne equally between domestic and external debt.[26] The supply curve for non-concessional debt is upward sloping with the interest rate rising by approximately 0.9 percentage points for each 10% of GDP increase in debt.

The key point from this table follows directly from the government's inter-temporal budget constraint: the rise in the public debt burden between steady-states necessarily entails a higher tax rate, *ceteris paribus.* Debt financing adds between 3.4 and 4.1 percentage points to the required consumption tax rate and between 3.3 and 3.6 percentage points to the output tax rate. While the additional tax burden necessarily eats directly into private consumption between steady states, the impact on output growth (and the social return to public investment) when revenue is raised through a consumption tax is minimal.

[26] This is true ex ante, although not ex post because of the evolution of prices in general equilibrium between steady states.

TABLE 6: *External and Debt Financing of Public Investment.*

Baseline settings as Table 1, columns (4) and (8); public investment increased by 3% of GDP

Domestic interest rate 10%; external interest rate $6\% + \theta(dc/y)$

	Consumption Tax			*Output Tax*			
Domestic debt (percent share of investment surge)	0	0	50	0	0	50	0
Non-concessional debt (share of investment surge)	0	100	50	0	100	50	0
Concessional debt (share of investment surge)	0	0	0	0	0	0	100
Final domestic debt stock (initial = 20% GDP)	17.51	17.57	35.06	18.32	19.13	38.03	18.18
Final external debt stock (initial = 0% GDP)	0	34.97	17.47	0	36.76	18.27	0
Final concessional debt stock (initial =50% GDP)	50	50	50	50	50	50	79.13
Final external interest rate	-	9.68	7.06	-	10.72	7.36	-
Final consumption tax rate (initial = 20%)	22.61	26.72	25.99	-	-	-	-
Final output tax rate (initial = 17%)	-	-	-	18.62	22.26	21.89	17.96
Initial (final) O&M cost (% current GDP)	1.95	1.95	1.95	2.01	2.01	2.01	2.01
	2.52	2.53	2.53	2.64	2.76	2.74	2.62
Increase in effective public capital (%) [1]	50.00	50.00	50.00	50.00	50.00	50.00	50.00
Crowding In	2.53	2.42	2.49	1.50	0.21	0.48	1.75
Real GDP [1]	14.61	14.26	14.48	12.97	8.88	9.43	13.73
Real consumption [1]	10.65	6.90	9.27	9.25	1.82	4.70	10.70
Real exchange rate [1]	-2.29	-2.29	-2.29	-1.85	-0.42	-0.57	-2.10
Initial social return to public investment (%)	15.46	15.46	15.46	14.68	14.68	14.68	14.68
Final social return	10.04	9.98	10.02	9.14	8.38	8.49	9.28

Note: [1] Percentage change between steady states.

By contrast, when government has recourse only to a distortionary output tax, the additional tax burden undercuts private investment and growth more decisively: the crowding-in coefficient is almost halved as we move between tax- and debt-financing and output growth is slightly more than three percent lower between steady states. In this instance, as the financing share of domestic debt rises (column 3 versus 2 and column 6 versus 5) the required tax burden decreases slightly as the lower external debt burden reduces the risk premium on external debt. More striking, though, is that growth in consumption is much higher in this case, reflecting the fact that domestic debt is held by the un-constrained domestic households, whereas external debt is held entirely by non-residents.

Whether debt- or tax-financed, and regardless of the tax regime, adjustment between steady states is slow following the public investment pulse (see Figures 1 and 2).[27] Public investment

[27] This is true even though, in contrast to Buffie et.al, adjustment and absorption costs associated with private and public capital formation have been suppressed.

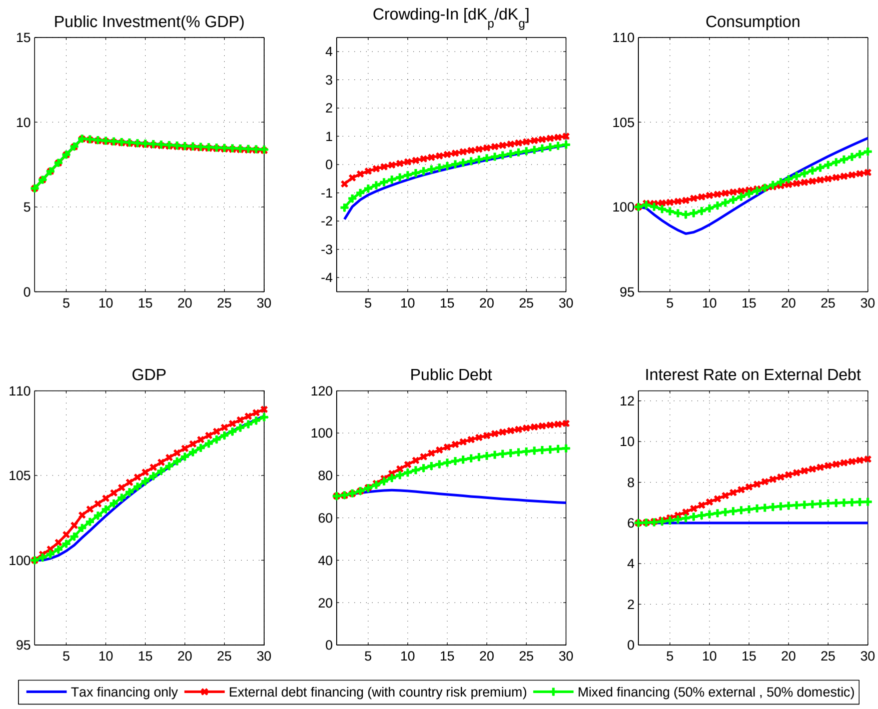

Figure 1: Debt Financing of Public Investment Surge: Consumption Tax

reaches its new steady state level after approximately 6 years, but the private sector response is much more attenuated. Even after 30 periods output and private consumption are still somewhat less than halfway to their new steady state levels, although convergence is marginally more rapid when investment is financed from external debt. The drag is being applied by a conventional crowding-out mechanism, over the first 10 to 15 year period, particularly when investment is financed through taxation only or domestic debt. When the economy operates under a consumption tax, the increase in the private capital stock between steady states is two and half times that of the public capital stock (Table 6), but as Figure 1 shows, even after 30 years, it has only just increased dollar-for-dollar. When the economy is operating under the output tax regime, the outlook is even more bleak since crowding out in this instance also operates through the impact on the net of tax private return to capital. This both lowers the long-run crowding-in and growth effects of public capital (Table 6) but also further reinforces the crowding out effects on public investment.

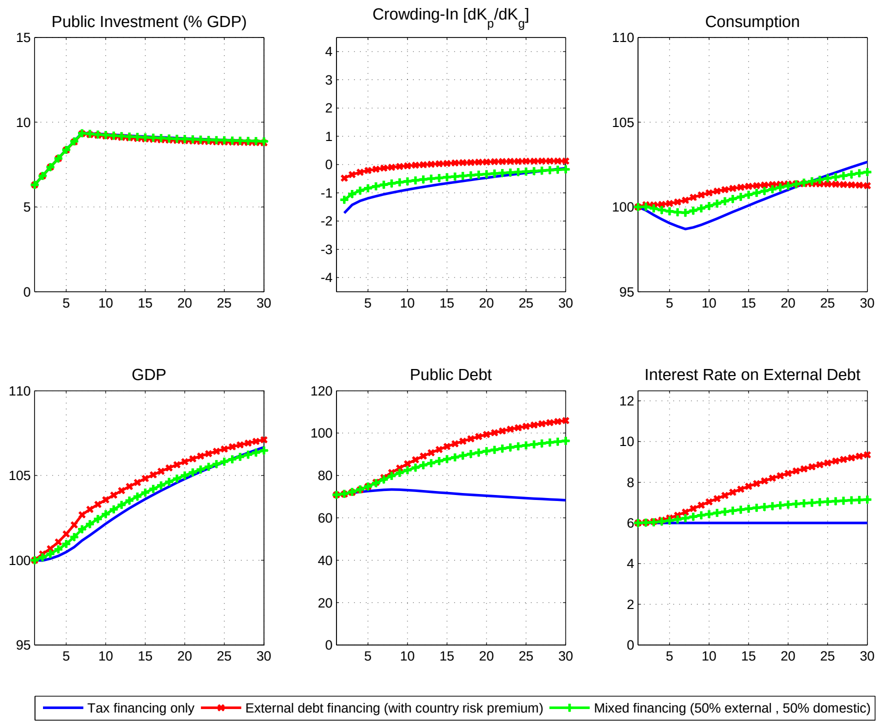

Figure 2: Debt Financing of Public Investment Surge: Output Tax

6.1 Constraints on taxation, debt and the tax profile

The rationale for wanting to investigate the whole issue of debt sustainability presupposes that circumstances may arise in which debt is not sustainable, and some form of forgiveness or default must ensue. Alternatively, the government or its creditors might come to the conclusion that a programme would in due course lead to unsustainability if it were persevered with, and that a change in the programme was necessary in order to avoid this. Modeling the former case, debt would eventually begin to explode, and the model would crash. In the latter, a switch to a less ambitious programme would be put in place before that happened. These types of exercise would permit exploration of how infeasible policies might arise, the path of the economy up to the crash, and the options for successful rectification. It would also be possible to explore changes in circumstance which would turn a feasible programme into an infeasible one.

Unfortunately, the type of model used here is not well designed to explore such possibilities; after any initial shock, the model's solution procedure relies on perfect foresight by the saving households.

If the government - which is not modeled as an optimizing agency - attempted to embark on an infeasible programme, the model would not solve at all. Thus, it is not possible directly to study, for example, the existence of limits to domestic revenue mobilization, arising from administrative constraints or considerations of political economy, which would prevent the tax rate being raised to a high enough level to cover the financing gap.

It seems important to be able to explore the question of feasibility, particularly in respect of the allowable tax rate, so we have adopted a form of 'reverse engineering'. The tax rate is initially allowed to move freely. If it moves above the hypothetical (but not yet enforced) bound, the investment surge is infeasible, and is scaled back progressively until the tax rate no longer breaches the bound. The proportion of the surge that can in fact be financed then defines the feasible limit to the programme.

This is not ideal, and we are exploring alternative model structures that can handle this class of infeasible investment strategy. In the meantime, Table 7 reports some results using the reverse engineering approach. We compute the feasible level of investment (as a share of the unconstrained pulse) when neither consumption nor output taxes can increase by more than 20 percent above their baseline values (hence for the consumption tax this places the ceiling at a tax rate of 24% and for the output tax at 20.4%). The first and third columns report the cases where there is no recourse to debt financing. Were there no limits on the tax rate, the surge would see the consumption tax peak at 25.5%.[28] With the tax ceiling in place, however, the original plan is infeasible and becomes feasible only when the investment programme is scaled back to 81% of the *ex ante* planned level, although this rises to 87% if half of the O&M costs associated with public capital can be recouped. Under an output tax, where the peak (unconstrained) tax rate hardly exceeds the ceiling, almost all of the investment surge can be financed and, indeed, a more ambitious surge could have been financed with cost recovery in place.

The difference between outcomes under the consumption and output taxes is quite striking but is, to some extent, an artifact of our definition of infeasibility and our chosen paramerization of the model. The proximate reason for this outcome is the differential growth rate of the relevant tax bases in the early years of the simulation. Recall that the consumption tax affects the inter-temporal path of the unconstrained household's consumption with an anticipated rise in the tax causing the household to choose a flatter path for consumption, which requires a steeper trajectory for the tax rate. Hence even though the long-run outcome is better under the consumption tax (consumption growth is twice as large between steady states and the proportional rise in the consumption tax rate is lower than that for the output tax in the unconstrained case) the stronger 'overshooting' path

[28] The required rate rises above 24% in year 7, peaks in year 11 and remains above the 24% ceiling until year 38 before trending down towards its final steady state level of 22.61 (Table 1, column 4).

of the consumption tax means that the economy is more likely to hit any given tax ceiling on the dynamic path. Increasing the share of constrained households and/or lowering the inter-temporal elasticity of substitution in consumption will reduce the difference between the consumption tax and output tax cases.

If the investment surge is debt-financed, however, either through non-concessional external borrowing or domestic bond financing, or a mixture of the two, the additional tax burden greatly compromises the fiscal feasibility of the investment programme. For example, with external debt financing, given a constant domestic debt target and no cost recovery, only 53% (60%) of the surge is feasible under the consumption (output) tax. Substituting (more expensive) domestic for external debt, as shown in columns 3 and 6, further lowers the feasible size of the investment programme.

TABLE 7: *Feasible public investment with tax ceiling.*

Baseline settings as Table 1, columns (4) and (8); public investment increased by 3% of GDP Domestic interest rate 10%; external interest rate $6\% + \theta(dc/y)$						
	Consumption Tax			*Output Tax*		
Domestic debt (share of investment surge)	0	0	50	0	0	50
Non-concessional debt (share of investment surge)	0	100	50	0	100	50
Tax ceiling	24.0	24.0	24.0	20.4	20.4	20.4
Maximum unconstrained consumption tax rate	25.5	28.6	26.1			
Maximum unconstrained output tax rate				20.8	24.1	22.2
Financeable share of investment (no cost recovery)	81%	53%	47%	98%	60%	45%
Financeable share (50% cost recovery on O&M)	87%	57%	54%	109%	66%	56%

Note: [1] Percentage change between steady states.

This is, however, only part of the debt financing story, since the key function of debt in this model (and in reality) is that it allows the borrower to break the concurrent (though not the inter-temporal) link between expenditure and taxation so as to allow for a different inter-temporal path of taxation. It may be that the government's revenue position (and any associated bound on tax rates) is expected to ease over time, as a consequence of improvements in tax administration, the growth of per capita income, or other anticipated events such as increased resource revenues. Borrowing permits tax rates to be kept down early on, even though the logic of the inter-temporal budget constraint means they have to rise higher later to cover the debt service, but the future relaxation in the revenue constraint may now make this feasible. To illustrate the nature of this inter-temporal trade-off, Figure 3 plots the different profiles for consumption and output taxes across the three scenarios discussed in Table 6. In both cases, although debt financing requires higher tax rates in the new steady state, the short-run pressure on taxation is moderated; taxes rise more

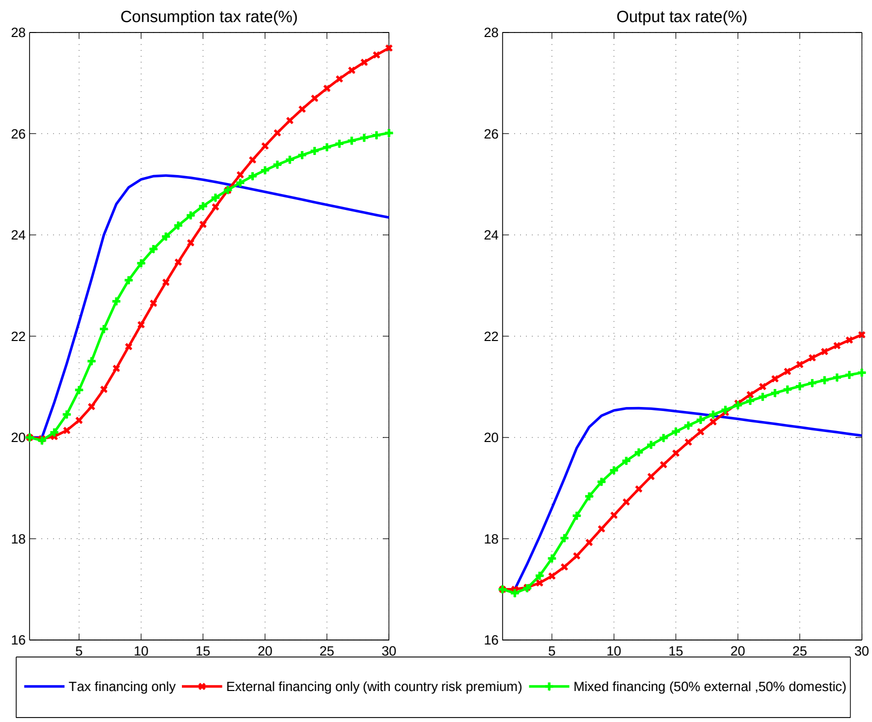

Figure 3: Tax rates under alternative financing arrangements

slowly and importantly are no longer characterized by potentially damaging 'overshooting'.[29] For both output and consumption taxes, the crossover comes after a little over 15 years so the policy question then becomes which profile is preferable; the answer would depend on views about discount rates and the (welfare) costs of tax-rate overshooting, as well as the anticipated future profile of revenue constraints.

Clearly, if the government is able to fund the public investment surge through concessional financing, the steady-state and dynamic outcomes look rather different. The final column of Table 6 reports the steady state outcomes when 100% of the capital cost of the public investment surge is financed from concessional sources (where the interest rate on concessional borrowing is zero), while Figure 4 illustrates the dynamics, for the case where the economy operates under the output tax. Concessional external finance allows the economy to enjoy both a consistently and permanently

[29]These calculations assume the new steady state is characterized by permanently higher external and domestic debt to GDP ratios. If it were intended to retire debt progressively, that would of course produce a hump in the tax profile for the borrowing cases, followed by a decline.

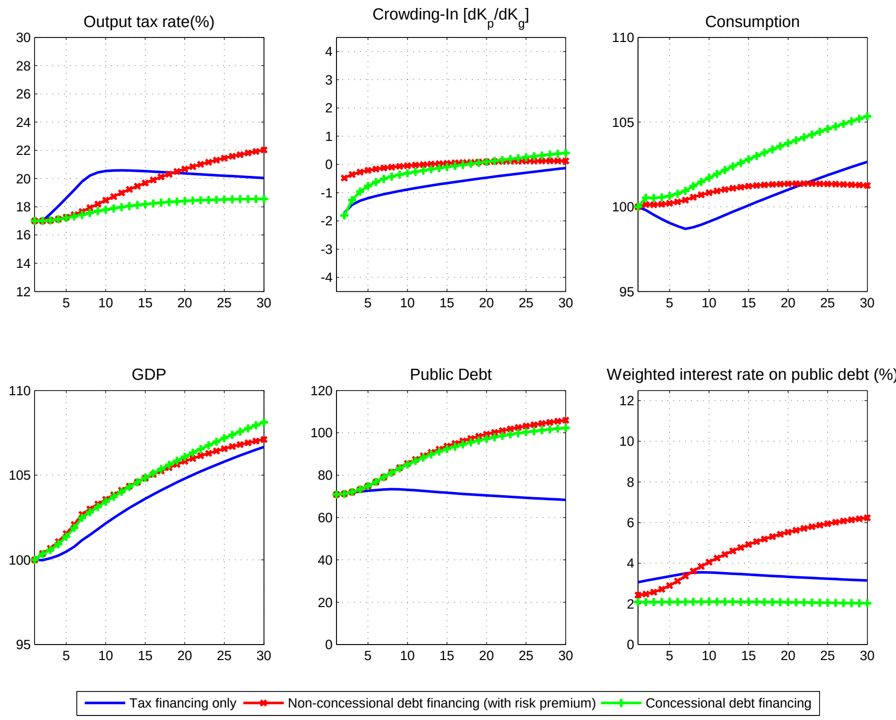

Figure 4: Concessional Debt Financing of Public Investment Surge: Output Tax

higher level of consumption than under either tax- or non-concessional debt-financing and a lower increase in the required tax rate. Moreover, as Figure 4 illustrates, since the required tax rate is also lower at all points on the dynamic path, the policy maker is no longer required to trade off lower current taxes against higher future taxes as discussed above: here the concessional financing path unambiguously dominates both the tax-only and non-concessional financing outcomes. It follows that this dominance result will also hold when the investment pulse is financed by a portfolio of external concessional and non-concessional financing, as long as the share of concessional financing is high enough. For the case just examined, a blend consisting of no more than 15 percent non-concessional financing would ensure that the required tax rate would never exceed that required under a pure tax-financing strategy.

7 Conclusion

Two staples, both of public finance theory, and of practical discussions of fiscal policy, are that taxation inflicts deadweight costs, and that public investment imposes ongoing budgetary costs for operations and maintenance for which provision is often inadequate. The paper by Buffie *et al* sets out to provide a systematic framework for analyzing the interactions between public investment, financing alternatives, the budget, and growth. However, it does not include treatment of these two issues. This paper extends their model to incorporate them. It is intended to demonstrate both how this can be done, and to illustrate some of the implications of doing so. The illustrations, which at this stage are calibrated to the same stylized economy as the original paper, but which nonetheless result in a plausible representation of the degree of distortion in many low-income countries, demonstrate both that these extensions have material consequences for the analysis of the public investment, debt sustainability and growth nexus in low-income countries. and that the potential payoff to various forms of fiscal reform, both tax reforms and reforms to the institutional arrangements for the budgeting and implementation of O&M expenditures, may be substantial, both in their own right and in combination with public investment programmes. Although the results as well as the experiment design remain rather stylized, they point to further developments of the research that will allow us to bring the model to bear on specific country public investment programmes. Two steps are of primary importance. The first involves further development of the model itself, in particular the introduction of a more nuanced representation of the tax system, allowing for differential taxation of labour and capital income and of different categories of consumption so that, amongst other things, the model can better analyze real-world tax reform programmes. This work is well in hand. Second, the current parameterization of O&M expenditures is based on a combination of Heller's original estimates and simplifications implemented in the interests of model transparency. Further work is therefore required to re-calibrate this part of the model to (the admittedly still very sparse) contemporary data on actual and 'efficient' O&M expenditures. This will require analysis of countries' budgetary and public expenditure records and of project-based data of the form collected by the World Bank under the aegis of the *Africa Country Infrastructure Diagnostic* project (see Foster and Briceno-Garmendia, 2010). With these developments in hand the modified model will be well-placed to offer *ex ante* assessment of country-specific policy programs.

References

[1] Auriol, E. and M. Warlters (2012), "The marginal cost of public funds and tax reform in Africa" *Journal of Development Economics* **97**(1) 58-72.

[2] Barro, R.J. (1990) "Government Spending in a simple model of endogenous growth" *Journal of Political Economy* **98**(5) s103-26.

[3] Barro, R.J. and X. Sala-i-Martin (1992), "Public finance in models of economic growth" *Review of Economic Studies* **59**(4), 645-61.

[4] Berg, A., S. Yang and L-F. Zanna (2014) "Modeling African Economies: A DSGE Approach" (mimeo, IMF)

[5] Buffie, E., A. Berg, C. Pattillo, R. Portillo and L-F. Zanna (2012) "Public investment, growth, and debt sustainability: putting together the pieces." *IMF Working Paper* WP12/144.

[6] Fay, M. and T. Yepes (2003) "Investing in Infrastructure: What is Needed from 2000 to 2010?" World Bank WPS 3102.

[7] Foster, V. and C. Briceno-Garmendia (2010) *Africa's Infrastructure: a Time for Transition* World Bank, Washington DC.

[8] Gray, C. and A. Martens (1983) "The Political Economy of the 'Recurrent Cost Problem' in the West African Sahel" *World Development* **11**(*2*), 101-117.

[9] Heller, P.S. (1974) "Public Investment in LDC's with Recurrent Cost Constraint: the Kenyan case" *Quarterly Journal of Economics* **88**(May), 251-77.

[10] Heller, P.S. (1991) "Operations and Maintenance" *IMF Public Expenditure Handbook* IMF, Washington DC.

[11] Keen, M. (2012) "Taxation and Development - Again" *IMF Working Paper* WP/12/220.

[12] Kloeden, D. (2011) "Revenue Administration Reforms in Anglophone Africa Since the Early 1990s" *IMF Working Paper* WP/11/162.

[13] Rioja, F.K. (2003) "Filling potholes: macroeconomic effects of maintenance versus new investments in public infrastructure" *Journal of Public Economics* **87,** 2281-2304.

[14] Sunderland, D. (2007) "Managing British Colonial and Post-Colonial Development: The Crown Agents, 1914-1974" Boydell Press, Woodbridge.

Appendix I: Baseline Calibration Parameters

Parameters	Value	Definition
g	1.5	Trend growth rate (% p.a.)
a	1.5	Ratio of non-saving to saving households
a_x, a_n	0.40, 0.55	Capital share in x and n sectors
a_k, a_z, a_{om}	0.5,0.5,0.5	Non-tradable cost share in private capital, public capital and O&M
ρ_x, ρ_n, ρ_m	0.20,0.43,0.37	Distribution parameters for x,n and m sectors
ε	0.5	Intra-temporal elasticity of substitution in consumption
τ	0.34	Inter-temporal elasticity of substitution
ϱ	0.0528	Pure subjective time preference rate
δ	5	Baseline depreciation rate (% per annum)
β_δ	1.0	Accelerated public capital depreciation parameter
h	20	Consumption tax rate (% consumption)
θ	17	Output tax rate (% GDP)
$\overline{s}$,s	0.6,0.6	Infra-marginal and marginal efficiency of public investment
$\bar{l}, \overline{q}$	2.5, 2.5	Efficient r-coefficients for O&M , cents per dollar public capital.
γ_p,γ_m	1.0,1.0	Baseline efficiency parameters for operations and maintenance expenditures
λ_h,λ_θ,λ_T	(1/0),(0/1),0	Steady state fiscal adjustment parameters
λ_{h1},λ_{h2},	(0.50,0.01),	Fiscal reaction parameters (consumption tax)
$\lambda_{\theta 1}$,$\lambda_{\theta 2}$	(0.50,0.01)	Fiscal reaction parameters (output tax)
f_p,f_m,f_d,f_r	(0,0,0,0)	Baseline cost recovery on operations, maintenance, depreciation and financing
bo,do,dco	20, 50, 0	Initial debt (domestic , concessional external and non-concessional external)
r, r_d,r_f	10, 0, 4	Initial interest rates (domestic, concessional and world risk-free interest rate) % p.a.
ν_g,η_g	2.0,3.0	Public external debt risk premium parameters
G, R	5.0, 4.0	Grants and remittances (% GDP)

Appendix II: Cost recovery and incomplete appropriability

Assume that the public capital stock grows at the steady rate g, that debt service on a unit of borrowing is d_t after time t, and that this is arranged to fall at the constant rate ϕ, so that for a dollar loan taken out at time 0, $d_t = d_0 e^{-\phi t}$. Also assume for the moment that the investment programme is entirely financed by borrowing; then, if the government's cost of borrowing is stationary at i, it follows that $d_0 = i + \phi$. Let the public capital stock be K_0 at time 0, so that gross investment, to cover both depreciation and the required net growth, is $(g+\delta)K_0$. It is then straightforward to show that, integrating over past investment, the payment to cover debt service on this cumulated, depreciated, investment at time 0 is:

$$\frac{(i+\phi)(g+\delta)K_0}{(g+\phi)}$$

To avoid a budgetary drain, the user charge (R) would have to be set to cover this cost as well as the O&M costs (r per unit of capital). In other words:

$$R \geq \left(r + \frac{(i+\phi)(g+\delta)}{(g+\phi)} \right)$$

Note that if the interest rate exceeds the growth rate, it is helpful to pay off the debt rapidly: if the growth rate exceeds the interest rate, it pays to do the reverse. Now consider the plausible scenario in which debt service on a particular loan is set to fall at the same rate as the rate of depreciation of the capital it was used to finance, so that $\phi = \delta$.Then the requirement simplifies to $R \geq (r + i + \delta)$.To avoid a drain, the budgetary return to capital needs to be at least equal to the sum of the r-coefficient, the interest rate, and the depreciation rate. For example, suppose the r-coefficient is 0.1, the real interest rate is 10%, and the depreciation rate is 5%. Then to prevent part of these costs becoming a burden on the budget, cost recovery will have to yield a gross return on capital of at least 25% per annum. This argument might appear to rely on the whole investment being financed by borrowing. However, even if part of the initial cost was tax financed, that revenue has an opportunity cost; in the absence of the investment, it could have been used to reduce public debt, and the government's borrowing rate is again a measure of this opportunity cost.

In these circumstances, the ratio of outstanding debt to the capital stock is stationary, whatever the value of ϕ. However, only when $\phi = \delta$ is the stationary ratio of the debt stock the same as the proportion of investment financed by borrowing. It seems reasonable that, if a government was content to finance x% of its current investment by borrowing, it should be content that its debt to capital ratio should also be x%, and that is achieved by setting $\phi = \delta$.

The problem of incomplete appropriability arises when a project generates a social return in excess of $(r+i+\delta)$, so is in principle worth carrying out, but cost recovery can only be achieved at a level below $(r+i+\delta)$, so that the project imposes a net budgetary cost. A decision then has to be made, given an estimate of the MCF, and/or the existence of bounds on achievable tax rates, as to whether the project should still be undertaken.

Finally, it is important to realize that this modeling of the financing costs seeks to focus on what the budgetary authorities ought to have in mind either in setting targets for user charges to cover these costs, or in facing up to the budgetary implications of failing to do so. The actual pattern of borrowings, interest payments and repayments is a separate issue, and the dynamic model picks these up in whatever detail the model user provides.

Appendix III: The social return to public investment

This appendix examines the social return to public investment in the presence of recurrent costs and inefficiency in capital formation. For convenience, it ignores the implications of distortionary tax, that the marginal social cost of public funds may exceed 1, though the full model picks this up via the impact of the output tax.

Suppose that the government spends an extra dollar on investment in period $t-1$. This purchases $s/P_{z,t-1}$ units of installed public capital. The value of extra output in t is:

$$\frac{\psi_x P_{x,t} Q_{x,t} + \psi_n P_{n,t} Q_{n,t}}{z^e_{t-1}} . \frac{s}{P_{z,t-1}}$$

Against this must be set the O&M costs incurred; as formulated above, these are, per dollar of investment:

$$[P_{om,t}(q_{p.t} + q_{m,t})] \cdot \frac{s}{P_{z,t-1}}$$

The quantity of extra public capital is:

$$\frac{s(1-\delta)}{P_{z,t-1}}$$

which it would have cost

$$\frac{(1-\delta)P_{z,t}}{P_{z,t-1}}$$

to acquire in t. Hence the social return to public investment is given by:

$$(1+R^I_t) = \frac{s(\psi_x P_{x,t} Q_{x,t} + \psi_n P_{n,t} Q_{n,t} - P_{om,t}(q_{p,t} + q_{m,t}) z^i_t)}{P_{z,t-1} z^e_{t-1}} + \frac{(1-\delta)P_{z,t}}{P_{z,t-1}}$$

In the initial undistorted steady state, with efficient O&M, $P_{x,t} = P_{n,t} = P_{om,t} = 1$, $P_{z,t} = P_{z,t-1}$, $z^i_t = z^e_{t-1}$,and $P_{x,t}Q_{x,t} + P_{n,t}Q_{n,t} = Y_0$. Also, the calibration sets $\psi_x = \psi_n = \psi$.

The initial social return to public investment in this case is therefore:

$$R^I_0 = \frac{s\left(\psi Y_0 - P_{om,0}(q_p + q_m) z^i_0\right)}{P_{z,0} z^i_0} - \delta$$

Note that the social return to (installed) public capital is:

$$R^z_0 = \frac{\left(\psi Y_0 - P_{om,0}(q_p + q_m) z^i_0\right)}{P_{z,0} z^i_0} - \delta$$

Having $s < 1$ inflicts a double hit in lowering the return to investment relative to the return to capital. First, it lowers the gross of depreciation return by the factor s, but, second, the deduction for depreciation to get the net return is unaffected, rather than being similarly reduced. For example, let $\left(\psi Y_0 / P_{z,0} z_0^i\right) = 0.30$, $\left(P_{om,0}(q_p + q_m)\right) / P_{z,0} = 0.05$, $\delta = 0.05$, and $s = 0.6$. Then $R_0^z = 0.35 - 0.05 - 0.05 = 0.25$. But $R_0^I = 0.6 * (0.35 - 0.05) - 0.05 = 0.18 - 0.05 = 0.13$. The gross of depreciation rate falls to 60% of the efficient value (0.18/0.30), but the net rate falls to only 52% of the efficient value (0.13/0.25).