Working paper

International Growth Centre

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November 2014

When citing this paper, please use the title and the following reference number:
S-43203-UGA-1

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Public Investment and Growth in Uganda*

November 25, 2014

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Abstract

We use a dynamic general equilibrium small open economy model to provide a systematic evaluation of several strategic choices confronting the Ugandan authorities as they consider a substantial increase in public infrastructure investment. The government anticipates future revenues from the development of the Lake Albert oil fields but may choose external borrowing in advance of oil revenues to front-load the investment programme. We allow for inefficiencies in public investment and under-provision of operations and maintenance expenditures. The scenarios considered suggest that it would be a mistake to attempt too much too soon and that, even with a reasonably cautious approach, it would be imprudent to try to invest more than a fraction (somewhere between a third and two thirds) of the oil revenues, net of any consumption dividend.

Keywords: macroeconomics; economic growth; public investment; tax reform; recurrent costs; operations and maintenance.

JEL Codes: E60, E62, O11, O23.

*This paper was written with the generous support of the International Growth Centre. We thank participants at the Bank of Uganda-IGC seminar held in Kampala on 23 October 2014 where we presented an earlier version of the paper. We are particularly grateful to Governor Emmanuel Tumusiime-Mutebile, Deputy Governor Louis Kasekende, Adam Mugume, Justine Bagyenda, Patrick Ocailap, Albert Musisi, Peter Richens and Richard Newfarmer for valuable comments and suggestions. All errors are our own.

1 Introduction

Uganda's public infrastructure is inadequate. Much of it is in need of rehabilitation and, for want of adequate recurrent operations expenditures, much of it operates at less than full efficiency. A deficient and degraded public capital stock depresses the returns to private capital, lowering aggregate economic growth relative to its potential. Uganda is not alone in this respect. Insufficient and poor quality public infrastructure is a common feature across many countries, both developed and developing (IMF, 2014), but the situation in Sub-Saharan Africa is particularly stark: the Africa Infrastructure Country Diagnostic (AICD) study completed in 2010 estimated that infrastructure spending needs for transport, power and telecommunications alone were around US$100bn per annum, equivalent to roughly 10% of the region's annual output. Tellingly, around 30% of this is accounted for by additional operations and maintenance expenditures required to rehabilitate the existing infrastructure capital (Foster and Briceno-Garmendia, 2010). Closing the 'infrastructure gap' effectively therefore entails both an increase in public investment rates and putting in place the institutional reforms required to ensure sufficient recurrent operations and maintenance (O&M) expenditures to sustain the flow of public capital services to private capital.

The corollary is that the growth effects of a public investment surge can be positive and, under the right circumstances, may be large enough to be "self financing". In other words, if the medium-term output multiplier is sufficiently greater than one, debt-financed public investment can coexist with a falling debt to GDP ratio (see Chapter 3 of the IMF World Economic Outlook, October 2014). Based on a range of empirical approaches, the IMF estimates the output multiplier to lie in the range from 1 to 1.3 for developed economies – in other words within the self-financing range – but that for emerging markets and developing countries it is substantially lower, although still positive. A forthcoming IMF meta analysis of a large number of empirical studies on developing countries suggests that the medium term elasticity of output with respect to public infrastructure capital is around 0.17.[1]

Whether these potential returns can be realized in the case of Uganda depends on a host of factors including: the efficiency of public investment and the subsequent maintenance of the installed infrastructure; the manner in which investment is financed, whether from donor grants or non-concessional debt, from new oil revenues, from conventional taxation or from user charges; the strength of the complementarity between public and private capital; and on the underlying structure of the economy, including how distortionary the tax system is. However configured, the fundamental constraint on the viability of an investment surge is that the economy-wide intertemporal solvency condition be satisfied. This means simply that increased expenditure is financed out of some combination of higher gross national income (the present value of domestic output plus unrequited grants or transfers from overseas) and reductions in other elements of

[1] Bom and Litgart (forthcoming). This estimate is the value used in the simulation model discussed here.

expenditure, in particular consumption spending. Debt can play a role in investment financing, but only to the extent that it alters the feasible profile of spending, essentially by delinking current spending from current income. Ultimately, it has to be repaid.

In practice, aid flows and other transfers such as remittances are unlikely to play much of a financing role in Uganda over the foreseeable future which means that any increased investment must be financed from the growth in output induced by higher public and private investment, from reductions in consumption (brought about by higher taxation and/or user charges) and, crucially, from revenues accruing to government from the development of the oil reserves. Given that oil revenues will not come on stream for a number of years, non-concessional borrowing can play an important role here, bridging the gap between current investment expenditures and future revenues. Uganda has not yet gone to the sovereign bond market to finance this gap, although it clearly could and, in the current climate, could probably access funds at a modest rate. Whether it is sensible to do so and at what scale will play a key role in the following analysis.

The objective of this paper is thus to offer a systematic evaluation of a range of strategic choices confronting the Ugandan authorities as they consider a substantial increase in public infrastructure investment. Following a brief summary of the Uganda context, Section 2 lays out the general modelling approach. Section 3 provides context for the policy simulations and the calibration to Uganda, before the specific scenarios are considered in Section 4. The final section concludes. Details of the model and the baseline calibration as well as the various policy simulations are described in a set of appendices.

1.1 The Uganda context

Uganda is, in many respects, an archetypical newly resource-rich low-income country. Per capita income in 2014 was estimated at $686 and has grown by an average of 3.2% over the past decade, though with a notable deceleration since the global financial crisis. At 3.0%, population growth is amongst the highest in the world, and at this rate the number of Ugandans will rise from 35 million today to 73 million by 2040. Rapid urbanisation is changing a largely rural country. Combined with a surging population, the expansion of urban centres will put further pressure on the country's limited and ageing infrastructure.[2] With the Lake Albert oil fields expected to come onstream towards the end of the decade, a public investment surge is now on the drawing board. Transport and energy infrastructure are particular targets of public investment plans that include new roads, a modern railway line from Kenya and on to Rwanda, South Sudan and DRC, two major hydropower dams and finally a small petroleum refinery and a pipeline to transport

[2] In his book *Journal of the Discovery of the Source of the Nile* (1864), the 19th century British explorer John Hanning Speke recorded with admiration the quality of transport infrastructure in the Kingdom of Buganda, noting that: "...The roads, and indeed they were every where, were as broad as our coach roads, cut through the long grasses, straight over the hills and down through the woods in the dells – a strange contrast to the wretched tracks in all the adjacent countries.

oil to the Kenyan coast. Beyond economic infrastructure improvements, the population increase will necessitate upgrading and new construction of social service facilities such as schools and hospitals.

The oil found in Uganda is a waxy and sulphurous crude that requires pre-processing before being transported to a refinery or export terminal on the coast. It is therefore relatively expensive to bring to market but, even so, preliminary estimates based on a reference price for West Texas Intermediate of US$75 imply that the government's share of oil revenues will reach slightly over 10% of initial GDP at peak production.[3] The cumulative revenues from the oil boom over its lifetime are estimated to be equivalent to approximately 250% of 2013 GDP. From a public finance perspective, oil revenues are expected to increase the resource envelope by about 40% of non-oil revenues (Ministry of Finance, Economic Planning and Development, 2014). Although important, oil revenues are not likely to be transformative in their own right. The challenge will be to ensure that they are used in a catalytic manner, to support the growth and development of the non-oil economy. Given the enclave nature of the oil sector, this catalytic role will principally be played by the government budget,primarily by means of the public investment programme.

2 The Modelling Approach

The purpose of this section is simply to sketch the general modelling approach, and to indicate the sorts of questions that can be addressed with it, as well as those for which it is not suited. The details of the simulation model are given in Appendix I. Our intention is to provide an integrated approach tailored to Uganda- though of potentially much wider application - to public investment, how it is financed, and the associated growth and consumption outcomes. The model used here is an adaptation of one developed recently by the IMF Research Department[4] and is intended to improve its public finance attributes.

2.1 The model and what it is designed to do

The model is a real small open economy model, with two sectors, tradables and non-tradables. Production in each sector is a function of public and private capital and of labour, and is carried out by competitive, price-taking firms. There are constant returns to the private factors, and increasing returns to all three factors taken together. There is steady trend growth in productivity, uniform across sectors. There is also an oil sector, but this is treated as an enclave which does not use domestic factors; it simply generates a flow of revenue to government. Public debt may be domestic, external concessional, or external non-concessional. Interest payable on the last of these may include a risk premium that rises with the government's indebtedness. Some households have access to financial markets, while others are credit constrained and consume

[3] This is based on the model assumption of a 3% per annum growth in underlying per capita GDP.

[4] Buffie et al, 2012

their current income. The former maximize an additive intertemporal utility function; for all households, instantaneous utility is a function of both consumption and leisure.

Taxes are levied on capital and labour incomes and on consumption. Given the characterization of firms and households, these taxes are distortionary and impose deadweight loses on the private sector; getting a dollar into the hands of the government inflicts more than a dollar of cost on the private sector. In addition, not all of the revenue that a given tax rate would raise, given the tax base, actually accrues to government as spendable resources. This leakage may reflect a range of things, including the costs of tax administration, the existence of tax exemptions, tax avoidance and tax evasion, and indeed some degree of corruption.

In principle, additional public capital raises the productivity of private factors and crowds in private investment. Together, these will raise the level of GDP and of the consumption that it can support. These consequences will be more marked when, as in the case of Uganda, the initial public capital stock is very inadequate.

However, the costs of public investment are not restricted to the upfront capital cost and associated financing; they also include ongoing recurrent costs for operations and maintenance, and since, even when adequately maintained, capital still depreciates, there will also be the cost of future replacement. The scale of recurrent costs per dollar of investment varies very significantly with the type of investment, tending to be much higher for social than for economic infrastructure (Heller, 1991). In addition, for reasons ranging from the technical to the political, government is typically unable or unwilling fully to recover these recurrent costs through user charges. In consequence, public investment creates fiscal burdens for which finance must be found.

Government is not modelled as an optimizer; it makes exogenous decisions, or follows rules of thumb. Its capital programme may be inefficient, both in the quality of public investment and in implementing the additional operations and maintenance expenditures that the programme requires. These inefficiencies mean respectively that an additional dollar of public investment may not lead to an additional dollar of public capital being installed; that what capital is installed may not deliver its full level of services; and that installed capital depreciates faster than it should. Unless great care is taken, these inefficiencies may all worsen during a phase of ambitious investment acceleration. There may also be adjustment costs during this phase, associated with capacity limitations in the private and public sectors, which raise the unit cost of investment.

The model is designed to provide an integrated assessment of the various benefits and costs of additional public investment, while taking into account deficiencies in the available financing options.

2.2 What the model is not, or is not designed to do

The model is a calibrated policy simulation framework designed to explore the properties of alternative scenarios and so cannot be used for forecasting. It is not a monetary model, so it does not examine inflation or nominal exchange rate dynamics. It is a value-added model, meaning that it cannot examine intermediate input linkages, and it is an aggregated macroeconomic model, so it cannot be used to examine the sectoral composition of public investment. Apart from aggregate public investment and the related operations and maintenance expenditures, other public expenditure is not modelled other than as a transfer to private consumers.

A comprehensive approach to public investment choices needs to address all these matters, but it would certainly be impractical, and perhaps undesirable, to attempt to do so within a single modelling framework. Instead, it will be necessary to pursue an array of complementary forms of analysis, ideally with some degree of iteration between them. The present model aspires only to be one element in such an array.

3 Calibration and the Context for Policy Simulations

Using models of this type for policy simulation require us to calibrate both the initial baseline solution and the policy simulations. The aim of the calibration is two-fold: to ensure that the initial numerical solution of the model replicates the broad macroeconomic contours of contemporary Uganda, and to ensure that the values of key behavioural parameters and elasticities governing the model behaviour generate plausible responses to the simulated policy experiments. In terms of the policy simulations, we seek to define a set of simulations that are consistent with the distribution of investment and financing packages currently under consideration by the authorities. The baseline calibration parameters are reported in Appendix II and the characteristics of the policy simulations in Appendix III.

3.1 Baseline model calibration

The baseline calibration, described in Table 1, reflects an economy operating with modest (single-digit) fiscal and current account deficits, sustained by a public debt stock of around 30% of GDP.[5] On the production side, the economy is broadly balanced between tradable and non-tradable production. Absorption exceeds GDP, which is reflected in a current account deficit of 10.7% of GDP before aid and remittances. The government account reflects a moderate deficit of 2.6% of GDP which is financed by grants from aid donors and domestic debt financing, and total

[5] The values defining the calibration will not match exactly the government's own accounts for FY2012/13 or, indeed, those produced by the IMF. These differences reflect, amongst other things, the fact that the model is a necessarily simplified representation of the economy and hence demands an equivalent 'simplification' of the data. The key issue is whether this calibration reflects the essential features of the economy, and we believe that it does.

government debt is 29% of GDP, split between concessional external debt and domestic debt. There is no non-concessional debt on the books in the initial calibration. Revenue is derived principally from taxes on expenditure (tariffs, excise and VAT / sales taxes) and government expenditures are split almost equally between recurrent expenditures including debt service and public capital formation.[6]

The baseline embodies both distortionary taxation and tax leakages, so that the revenue yield of 12.8% of GDP requires effective marginal tax rates on consumption, profits and wages that are higher than would be the case if all revenue accrued to government. It also assumes inefficiencies in public capital formation and that O&M expenditures are at less than their efficient levels. Given these settings and the economy-wide labour endowment, the calibration generates an initial GDP that is normalized to 100, an initial price and wage vector of unity (we can think of these as price indices), and a set of parameters defining production and the elasticity of output with respect to public capital. An important feature of this calibration is that the initial equilibrium is inefficient, in the sense that there are distortions in the public sector (the inefficiencies in capital formation, deficient O&M and tax leakage as discussed above). Moreover, while the model assumes that the private sector optimizes its consumption and production behaviour given its endowments and the prices and taxes it faces, the government is not an optimizing agent. Rather it is assumed to operate by making simple exogenous policy choices over expenditure, taxation, and borrowing. This set-up allows us to undertake a positive analysis of alternative policy simulations.

3.2 Policy simulations

The policy simulations examined in this paper share a common core in which the authorities seek to use the discovery of oil to raise the share of public investment in GDP for an extended period, in an investment "pulse". Following the pulse, investment is scaled back (as a share of GDP) so that the public capital stock is stabilized at a higher public capital-output ratio; in our baseline simulation the new steady-state public capital-output ratio is approximately 30% higher than in the initial steady state. In conducting the analysis we define an initial policy simulation and then explore the consequences of variations along several dimensions. In policy terms, the government may change the scale, duration and timing of the investment pulse and alter the proportion of the investment pulse that is covered by sovereign borrowing. We also allow for changes in the general policy environment and in external economic conditions. In the former case we focus on the risk of deteriorating fiscal conditions that result in greater inefficiency in public investment and lower budgetary provision for necessary O&M expenditures. In the latter, we consider the effects of a fall in oil prices and an increase in the country risk premium demanded in the sovereign debt market.

[6] The public investment figure used here is somewhat higher than that given in government or IMF accounts for Uganda.

It is important to note that the simulations considered below represent a small fraction of the range of scenarios that the model can examine. For example, we do not explore broader issues of tax and expenditure reforms that might be geared towards minimizing the aggregate excess burden of taxation or reducing tax leakages. Similarly, we do not examine how the results vary in response to different assumptions about the efficient levels of O&M expenditures, nor do we look in any detail at the so-called 'investing-in-investing' agenda that seeks to improve the efficiency of public investment. These are all legitimate and feasible issues to explore through simulation in this framework, but we necessarily limit our attention to some of the pertinent strategic choices facing Uganda today.

3.2.1 The oil windfall

Our assumptions about the structure and profile of oil revenues are the same across all the simulations except one. First, we assume that oil revenue flowing to government will follow a hump shape, starting at around 6 years from the start of the simulation period (which we take as FY 2012/13), peaking around a decade later, then falling to a negligible level around 20 years after that (see Figure 1, which plots the windfall as a share of the model's trend non-oil GDP). While estimates of production, and hence the shape of the windfall, appear to be reasonably firm, uncertainty about future prices means that the value of the windfall is difficult to predict. The figures used to calibrate the experiments are based on data made available by the Ministry of Finance in April 2014, but we also explore the consequences of (adverse) movements in the oil price.

In principle, it would be possible to spend these oil revenues as and when they accrue, in which case they would be fiscally neutral, having no direct implication for the profile of government debt or taxes, though the public spending would of course have welfare consequences as well as implications for macroeconomic balances and growth. In practice, such a course is both unattractive and infeasible, because of the imminent desire to develop the country, and because of the impractically steep spending profile that would result. Instead, some decision has to be made as to how much of the revenue windfall to spend and invest each year, when to start, and for what duration. Our simulations generally assume that government has decided not to delay the start of the investment pulse, so that additional expenditures will be made before oil revenues accrue; this will necessitate some combination of additional borrowing and additional taxation in the early years. The scope for both may be circumscribed which limits the increase in the investment rate that can realistically be financed. A final simulation is included to illustrate the consequences of delaying the investment pulse until oil revenues start to flow.

3.2.2 Spending the oil revenues: current transfers and public investment

Government may choose to use part of the revenue windfall as a 'consumption dividend', paid out over a finite period or in perpetuity, and allocate another fraction of the windfall to public capital formation. We vary the shape of the investment pulse along two dimensions, its duration and its overall scale. In either case we define a gross dollar value of investment of amount iz_t per annum for T years. This steady gross investment rate is achieved only following a four-year linear build-up phase. The investment pulse ends with $iz_t = 0$ from $T + 5$ onwards. The first variation is to allow for shorter or longer investment pulses, for example, $T = 20$, $T = 10$ or $T = 5$ although in each case the duration of the build-up phase remains constant. For a given total sum allocated to gross public investment, the installed public capital rises by more the shorter is the duration of the pulse. The second choice is simply how much of the oil windfall, net of the consumption dividend, to allocate to investment. Two critical features complete the characterization of the investment pulse. The first is that we assume that the windfall finances the *gross* investment only so that the depreciation costs on the enhanced capital, along with associated O&M expenditures, are charged against the general government budget and not the windfall. The second is what happens after the pulse: here we assume that the gross public investment from $T + 5$ onwards is sufficient to stabilise the ratio of public capital stock to trend GDP at a level approximately 30% higher than the baseline in perpetuity. The full cost of doing so is a direct charge on the budget.

3.2.3 Sovereign Wealth Fund

Once oil revenues have increased above the sum of the consumption dividend and public investment spending, the excess is placed in the sovereign wealth fund (SWF). Income earned on the SWF accrues directly to the budget while government chooses a draw-down path for the Fund. Government could choose to draw down the Fund over a finite period, or could choose to consume only the annuity value of the SWF in perpetuity. In circumstances like Uganda's, where the return to public capital is likely substantially to exceed that on the SWF, the former will usually be preferable. Our default setting allows for the SWF to be drawn down gradually after the end of the oil boom.

3.3 External debt financing

We assume that government can access the sovereign bond market and structure its borrowing to the required profile of financing needs. Hence, the government can contract sovereign debt sufficient to meet some fraction of the excess of gross investment over oil revenues for the first 15 years of the investment pulse (which coincides with the sharpest rise in oil revenues). Sovereign bonds are priced initially at 700 basis points above the risk free rate (1.5% per annum) but face a risk premium that is increasing in the stock of external debt net of the value of the SWF.

Across all the simulations discussed in the next section we assume that external non-concessional borrowing is temporary so that the overall debt burden eventually returns to its initial level.[7]

4 Policy Simulations

4.1 Introduction

It was noted in the previous section that while the simulations presented here are quite restricted in scope, the model could be used to explore a very wide variety of possible futures. In particular, a single scale and time profile of oil production volumes is postulated, and, with one exception, a single oil price. The intention is not to explore uncertainties surrounding oil revenues, or indeed any other uncertainties, such as those involving other terms of trade shocks or production shocks. It is rather to focus on the consequences of different policy responses to a given characterization of the oil windfall. An investment 'pulse' is considered in each case, which may vary in start date, duration, and level.

We limit ourselves to ten simulations, presented in Figures 1 to 10, a brief description of each of which is provided in Table 2. The same nine panels are presented for each scenario, graphing variables of interest over a forty year horizon. The reader may wish to consult one of the Figures to get the most out of the following description. The top left panel plots the three investment rates for the tradable, non-tradable and public sectors – all as per cent of trend GDP – with the public investment pulse prominent. The middle left panel plots the two real exchange rates, one for consumption, the other for production, both indexed to the initial value of the production real exchange rate. The lower left panel plots the three debt stocks, again as per cent of GDP. The upper central panel plots actual GDP (including oil), consumption and government transfers, all relative to their initial values. The middle central panel plots the required non-oil revenue share in non-oil GDP for the other variables to hold. If that revenue share were unobtainable, something else would have to give (such as more external borrowing, or less investment). The lower central panel plots oil revenue (a flow) and the sovereign wealth fund (a stock), both relative to GDP. The upper right panel plots non-oil GDP for the tradable and non-tradable sectors separately, both relative to their initial values. The middle right panel plots the percentage rates of return to the three capital stocks (net of tax for the private stocks). The lower right panel plots the three capital stocks themselves, relative to their initial values. In Table 3 we provide a numerical summary of the evolution of non-oil output, aggregate consumption, the required tax revenue and public debt at three key points along the dynamic path; at $t = 7$, just before the oil flows, at $t = 15$ at the end of the investment boom (in all but two of the scenarios) which happens to coincide with the peak of the oil revenues, and at $t = \infty$,

[7] This is a modelling choice: there is no presumption that the initial debt ratios are, in any sense optimal, and hence there is no strong argument for returning to this level as opposed to allowing the debt stock to rise permanently.

corresponding to the new long-run steady state. For convenience we also report the extreme value for each of the variables (which is a maximum in the case of all variables except for private consumption.

It was felt desirable to provide a standard set of plots for all scenarios, but no attempt is made in what follows to discuss all of them; a handful of highlights is noted in each case. The reader can choose to focus on some subset of the scenarios provided here. Before looking at the detail, three systematic features of the whole set may be highlighted.

The first is that it is not feasible to invest the whole windfall, even if that were desired. The reason is implicit in the discussion of Section 2. An additional dollar of gross investment carries with it a complicated burden of financing, depreciation, operations and maintenance costs which must also be provided for. The increased GDP consequent on the investment provides some additional revenue through the operation of the existing tax system, and there may be some element of cost recovery, but in general there will be a financing deficit which may substantially increase the need for domestic taxation if too much of the windfall is invested. Recourse to external borrowing can shift the time profile of this need, but not reduce its overall burden. Of course, it would be possible to compute the present value of the total costs of investment to take all these consequential costs into account, but that is not the way in which the costs of investment are conventionally calculated, nor is it the way in which alternative investment programmes are currently being discussed in Uganda. Instead, a public investment plan with projects approved according to various criteria exists and competes for resources with new initiatives.

Secondly, it is worthwhile to highlight that the altogether understandable desire to start investing the windfall as soon as it is reasonably assured, rather than waiting until the revenues are currently available, does have serious consequences. Paying for the investment before the revenues arrive means some combination of higher taxes and external borrowing at relatively high interest rates. Since there are quite severe limits as to how much additional domestic revenue can be raised, this means that the level of the pulse may be quite limited because of financing considerations, even if it were not limited by absorptive capacity constraints. Of course, that problem could be ameliorated if it were possible to persuade donors to provide additional concessional financing for these infrastructure investments.

The third feature involves temporary shifts in domestic production. Given the structure of taxation in Uganda, and assuming that any increased tax revenue broadly reflects this structure, any rise in tax rates is likely to bear disproportionately on consumption, and this is apparent in the simulations. A sharp temporary reduction in private consumption during an oil windfall would be undesirable from a welfare perspective and would likely be politically infeasible, so one feature of a feasible policy programme would be a path for consumption which at least maintained it along its trend. However, achieving this would have one potentially awkward consequence, involving Dutch Disease effects. As modelled, there is a 50% non-traded component in public investment. If an investment pulse is financed by taxes that substantially lower private consumption, the increased demand for non-tradables from the investment sector is largely offset by a reduction in the demand for them for consumption. If, however, the pulse is financed in a way that protects consumption, there is no such offset, and the real production exchange rate appreciates sharply. What is involved is a substantial shift into non-tradable production during the pulse, which is subsequently reversed. The present model allows this reversible shift to take place costlessly, whereas it might be disruptive in practice, initially with sharp cost increases in non-tradables and idle resources in tradables, and subsequently the converse.

Finally, it should be stressed that the purpose of these exercises is not to identify an optimal strategy, which should be the outcome of the political process. It is rather to begin mapping a set of feasible policy combinations within which policy choices can sensibly be made.

4.2 The ten simulations

Scenario 1: Baseline ten-year investment pulse

The baseline simulation is designed to be reasonably reflective of current investment plans. The public investment pulse starts immediately, builds up in linear fashion over 4 years, and is then sustained in constant shilling terms for a further 10 years. Gross public investment increases by 56%, growing from 7.6% to 11.9% of GDP over your years and is then sustained from years 5 to 14. At the end of that period, public investment is stabilised at the value needed to maintain the enhanced public capital stock. Also anticipating the oil revenues, a consumption transfer equal to 2.5% of GDP is started immediately and maintained for 20 years. In sum, these assumptions mean that 30% of the windfall, net of the consumption transfer, is invested during the pulse. It is assumed that 60% of this is financed by non-concessional borrowing, with the residue coming from taxes. This 60% financing assumption is common to all scenarios other than scenarios 2 and 10. There is also some temporary accommodating domestic borrowing, mainly to smooth adjustments to taxes, which may be quite substantial. It is further assumed that investment efficiency is 75% (so that a dollar of investment yields 75 cents of additional capital), that operations and maintenance expenditures are at 80% of efficient levels, and that the tax wedge reflecting revenue losses is at 20%. No cost recovery takes place in this scenario.

The notable outcomes of this scenario are that the public capital stock rises by a little under 50%, non-concessional debt peaks at around 20% of GDP, and the non-oil revenue mobilisation requirement rises by nearly 6 percentage points to 18.6% of non-oil GDP after 9 years. It eventually falls back to 14.4% of GDP. This would require a pretty dramatic temporary rise in tax rates, even supposing the tax wedge did not rise, and would induce a temporary, though fairly mild dip in consumption. Even so, domestic borrowing rises by more than 6% of GDP (to more than one and a half time its initial value) by the time the oil revenues start to flow. It is natural to wonder whether the profile could be improved by increased external borrowing, and scenario 2 looks at this.

Scenario 2: Baseline with higher sovereign borrowing

All the assumptions of scenario 1 are maintained, with the exception that all of the investment pulse is now financed with non-concessional debt, which rises to more than 30% of GDP. While this higher debt financing serves to keep the required tax revenue on an initially lower path, 'saving' around 1.5 percentage points of GDP per annum in the first decade, the revenue share nonetheless still has to rise to 17.3% of GDP after 9 years and exceeds the Scenario 1 level from year 12 through year 40. This reflects the cost of servicing the higher volume of non-concessional finance, reinforced by a rising risk premium. The implication is that increased external borrowing smoothes the tax adjustment but does little to alleviate the tax problem associated with this investment pulse over the medium term.

Scenario 3: Ambitious investment pulse

Before we explore alternative phasings of the investment pulse, it is worth pushing the baseline a bit harder to consider what happens when the authorities seek to implement a higher investment volume. To illustrate this, we repeat the baseline scenario except that public investment now increases by 125% from 7.6% to 16.2% of GDP from years 5 to 15. Required revenue peaks at 23.7% of GDP after 9 years and total debt rises to 65.5% of GDP. Consumption falls by 5.1% in the short run before recovering. Were this scenario feasible, it would yield a much higher public capital stock and enhanced long run GDP and consumption outcomes in the long run. However, although the model itself comfortably solves – so that the path is 'model feasible' – the implied path for tax revenue is so far from what might be either politically or technically feasible in contemporary Uganda that we might reasonably view this as a non-credible simulation.

Scenario 4: False economy

Confronted by this revenue requirement, it is reasonable to consider the alternatives. In the following scenarios we explore the effects of altering the profile of the investment pulse. Before doing so, we consider what might happen if the government tries to stick to its investment guns and is unwilling to see taxes rise, so instead implements expenditure cuts that result in a scaling-back of O&M expenditures from 80% to 60% of the efficient level. Observing this back-sliding on recurrent expenditures, private creditors mark up their country risk premium. This strategy does indeed keep tax rates lower for the first few years of the simulation but not for long: The false economy of scaling back O&M expenditures would have the consequence of reducing the long-run gain in capital stock from something over 50% in scenario 3 to virtually nil in this scenario. Moreover, beyond the first few years, it does not reduce, but exacerbates the tax problem, raising required revenue in the long run to nearly 25% of GDP. Not only does this fail to solve the tax problem, it also exacerbates the consumption problem, with this falling by more than 9% in both short and long runs.

The evident difficulties associated with attempts to force through a rapid and large investment pulse poses the question as to what might happen if the same scale of investment were spread out over a longer horizon. Scenarios 5 and 6 look at this.

Scenario 5: Extended investment pulse

Because the total volume of investment is unchanged, public investment now increases by a more modest amount, up 26% from 7.6% to 9.6% of GDP, where it remains from years 5 to 24. Now tax revenue has to rise only to 15.9% of non-oil GDP, or by which is a little over 3 percentage points. The required level of external borrowing is much as in Scenario 1, while domestic borrowing is flatter, consistent with the reduced extent of the tax smoothing problem. While this configuration essentially halves the required tax rise, which is now much more likely to be politically achievable, it is not without cost. The ultimate increase in capital stock in this case is substantially reduced, and so, in consequence, there is some reduction in final GDP and consumption. In the long run GDP is 2.3% lower and consumption 1.4% compared to Scenario 1. On the other hand, the flatter required tax profile means that consumption no longer dips in the early years.

Scenario 6: Enhanced extended investment pulse

A natural corollary of extending the investment pulse is that a higher share of the windfall can be allocated to investment. This scenario therefore combines the extended 4+20 year pulse but in this case raises investment to the same 11.9% of GDP as in scenario 1. This implies that 65% of the windfall net of transfers is invested. Since 60% of this is financed by external borrowing, non-concessional debt now rises to over 40% of GDP and tax revenue to 17.8%. Total public debt peaks at 73.8% of GDP, making this a very high risk strategy. However, if these risks did not materialize, the addition to the public capital stock would be greater, resulting in higher final GDP and consumption.

Scenario 7: Crumbling fiscal control

So far, the scenarios have assumed no change in the efficiency of the fiscal system. This scenario describes the case where the investment plans of Scenario 1 place the budgetary system under such pressure that fiscal control deteriorates in two respects. First, as tax rates are pushed up, so tax leakages increase: instead of 80% of notional revenue reaching government, only 60% does. Second, actual budgetary provision for O&M expenditures declines from the initial value of 80% to 60%, reducing the effectiveness of public capital and accelerating its depreciation. The combined effect is extremely damaging. As tax leakages rise, nominal tax rates have to be increased still further to generate the required revenue; the consequence is a steep fall in consumption by around 10%. What is more, the reduced O&M so reduces the viability of public capital that the public investment programme fails to increase the effective public capital stock.After some recovery in the middle years, consumption reverts to 10% below its initial value in the long run. In effect the windfall is not only wasted in terms of adding to the capital stock, it leads to permanent immiserization of consumers.

Scenario 8: Poor resource management

We now suppose that these fiscal control problems are compounded by the kinds of political economy and external risks that can confront resource-dependent economies, problems of the kind that are currently afflicting Ghana. This run replicates scenario 5, with three added twists. First, the consumption transfer is now doubled from 2.5% to 5% of GDP and sustained indefinitely, rather than phased out after 20 years. Second, there is a significant deterioration in the risk premium associated with external debt as creditors demand ever greater compensation for country risk . Third, the oil price settles at only 75% of the value previously assumed. The required revenue share now leaps to a completely infeasible 21.1% of GDP after 7 years, and ultimately to 23.3% in the long run. Public and private capital stocks contract even more and the long run fall in consumption is now 14.5%. Clearly, this type of catastrophic path would be infeasible; something would eventually have to give. The purpose of this simulation is not to suggest that these outcomes would be feasible, though highly undesirable. It is rather to explore policy combinations which could not reasonably be sustained in practice, so should not be embarked upon in the first place. While moderate consumption transfers can be valuable, their level should be limited to safeguard resilience to macroeconomic shocks.

Scenario 9: Partial cost recovery

So far we have assumed that the financing of investment – recurrent O&M, depreciation and interest costs – falls on the budget. Here we consider the case where some share of this cost is met through a user charge. Scenario 9 replicates the baseline scenario with only one change, namely that user charges recover 20% of the total ongoing costs of the investment. The user charge is levied directly on households *pro rata*. Since, in the model, these charges do not reduce useage of the services of public capital, they act like a lump sum tax, or reduction in the transfer. In consequence, they alleviate the tax problem somewhat, and since this reduces tax distortions, outcomes are improved, but not dramatically.

Scenario 10: Deferred investment pulse

Our final simulation returns to the nature of the investment pulse to examine the consequences of adopting the very conservative approach of refraining from any increased public expenditure until the oil revenues come on stream. We therefore make three variations to the baseline scenario. First, the start of investment is delayed until substantial oil revenues come on stream.

The pulse, once started, again takes the form of a four year build-up, and ten years at the new higher level. Second, and in consequence of the delay, no non-concessional borrowing is required. Third, and even without borrowing, it is now feasible to increase the investment level so that 50% of the windfall net of consumption transfers can be invested. The required revenue share is now relatively flat, rising only to 16% of non-oil GDP. Consumption shows a slight dip in the early years, but rises in the long run by 6.1% relative to trend, a better outcome than for any scenario other than the reckless Scenario 3. The same is true of output, which grows by 10% relative to trend. From a policymaker's perspective, Scenario 10 looks very attractive, except for two features. The first is that while the volume of the windfall that can be invested has increased, the gains from this investment are delayed. How large a cost this is would require us to define an explicit social welfare measure. The second is that, as noted above, the smooth consumption path means that a sharp appreciation of the production real exchange rate is required to generate a sufficient supply of non-tradables to meet the demand for capital goods, resulting in problems for exporters.

5 Conclusion

Uganda has been very successful in maintaining a high rate of growth over an extended period, but faces real challenges in sustaining this level of performance in future. One of these challenges is the inadequate level and poor state of the country's infrastructure. The discovery of substantial oil reserves and the projected consequential increase in budgetary resources provides a significant opportunity to address this problem. However, as well as an opportunity, it also carries risks. To maximize the benefit without incurring excessive risk, policy makers will have to consider just how much of these revenues should be invested, and how rapidly. Too high a level of investment prior to the arrival of the revenues may require unacceptable levels of non-concessional borrowing or domestic taxation; too cautious an approach will unacceptably defer the benefits of public investment. This paper attempts to provide a means, amongst others, of weighing up these different costs and benefits, and the associated risks, which can assist in this difficult policy process. The scenarios considered suggest that it would be a mistake to attempt too much too soon and that, even with a reasonably cautious approach, it would be imprudent to try to invest more than a fraction (somewhere between a third and two thirds) of the oil revenues, net of any consumption dividend that may be planned.

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Appendix I: the Model

The model describes a two-sector small open economy producing a traded good q_x and a non-traded good q_n from private capital, labour, and government-supplied infrastructure. Domestic production is augmented by an enclave oil sector that generates a flow of resource rents to the government. Households consume domestically-produced goods along with imported consumption goods c_m. Capital goods (machines) m_m, are also imported and combined with the non-traded good to produce 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 and t is the time index. The model abstracts from money and all nominal rigidities, but includes taxation 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.

5.1 Firms

5.1.1 Technology

In each productive 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 non-excludable public good, into output:

$$q_{j,t} = a_j (z^e_{t-1})^{\psi_j} (k_{j,t-1})^{\alpha_j} (L_{j,t})^{1-\alpha_j} \tag{5.1}$$

where the a_j are sector-specific productivities. There are constant returns to private factors, with capital shares α_j, but increasing returns in the presence of public infrastructure as measured by ψ_j. Public and private capital is built by combining imported machines and a non-traded input (e.g., construction) in fixed proportions, determined by a_k and a_z respectively. The supply prices of private capital and infrastructure are thus:

$$P_{k,t} = (1 - a_k) P_{m,t} + a_k P_{n,t} \tag{5.2}$$

$$P_{z,t} = (1 - a_z) P_{m,t} + a_z P_{n,t} \tag{5.3}$$

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

5.1.2 Factor demands

Competitive profit-maximizing firms equate the (private) marginal value product of each input to its factor price,

$$P_{j,t}(1-\alpha_j)\frac{q_{j,t}}{L_{j,t}} = (1+\theta_{w,t})w_t \tag{5.4}$$

$$P_{j,t}\alpha_j\frac{q_{j,t}}{k_{j,t-1}} = (1+\theta_{j,t})r_{j,t} \tag{5.5}$$

for $j = x, n$ where w is the net of tax wage, r_j is the net rental earned by capital in sector j and $\theta_w$and θ_j are tax rates on labour and (sector-specific) capital income respectively. Labour is intersectorally mobile, so the same wage appears in (5.4) for $j = x$ and $j = n$. Capital is sector-specific but at equilibrium the allocation of k_x and k_n ensures net-of-tax rentals are equalized. Critically, taxes on factors drive wedges between private and social values. In the presence of a tax on labour, the real wage is reduced below the marginal product of labour. For private capital, faced with a given steady state r, which is determined in the model by savers' preference parameters over the infinite horizon, the output to capital ratio must rise by $(1+\theta_j)$. This, in turn, means private capital stocks are lower than what would have been the case in the absence of capital taxes, for example had all government revenue been raised from a lump sum tax. Notice, also, that the lower capital stock in equilibrium lowers the marginal product of labour (and the real wage).

5.2 Households

There are two types of private households, savers and non-savers, distinguished by the superscripts $i = s, h$ respectively. The ratio of non-saver to saver households is given by a. Households are infinitely-lived with utility, for both savers and non-savers, defined by the following function: :

$$U^i = \sum_{t=0}^{\infty}\beta^t\left[\frac{(c_t^i)^{1-1/\tau^i}}{1-1/\tau^i} - \kappa^i\frac{\left(L_t^i\right)^{1+1/\iota^i}}{1+1/\iota^i}\right] \tag{5.6}$$

where β is the discount factor; τ is the inter-temporal elasticity of substitution in consumption and ι the 'Frisch' elasticity of labour supply. Aggregate consumption, c_t, is defined as a constant elasticity of substitution (CES) aggregate defined over the domestic traded good $c_{x,t}^i$, the foreign traded good $c_{m,t}^i$, and the domestic non-traded good $c_{n,t}^i$ for $i = s, h$, thus:

$$c_t^i = \left[\rho_x^{\frac{1}{\epsilon}}(c_{x,t}^i)^{\frac{\epsilon-1}{\epsilon}} + \rho_m^{\frac{1}{\epsilon}}(c_{m,t}^i)^{\frac{\epsilon-1}{\epsilon}} + \rho_n^{\frac{1}{\epsilon}}(c_{n,t}^i)^{\frac{\epsilon-1}{\epsilon}}\right]^{\frac{\epsilon}{\epsilon-1}} \tag{5.7}$$

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 elasticity of substitution between the commodities. These parameters are common across the two households. The true consumer price index associated with the (common) consumption basket (5.7) is:

$$Pc_t = \left[\rho_x P_{cx,t}^{1-\epsilon} + \rho_m P_{cm,t}^{1-\epsilon} + \rho_n P_{cn,t}^{1-\epsilon}\right]^{\frac{1}{1-\epsilon}}$$

with demand functions for each good:

$$c_{l,t}^i = \rho_l \left(\frac{P_{cl,t}}{Pc_t}\right)^{-\epsilon} c_t^i$$

for $l = x, m, n$ and $i = s, h$. Consumer prices are defined as

$$P_{cl,t} = (1 + h_l)P_{l,t}$$

where h_l denotes the consumption tax rate on commodity c_l.

5.2.1 Household budget constraints and first order conditions

The representative saving household spends on final consumption, c_t^s, invests quantities i_x and i_n in private capital that depreciates at the rate δ, pays user fees charged for infrastructure services according to μz^i, and buys domestic bonds b_t^s. Domestic bonds, which cannot be held by foreigners, pay a real interest rate r. This household maximizes its utility (5.6) for $i = s$ subject to the budget constraint:

$$\begin{aligned} \triangle b_t^s = {} & \sum_j (1 + (1 - t_j)\theta_{j,t}) r_{j,t} k_{j,t-1}^s + \frac{1}{1+a}[(1 + (1 - t_w)\theta_{w,t}) w_t (L_{n,t} + L_{x,t}) + T_t + R_t \\ & + \sum_l (1 - t_{cl}) h_{l,t} P_{l,t} c_{lt} - \mu z_{t-1}^i] + r_{t-1} b_{t-1}^s - P_{k,t}\left(i_{x,t}^s + i_{n,t}^s\right) - Pc_t c_t^s \end{aligned} \tag{5.8}$$

where $\triangle b_t^s = b_t^s - b_{t-1}^s$and the equations of motion for capital in the tradable and non-tradable sectors respectively are

$$(1 + g)k_{j,t}^s = i_{j,t}^s + (1 - \delta)k_{j,t-1}^s \tag{5.9}$$

for $j = x, n$. The household receives a flow of remittances from overseas, R_t and transfers from government, T_t (which may include 'citizen dividend' payments out of oil revenues). The household also pays taxes. The terms t_{cx},t_{cm},t_{cn},t_w,t_x,t_n represents the proportion of the tax revenue levied on consumption and on factors that finds its way to government (with $1 - t_s$ the proportion retained by households for each tax,s). These tax wedges are discussed in more detail below, but essentially the terms in t in (5.8) capture tax revenue that does not get remitted to government. Remittances, transfers and the 'retained' taxes paid on wages and user charges for infrastructure are proportional to the agent's share in aggregate employment.

The first order conditions describing the solution to the saving household's optimization problem are:

$$\frac{c_{t+1}^s}{c_t^s} = \left(\beta \frac{1+r_t}{1+g} \frac{Pc_t}{Pc_{t+1}}\right)^{\tau^s} \tag{5.10}$$

$$L_t^s = \left[(c_t^s)^{-1/\tau^s} \left(\frac{1}{\kappa^s}\right) \frac{w_t}{Pc_t}\right]^{\iota^s} \tag{5.11}$$

$$\frac{r_{j,t+1}}{P_{k,t+1}} + 1 - \delta = (1+r_t)\frac{P_{k,t}}{P_{k,t+1}} \tag{5.12}$$

Equation (5.10) is an Euler equation in which the slope of the consumption path depends on the bond interest rate adjusted for trend growth (g) and on changes in the (tax inclusive) consumer price index. Equation (5.11) is the saving household's labour supply equation, and (5.12) the arbitrage conditions, requiring the rate of return on capital in each sector $j = x, n$ to equal the interest rate.[8]

Non-savers maximize the same utility function as that of savers (5.6). The labour supply by this household is analogous to (5.11) and is given by

$$L_t^h = \left[\left(c_t^h\right)^{-1/\tau^h} \left(\frac{1}{\kappa^h}\right) \frac{w_t}{Pc_t}\right]^{\iota^h} \tag{5.13}$$

With no access to capital markets, however, non-saving households have no claims on either fixed capital or on bonds so that their income consists of wages, remittances, transfers and their share of the labour and consumption taxes not remitted to government less their share of user fees for the use of public capital. The consumption of non-saving households is therefore defined directly from their budget constraint :

$$Pc_t c_t^h = \frac{a}{1+a}[(1+(1-t_w)\theta_{w,t})w_t(L_{n,t}+L_{x,t}) + T_t + R_t + \sum_l (1-t_{cl})h_{l,t}P_{l,t}c_{lt} - \mu z_{t-1}^i] \tag{5.14}$$

These hand-to-mouth consumers are a realistic feature of the data and their inclusion breaks Ricardian equivalence. Households are aggregated over $i = s, h$, so that $x_t = x_t^s + x_t^h$ for $x_t = c_{l,t}, L_t, b_t, i_{j,t}, k_{j,t}$, and the sub-indices $l = x, n, m$ and $j = x, n$. By definition, for non-saving households $b_t^h = i_{j,t}^h = k_{j,t}^h = 0$ for $j = x, n$.

5.3 The Government

Government provides public infrastructure and makes transfers to both households. To finance these activities it raises taxes on domestic economic activity, borrows from domestic and external creditors and receives concessional aid and grants from development partners. Government may also levy user charges on households for the use of public capital. Finally, government receives

[8] In principle, the private sector may incur adjustment costs when it invests. We suppress these here, but see Buffie *et al* (2012) p12 for how these modify the arbitrage conditions (5.12).

royalty revenues from the extraction of oil which it may choose to accumulate in a sovereign wealth fund. We describe these elements in turn:

5.3.1 Infrastructure, public investment and efficiency

The model allows for inefficiencies in the construction and use of public capital. This requires us to 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 reflects problems in the public investment process. Public investment i_z produces additional units of notional infrastructure z according to:

$$(1+g)z_t = (1-\delta)z_{t-1} + i_{z,t} \tag{5.15}$$

but with corruption and/or other inefficiencies the capital actually installed in the economy evolves according to :

$$z_t^i = \bar{s}\bar{z} + s(z_t - \bar{z}) \tag{5.16}$$

where $\bar{s}, s \in [0,1]$ are parameters of efficiency at and off steady state, and $\bar{z}$ is the notional public capital at the (initial) steady state. Assuming inefficiencies in capital formation, one unit of additional notional capital investment generates $s \leq 1$ units of installed capital. Combining equations (5.15) and (5.16) yields the following equation of motion for installed capital:

$$(1+g)z_t^i = (1-\delta)z_{t-1}^i + s(i_{z,t} - \bar{i_z}) + \bar{s}\bar{i_z}. \tag{5.17}$$

In addition to inefficiencies in construction we allow for additional adjustment costs associated with increasing public investment. These are costs, such as the additional costs of coordination or the pure costs of corruption (i.e. corruption is not a transfer) that drive a wedge between the cost of acquiring infrastructure in the market and the final cost to government;this wedge is increasing in the extent to which public investment exceeds its steady state value. We follow Buffie *et al* (2012) in assuming that the marginal cost of public investment to the fiscal authorities is defined as $\Pi_t P_{z,t}$ where $P_{z,t}$ is the cost of public capital as defined in (5.3) and

$$\Pi_t = \left((i_{z,t} - \bar{i_z}).(1 + \frac{i_{z,t}}{z_{t-1}} - \delta - g)^{\phi} + \bar{i_z} \right) / i_{z,t} \tag{5.18}$$

Note that in the initial steady state, where $i_{z,t} = \bar{i_z}$ so that $\frac{\bar{i_z}}{z_{t-1}} = \delta + g$, $\Pi_t = 1$. Hence the adjustment costs accrue only on marginal public investment.

5.3.2 Operations and maintenance expenditures

Operations and maintenance expenditures affect public capital through two channels in the model. On the one hand, deficient maintenance expenditure leads to an increase in the rate at which the public capital stock depreciates through time. On the other, deficient operations expenditure reduces the flow of output produced by the current stock of public capital. Both effects can be temporary so that a return to 'full' maintenance and operations expenditures restores the (technical minimum) depreciation rate and the full flow of output respectively.[9]

To operationalize these ideas we assume that installed public capital depreciates at a rate determined by the level of maintenance expenditure. The depreciation rate of (installed) public capital is defined as

$$\delta_z^i = \delta_z \left[1 + (1 - \gamma_m)\beta_\delta\right] \tag{5.19}$$

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.

Finally, 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. 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 are modeled as the use of traded and non traded goods, where we assume that the composition of traded and non-traded goods is fixed and is the same as the initial composition of domestic absorption. The composite price of O&M is $P_{om,t} = (1-a_n)P_{x,t} + a_n P_{n,t}$ where a_n is the non-tradable share in absorption, so that 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 $q_{p,t} z_{t-1}^i$and $q_{m,t} z_{t-1}^i$where $q_{p,t} = \gamma_{p,t}\overline{q}_p$ and $q_{m,t} = \gamma_{m,t}\overline{q}_m$ with $\bar{q_p}$ and $\bar{q_m}$ measures of 'efficient' O&M goods expenditures per unit of installed capital.[10]

Estimates of the scale of 'efficient' O&M costs are extremely sparse. In this model we calibrate to values that are broadly consistent with Heller's (1991) 'r-coefficient' estimates. These are estimates of the required annual recurrent expenditure in dollars per dollar of installed capital

[9] This is 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.

[10] It might seem natural to consider operations expenditures 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 since conventional national accounting tends to value these activities at cost we treat them as part of GDP.

(see Heller, 1991). His estimates are, however, highly dependent on the type of public capital involved, with the coefficients covering a 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 landline 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.

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, our proportionality assumption again seems on the conservative side .[11]

Importantly, 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.[12] 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

$$\left[P_{om,t}(q_{p,t}+q_{m,t})+(\delta^{i}_{z,t}+r^{g}_{t})P_{z,t}/s\right]z^{i}_{t-1} \tag{5.20}$$

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,

[11]In practice, operations expenditures tend to be composites, the components of which are likely to be required in fixed proportions. Since inadequate spending is itself inefficient, it seems most unlikely that the reduction would be allocated optimally between these components. 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.

[12]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.

where r_t^g is the marginal cost of government (non-concessional) borrowing, recognizing that a unit of installed capital costs P_z/s to replace.[13]

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

$$\mu_t = \left[P_{om,t}(f_{p,t}q_{p,t} + f_{m,t}q_{m,t}) + (f_{d,t}\delta^i_{z,t} + f_{r,t}r_t)P_{z,t}/s\right] z^i_{t-1} \tag{5.21}$$

where $0 < f_n \leq 1$ for $n = p, m, d, r$ 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 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.

5.3.3 Tax leakage

To allow for inefficiencies or corruption or other forms of leakage in revenue collection we introduce a wedge which determines what proportion of the tax levied on a particular base actually finds its way onto the government budget. We define $0 < t_s \leq 1$ as the share of the tax collected on tax base s that is remitted to government with $(1 - t_s)$ of the revenue retained by the owner of the tax base. Crucially, firms and households always face the *nominal* tax rates when making choices over factor allocations and consumption decisions: tax revenues that are 'retained' are treated as if they were lump-sum transfers from government. What this means is that when $t_s < 1$ a given given government revenue requirement entails a structure of nominal tax rates that is higher and thus more distortionary that in the absence of any leakages.

5.3.4 Oil revenues and the sovereign wealth fund

The model allows for an enclave oil sector exploiting a finite sub-soil oil reservoir. Productive assets in the sector are wholly owned by a foreign investor who also sources all labour offshore and retains rights over the sale of the output (all of which is sold offshore). There are therefore no backward or forward linkages from the oil sector to the domestic economy, except through the fiscal channel. Here the link derives from the fact that the sub-soil assets are owned by the government which receives a royalty payment from the foreign investor. We treat this as an addition to GDP (these are factor payments to land) that accrues wholly and directly to government. This revenue, denoted $N_t = p^o_t n^o_t$where n^o_t is the royalty in barrels of oil and $p^o_t$the 'world' price of oil, accrues to the budget but government may offset this by increasing contributions to a sovereign wealth fund (SWF). Deposits to the SWF are denoted S_t, and assets invested in the SWF earn the world risk-free rate. Interest income on the SWF, along with any

[13]The rationale for treating the financing cost as equivalent to the cost of borrowing is discussed in Appendix II of Adam and Bevan (2014).

drawdowns from the fund, accrue to the budget. The dynamic evolution of the sovereign wealth fund is as follows:

$$nir_t = S_t + (1 - nr - dnr_t)\frac{nir_{t-1}}{1+g} \tag{5.22}$$

where nr is a stationary depletion rate and dnr_t a time-varying depletion rate where $nr + dnr_t \leq 1$. Taken together these parameters encompass a wide range of potential profiles for the SWF.

5.3.5 Public sector budget constraint

Combining these elements we derive the government's budget constraint. The government spends on debt service, infrastructure investment, associated operations and maintenance, and transfers to the private sector, including 'citizen dividend' transfers out of the oil revenue (denoted dT_t). It collects tax revenue from consumption taxes and from taxes on capital and labour, in all cases net of 'leakages' to the private sector. Additional revenue accrues from oil royalties, income on and net drawdowns from the SWF, grants from development partners, and from user fees for infrastructure services . 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:

$$\begin{aligned} \Delta b_t + \Delta d_{c,t} + \Delta d_t = {} & \frac{r_{t-1} - g}{1+g} b_{t-1} + \frac{r_{d,t-1} - g}{1+g} d_{t-1} + \frac{r_{dc,t-1} - g}{1+g} d_{c,t-1} + P_{z,t}\Pi_t i_{z,t} \\ & + P_{om,t}(q_{m.t} + q_{p,t}) z^i_{t-1} + T_t + dT_t - \frac{r_f}{1+g} nir_{t-1} - N_t + S_t - (nr + dnr_t)\frac{nir_{t-1}}{1+g} \\ & - \sum_j t_j \theta_{j,t} r_{j,t} k^s_{j,t-1} - t_w \theta_{w,t} w_t (L_{n,t} + L_{x,t}) - \sum_l t_{cl} h_{l,t} P_{l,t} c_{lt} - G_t - \mu z^i_{t-1} \end{aligned} \tag{5.23}$$

for $j = x, n$ and $l = x, m, n$ where G denotes grants. The world risk free rate is r_f , 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 $ed_t = \frac{d_t + d_{c,t} - nir_t}{y_t}$ from its (initial) steady state value where $y_t = P_{x,t} q_{x,t} + P_{n.t} q_{n,t}$ is GDP. That is,

$$r_{dc,t} = r_f + \upsilon_g e^{\eta_g \left(ed_t - \bar{ed}\right)}. \tag{5.24}$$

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.

5.4 Fiscal adjustment and policy rules

Given the exogenously determined paths for public infrastructure investment, concessional and non-concessional sovereign external borrowing, and the sovereign wealth fund, the residual fiscal adjustment falls on domestic taxes and domestic debt. To illustrate, we start with a measure of the fiscal gap before adjustment (Ω_t):

$$\begin{aligned}\Omega_t = P_{z,t}\Pi_t i_{z,t} + P_{om,t}(q_{p,t}+q_{m,t})z^i_{t-1} + +T_t + dT_t + \frac{1+r_d}{1+g}d_{t-1} - d_t + \frac{1-r_{dc,t-1}}{1+g}dc_{t-1} \\ -dc_t + \frac{r_{t-1}-g}{1+g}b_{t-1} - \frac{r_f}{1+g}nir_{t-1} - N_t + S_t - (nr+dnr_t)\frac{nir_{t-1}}{1+g} - \sum_j t_j\theta_{j0}r_{j,t}k^s_{j,t-1} \\ -t_w\theta_{w0}w_t(L_{n,t}+L_{x,t}) - \sum_l t_{cl}h_{l0}P_{l,t}c_{lt} - G_t - \mu z^i_{t-1}.\end{aligned} \tag{5.25}$$

Ω_t corresponds to expenditures (including interest payments) less revenues and concessional borrowing, when taxes are kept at their initial levels $\{\theta_{x0}, \theta_{n0}, \theta_{w0}, h_{cx0}, h_{cm0}, h_{cn0}\}$. Using this definition, the government budget constraint (5.23) can be rewritten as:

$$\Omega_t = \Delta b_t + \sum_l t_{cl}(h_{l,t}-h_{l0})P_{l,t}c_{l,t} + \sum_j t_j(\theta_{j,t}-\theta_{j0})r_{j,t}k^s_{j,t-1} + t_w(\theta_{l,t}-\theta_{l0})w_t(L_{n,t}+L_{x,t}). \tag{5.26}$$

In other words, given the investment programme, this gap can be covered by some mixture of domestic borrowing and tax adjustments. Debt sustainability necessarily requires that domestic debt is bounded (for example, we may assume that the domestic debt is constrained to converge to a constant share of trend GDP) which means that taxes eventually adjust to cover the entire gap, conditional on the long-run domestic debt ratio. Policymakers divide the long-run burden of adjustment across different taxes as follows:

$$h^{target}_{lt} = t_{cl}h_{l0} + \lambda_{hl}\frac{\Omega_t}{P_{l,t}c_{l,t}} \qquad l = \{x, m, n\} \tag{5.27}$$

$$\theta^{target}_{jt} = t_j\theta_{j0} + \lambda_{kj}\frac{\Omega_t}{r_{j,t}k_{j,t}} \qquad j = \{x, n\} \tag{5.28}$$

$$\theta^{target}_{wt} = t_w\theta_{w0} + \lambda_w\frac{\Omega_t}{w_t(L_{n,t}+L_{x,t})} \tag{5.29}$$

where $0 \le \lambda_{hl}, \lambda_{kj}, \lambda_w \le 1$ are policy parameters that split the *long-run* fiscal adjustment between different taxes and domestic debt. When $\sum\lambda = 1$domestic debt is held constant (as a share of trend GDP) in the long run. When $\sum\lambda < 1$ the new steady-state entails a *rise* in the domestic debt ratio and *vice versa* when $\sum\lambda > 1$.

Finally, we assume that taxes cannot adjust instantaneously to their new target levels so that over the adjustment path domestic debt may overshoot its steady-state level. The actual path for taxes is defined as follows (with the evolution of domestic debt determined implicitly from the substitution of these dynamic equation into the government budget constraint (5.23):

$$t_{cl,t}h_{l,t} = t_{cl,t-1}h_{l,t-1} + \lambda_{h1}^{d}(h_{lt}^{target} - t_{cl,t-1}h_{l,t-1}) \qquad l = \{x, m, n\} \tag{5.30}$$

$$t_{j,t}\theta_{j,t} = t_{j,t-1}\theta_{j,t-1} + \lambda_{kj}^{d}(\theta_{jt}^{target} - t_{j,t-1}\theta_{j,t-1}) \qquad j = \{x, n\} \tag{5.31}$$

$$t_{w,t}\theta_{w,t} = t_{w,t-1}\theta_{w,t-1} + \lambda_{w}^{d}(\theta_{wt}^{target} - t_{w,t-1}\theta_{w,t-1}) \tag{5.32}$$

with $\lambda_{h1}^{d}, \lambda_{kj}^{d}, \lambda_{w}^{d} > 0$.

5.5 Market-clearing conditions

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

$$L_{x,t} + L_{n,t} = L_t^h + L_t^s. \tag{5.33}$$

Aggregating over both types of consumers, and taking into account private and public investment and O&M expenditures, equilibrium in the non-tradable sector is:

$$q_{n,t} = \rho_n \left(\frac{P_{n,t}}{P_t}\right)^{-\epsilon} c_t + a_k(i_{x,t} + i_{n,t}) + a_z \Pi_t i_{z,t} + a_n(q_{m,t} + q_{p,t}) z_t^i. \tag{5.34}$$

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

$$\begin{aligned} \Delta d_t + \Delta d_{c,t} - \Delta nir_t = &\frac{r_d - g}{1+g} d_{t-1} + \frac{r_{dc,t-1} - g}{1+g} d_{c,t-1} + \frac{g - r_f}{1+g} nir_{t-1} + P_{z,t}\Pi_t i_{z,t} \\ &+ P_{k,t}(i_{x,t} + i_{n,t}) + P_{om,t}(q_{p,t} + q_{m,t}) + P_t c_t - P_{n,t} q_{n,t} - P_{x,t} q_{x,t} - N_t - R_t - G_t \end{aligned} \tag{5.35}$$

Appendix II: Baseline Calibration Parameters

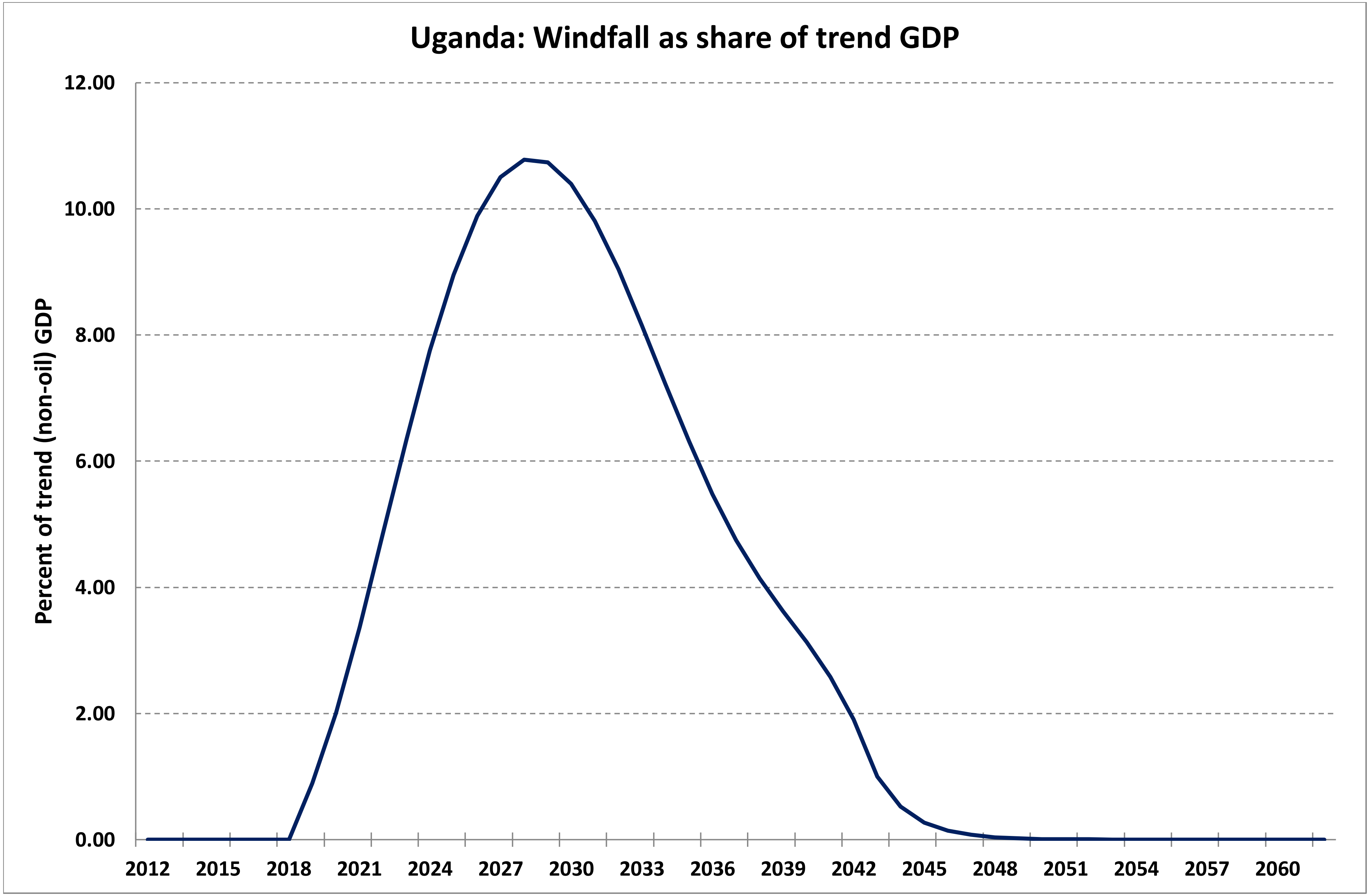
Parameters	Value	Definition
g	3.0	Trend *per capita* growth rate (% p.a.)
a	1.75	Ratio of non-saving to saving households
a_x, a_n	0.40, 0.55	Capital share in x and n sectors
a_k, a_z, a_{om}	0.5,0.5,0.5	Non-tradable cost share in private capital, public capital and O&M
ρ_x, ρ_n, ρ_m	0.20,0.50,0.30	Distribution parameters for x,n and m sectors
ε	0.5	Intra-temporal elasticity of substitution in consumption
τ	0.50	Inter-temporal elasticity of substitution
ι	0.25	Frisch elasticity of labour supply
ϱ	0.0636	Pure subjective time preference rate
δ	5	Baseline depreciation rate (% per annum)
β_δ	1.0	Accelerated public capital depreciation parameter
h_x, h_m, h_n	3.75,31.25,6.25	Consumption tax rate (% consumption)
θ_w	7.5	Labour tax rate (% of wage bill)
θ_x, θ_n	5.0,7.5	Profit tax rates (% sector-specific profits)
$\overline{s}, s$	0.6,0.75	Infra-marginal and marginal efficiency of public investment
$\overline{m}, \overline{q}$	2.5, 2.5	Efficient r-coefficients for O&M , cents per dollar public capital.
γ_p, γ_m	0.8,0.8	Baseline efficiency parameters for operations and maintenance expenditures
$\lambda_{hx}, \lambda_{hm}, \lambda_{hn}$	0.036,0.412,0.15	Steady state fiscal adjustment parameters (consumption taxes)
$\lambda_{kx}, \lambda_{kn}$	0.094,0.078	Steady state fiscal adjustment parameters (profit taxes)
λ_w	0.23	Steady state fiscal adjustment parameters (labour taxes)
$\lambda_{hl}^d, \lambda_j^d, \lambda_w^d$	0.5	Dynamic adjustment parameters (all taxes)
t_j, t_l, t_w	0.8,0.8,0.8	Tax wedges (profit taxes, j, consumption taxes j and labour taxes, w)
f_p, f_m, f_d, f_r	0,0,0,0	Baseline cost recovery on operations, maintenance, depreciation and financing
bo, do, dco	11, 18, 0	Initial debt (domestic , concessional and non-concessional external) % GDP
r, r_{dc}, r_d, r_f	10, 8.5, 1, 1.5	Initial interest rates % p.a.
η_g	1.0	Public external debt risk premium parameters
ϕ	5.0	Public investment adjustment parameter
G, R	1.7, 8.5	Grants and remittances (% GDP)

Appendix III: Calibration of Policy Simulations

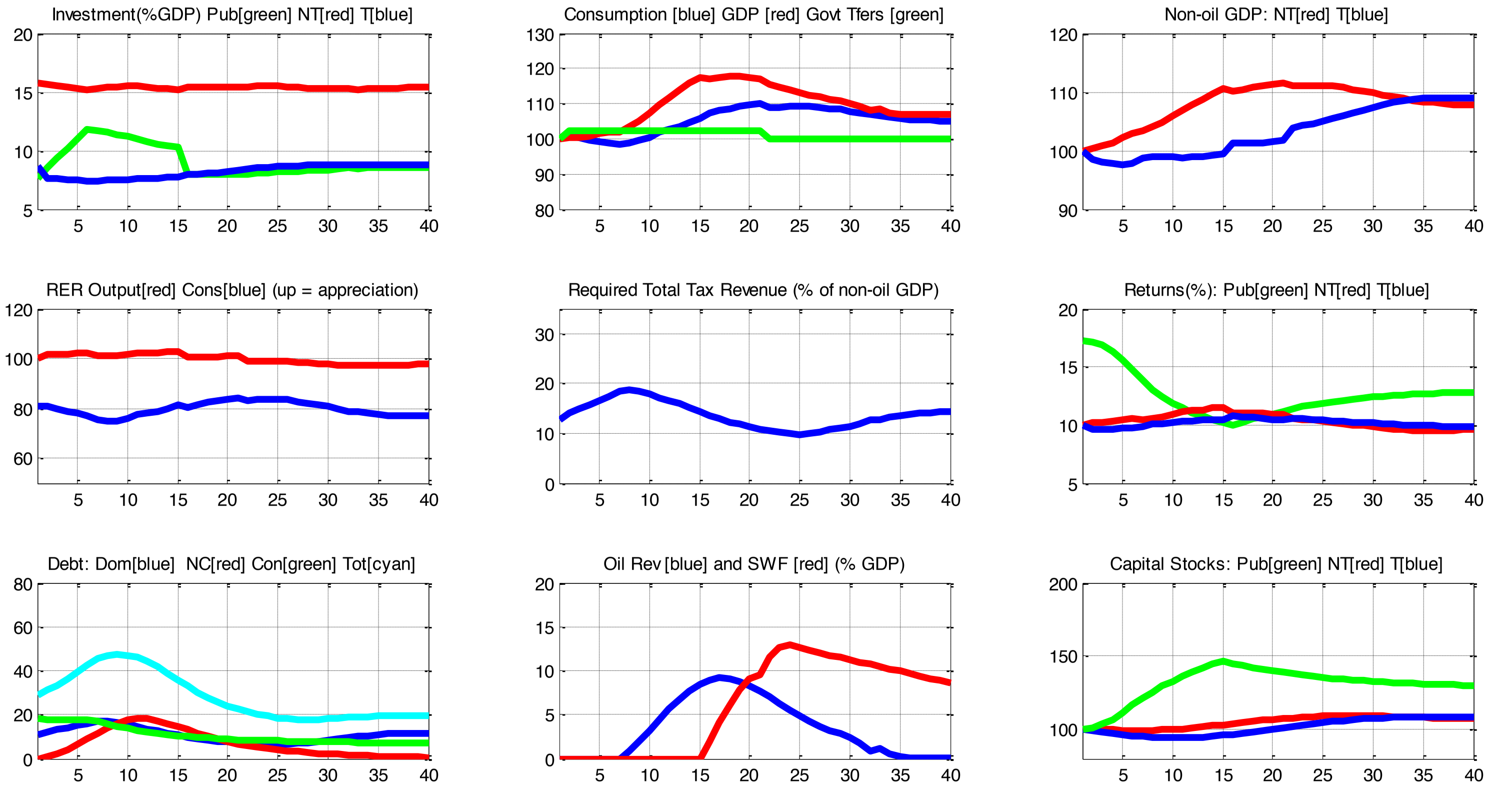
		Experiment									
		1	2	3	4	5	6	7	8	9	10
Investment	[1]										
Scale: share of oil windfall		30%	30%	60%	60%	30%	65%	30%	30%	30%	50%
Duration (post build-up)		10	10	10	10	20	20	10	10	10	10
Start date		1	1	1	1	1	1	1	1	1	10
Consumption Transfers	[2]										
Size		2.50%	2.50%	2.50%	2.50%	2.50%	2.50%	2.50%	5.00%	2.50%	2.50%
Duration		20	20	20	20	20	20	20	Perm	20	20
Start		1	1	1	1	1	1	1	1	1	1
Sovereign Borrowing	[3]										
Scale (share of gross investment pulse)		60%	100%	60%	60%	60%	60%	60%	60%	60%	0%
Risk Premium		Low	Low	Low	High	Low	Low	Low	High	Low	Low
Fiscal Parameters	[4]										
Investment efficiency		0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
O&M (relative to efficient level)		0.8	0.8	0.8	0.6	0.8	0.8	0.6	0.6	0.8	0.8
Tax leakage		0.2	0.2	0.2	0.2	0.2	0.2	0.4	0.4	0.2	0.2
Cost recovery		0	0	0	0	0	0	0	0	0.2	0
World Oil Prices		1	1	1	1	1	1	1	0.75	1	1

Notes

[1] Gross public infrastructure investment as a share of the (undiscounted) value of the oil windfall net of the consumption transfer. Build-up lasts 4 years regardless of duration. Model is calibrated so that t=0 corresponds to FY2012/13. **[2]** Consumption transfer is set as share of trend GDP; over the 20-year horizon, this accounts for approximately 25 percent of the oil windfall at baseline prices. **[3]** Gross sovereign borrowing lasts for 15 years. The scale of sovereign borrowing is expressed as a share of the public investment pulse per annum. For example in Scenario #1 when the public investment surge is equivalent to 30% of the windfall, this corresponds to an increase in public investment from 7.6% of GDP level of 11.9% of GDP per annum sustained over the pulse. 60% of this increased investment expenditure is debt financed over the first 15 years of the simulation. The risk premium is calibrated such that when the premium is 'low' an additional 10% of GDP in public debt raises the government borrowing costs on sovereign debt by 90 basis points over the baseline rate of 8.5%, whereas an additional 40% adds 410 basis points. When the risk premium is high, an additional 10% of GDP in debt adds 290 basis points over the baseline and an additional 40% would add over 1000 basis points. **[4]** See text for explanation of the fiscal parameters.

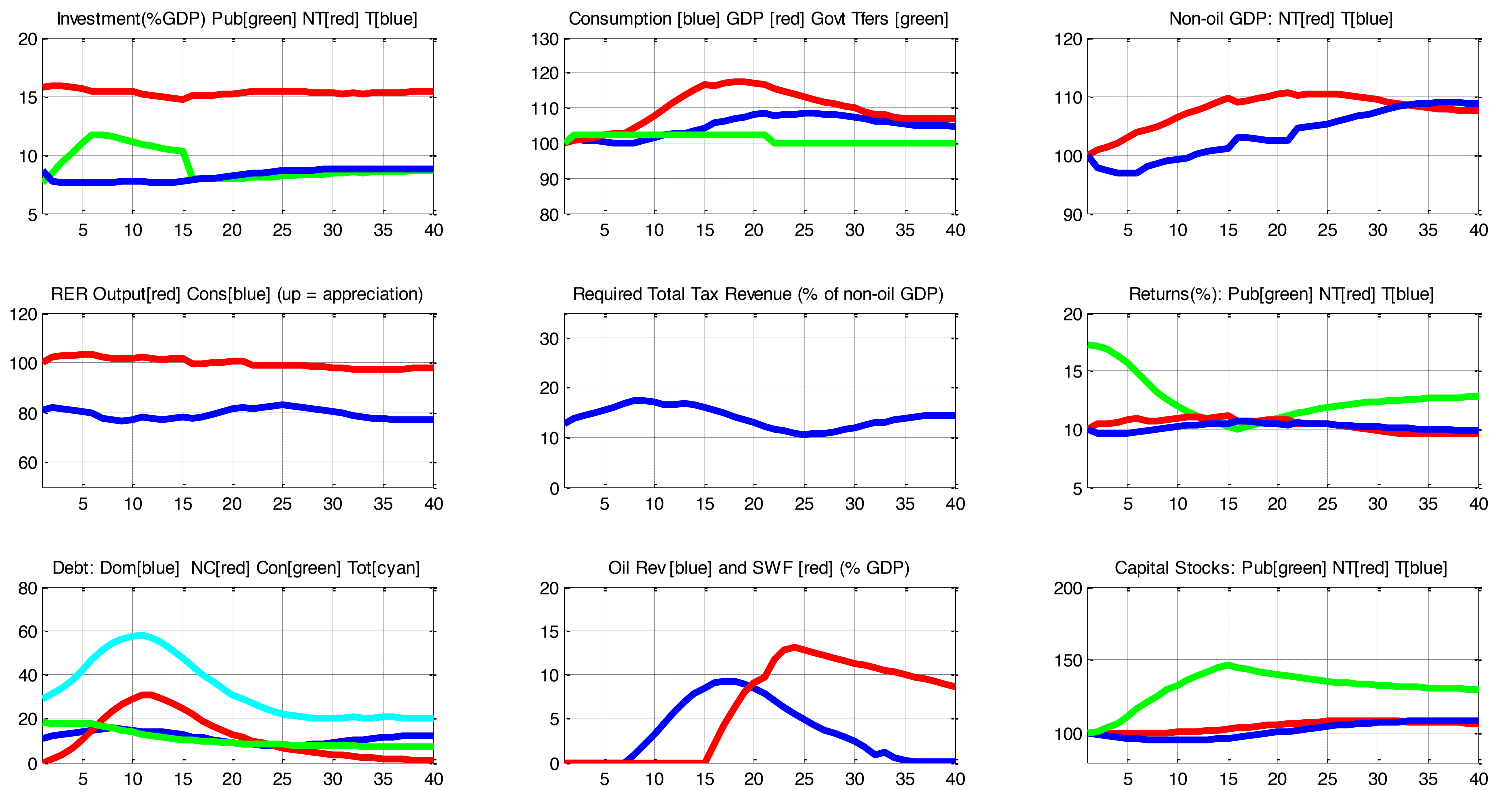

Uganda: Windfall as share of trend GDP
Percent of trend (non-oil) GDP
12.00
10.00
8.00
6.00
4.00
2.00
0.00
2012
2015
2018
2021
2024
2027
2030
2033
2036
2039
2042
2045
2048
2051
2054
2057
2060

Scenario 1: Ten-Year Investment Pulse



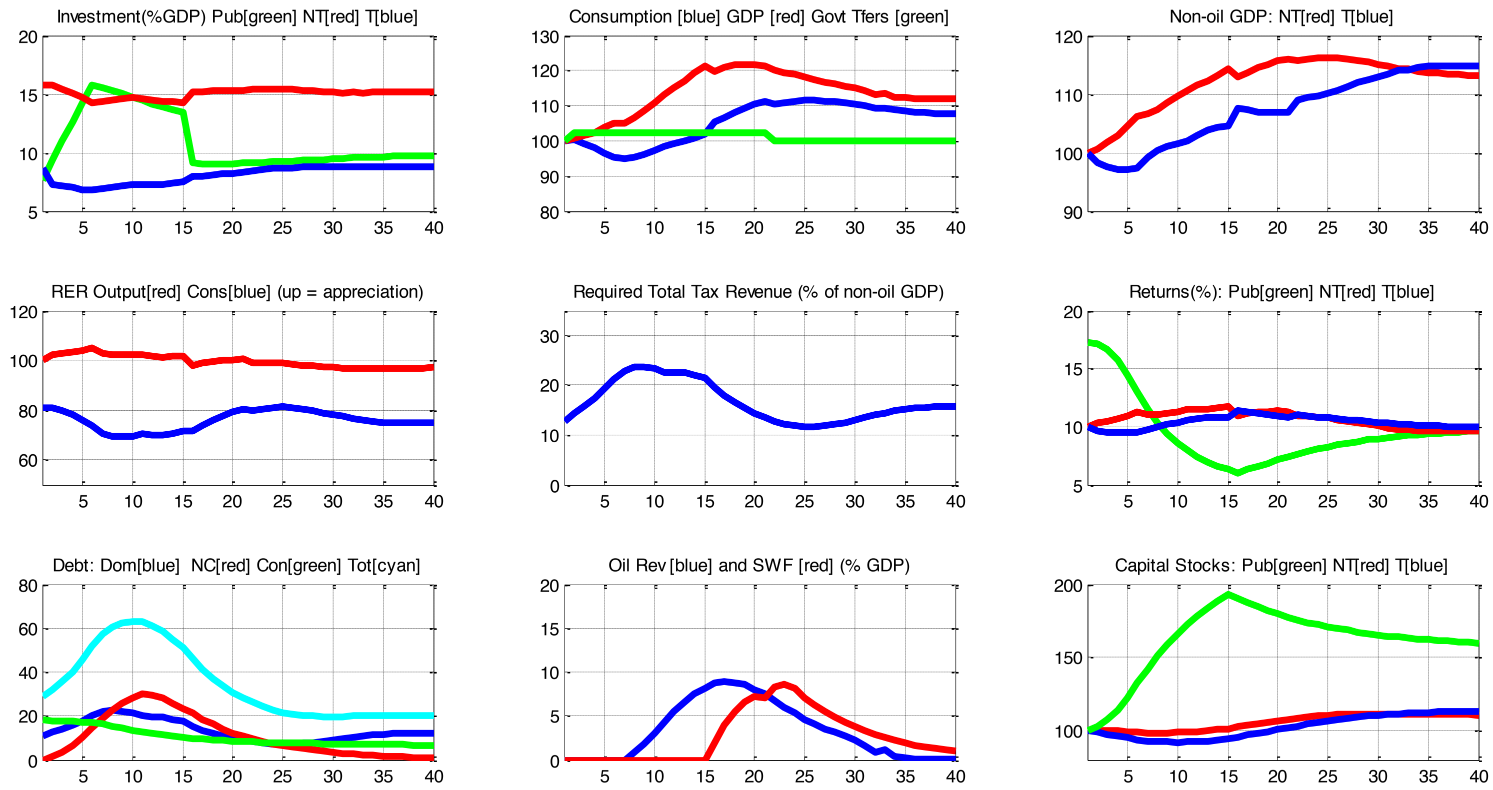
Source: *Ver3\BoU_memo\Ug01.mat and Ug01.fig*

Scenario 2: Base with higher sovereign borrowing



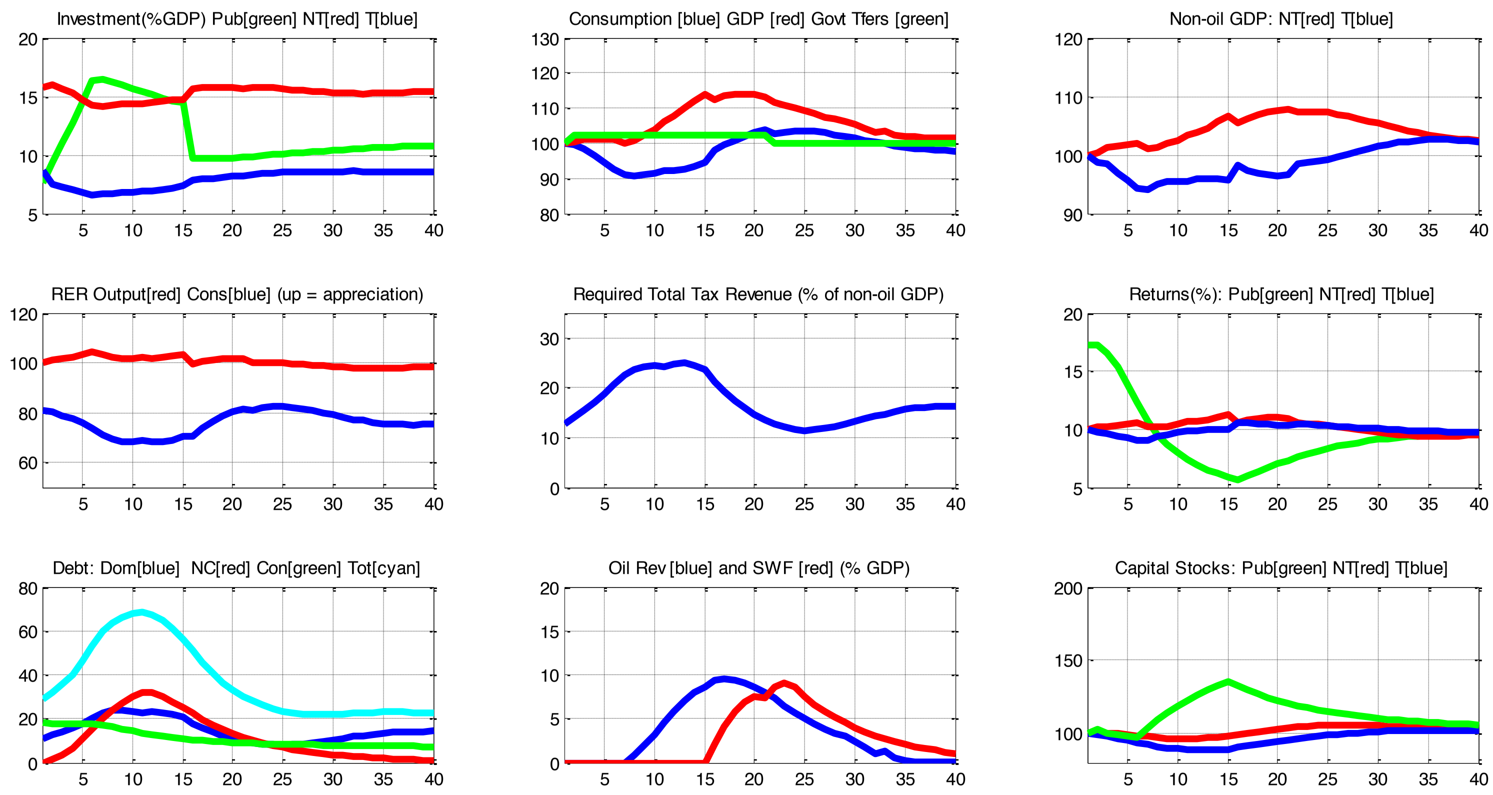
Source: *Ver3\BoU_memo\Ug01x.mat and Ug01x.fig*

Scenario 3: Ambitious investment pulse



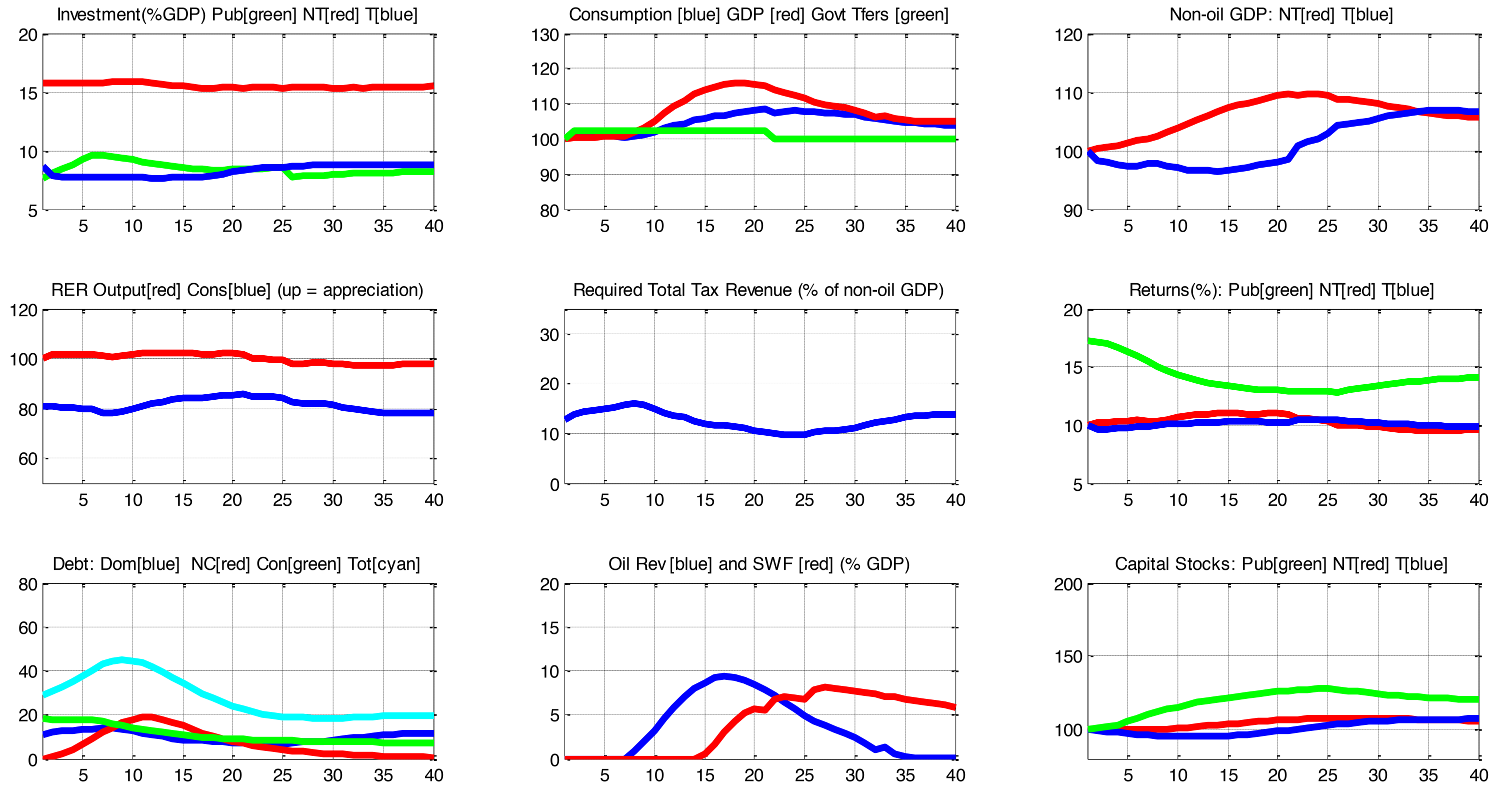
Source: *Ver3\BoU_memo\Ug06.mat and Ug06.fig*

Scenario 4: False economy



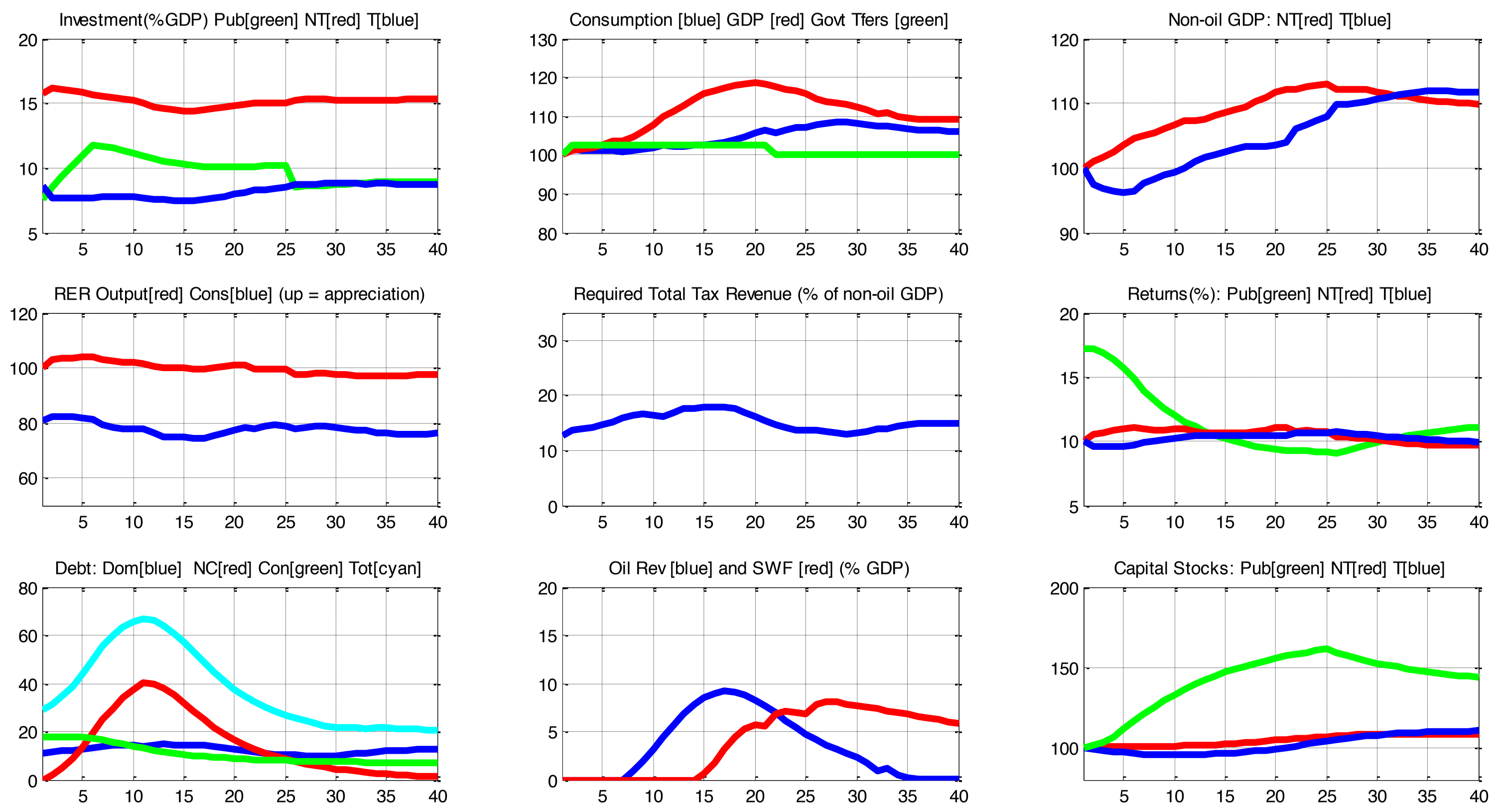
Source: *Ver3\BoU_memo\Ug06a.mat and Ug06a.fig*

Scenario 5. Extended Investment pulse



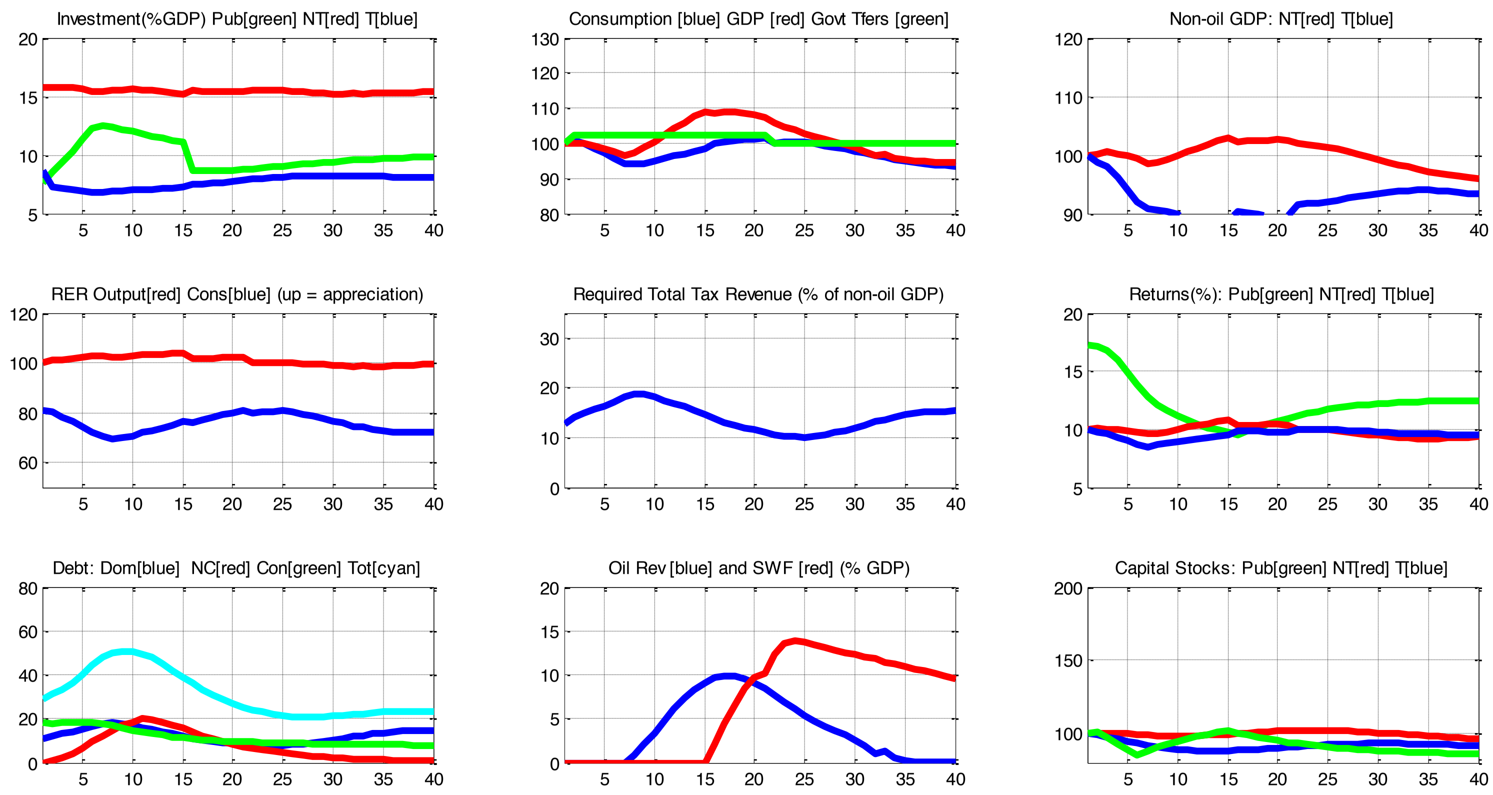
Source: *Ver3\BoU_memo\Ug02.mat and Ug02.fig*

Scenario 6: Enhanced extended investment pulse



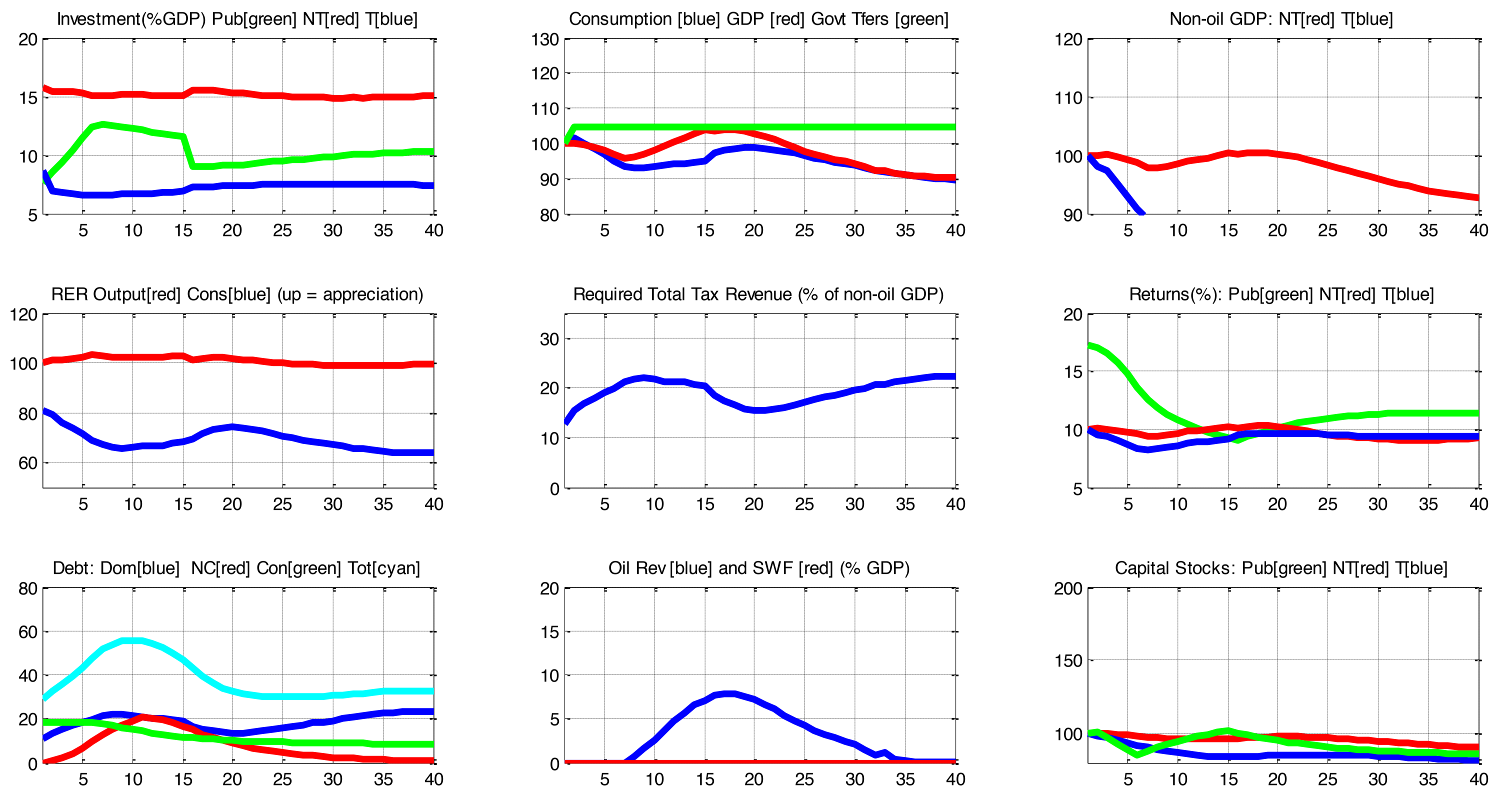
Source: *Ver3\BoU_memo\Ug02a.mat and Ug02a.fig*

Scenario 7: Crumbling fiscal control



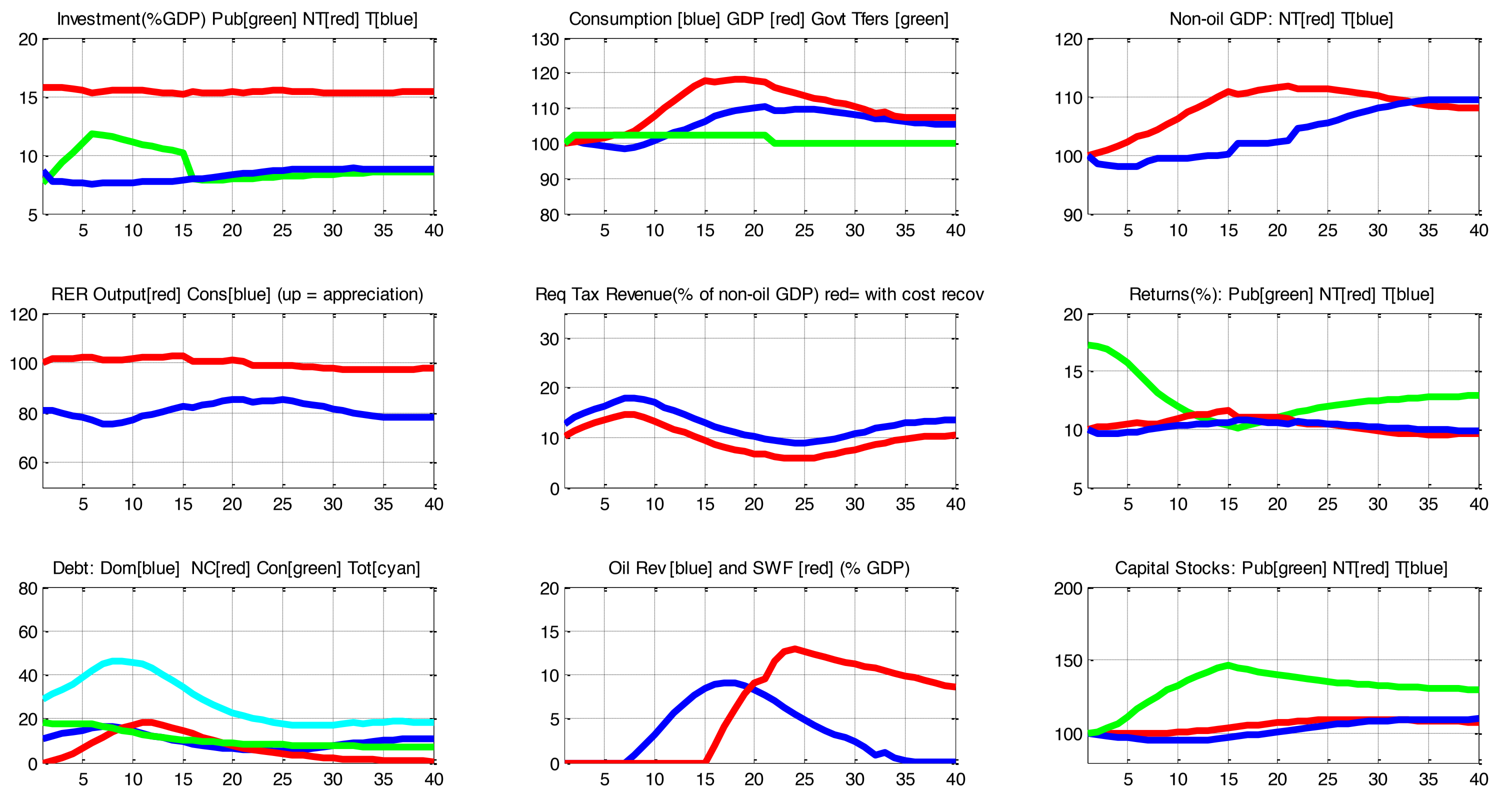
Source: *Ver3\BoU_memo\Ug03.mat and Ug03.fig*

Scenario 8: Poor resource management



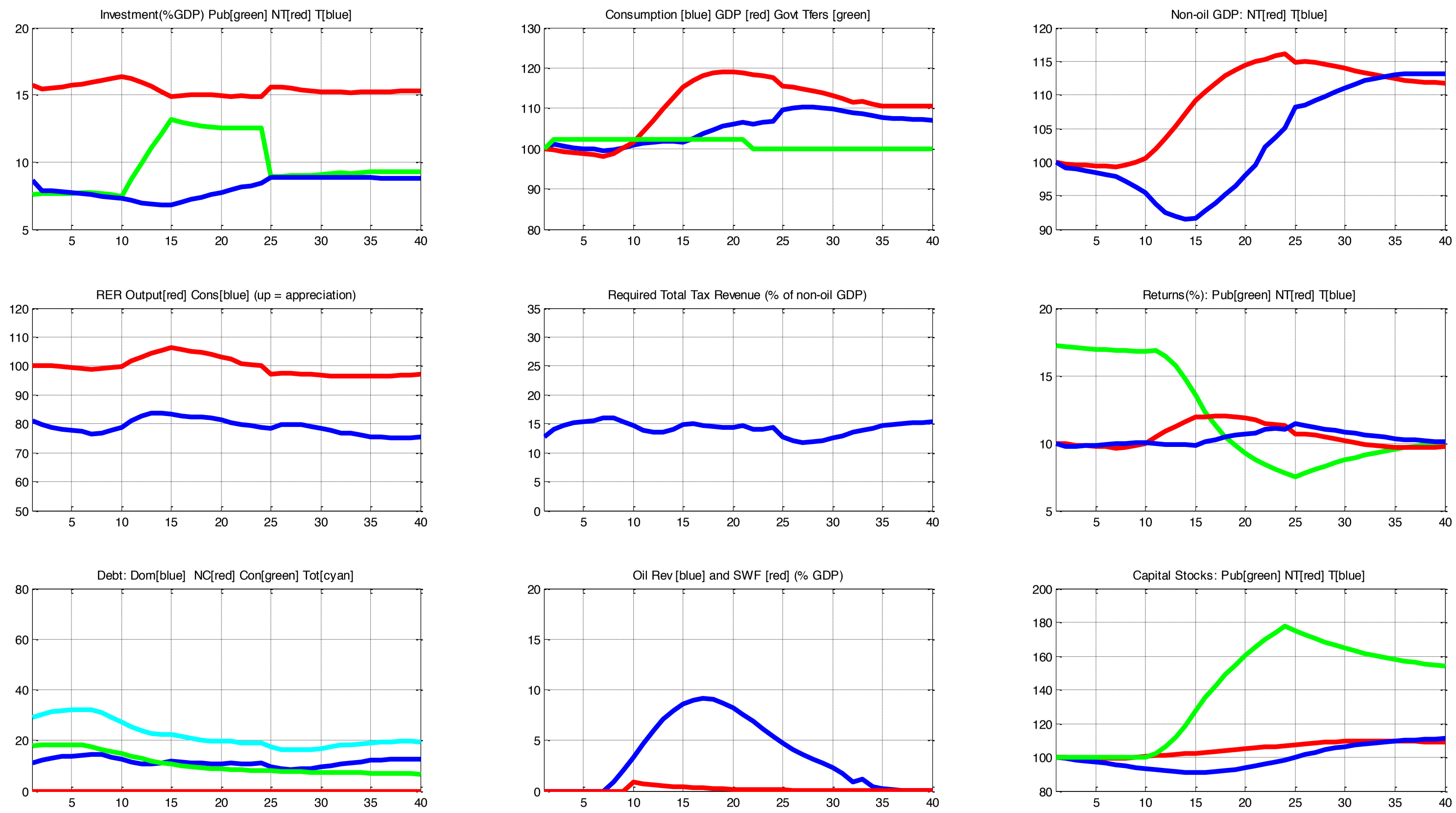
Source: *Ver3\BoU_memo\Ug04.mat and Ug04.fig*

Scenario 9: Partial cost recovery



Source: *Ver3\BoU_memo\Ug05.mat and Ug05.fig*

Scenario 10:Deferred investment pulse



Source: *Ver3\BoU_memo\Ug07.mat and Ug07.fig*

Table 1: Baseline Calibration

(as % of GDP at factor cost)

GDP	100	**Current Account**	-10.7
Tradable	43.6	*Financing:*	
Non-Tradable	56.4	Aid	1.7
		Remittances	8.5
Absorption	115.8	Debt financing	0.5
Consumption	76.5	**Debt Stocks**	29.0
Tradable	37.2	Concessional	18.0
Non-tradable	39.3	Non-Concessional	0.0
		Domestic	11.0
Investment	31.5		
		Fiscal Balance	
Private	23.9	*Revenue*	12.8
Public	7.6		
		Cons	7.7
Government	7.8	Labour	2.9
		Capital	2.2
O&M	2.0		
Transfers	4.5	*Expenditures*	15.4
Interest	1.3		
		Deficit	-2.6
		Financing:	
		Grants	1.7
		Debt	0.9

Notes and Sources: Bank of Uganda, Ministry of Finance, Uganda Bureau of Statistics data for FY2012/13

Table 2: Policy Simulations

Number	Name	Details
1	**Baseline ten-year investment pulse**	Cumulative gross public investment equal to 30% of oil windfall after consumption transfers; public investment increased from 7.6% of GDP to 11.9% from t=5 to t=14; sovereign borrowing covers 60% of additional public investment during first 15 years.
2	**Baseline with higher sovereign borrowing**	Same investment pulse as described in Scenario 1 but with sovereign debt covering 100% of additional gross investment over first 15 years.
3	**Ambitious investment pulse**	As Scenario 1 but with cumulative gross public investment equal to 60% of oil windfall after consumption transfers; public investment rises from 7.6% to 16.2% from t=5 to t=14; sovereign borrowing covers 60% of additional public investment during first 15 years.
4	**False economy**	As Scenario 3 but O&M expenditures fall to 60% of efficient level and sovereign risk premium increases.
5	**Extended investment pulse**	As Scenario 1 but with same cumulative-valued investment pulse spread over 4+20 years. Public investment increased from 7.6% to 9.6% of GDP from t=5 to t=24
6	**Enhanced extended investment pulse**	As Scenario 5 but with cumulative-value of investment pulse equal to 65% of windfall, allowing public investment increased from 7.6% to 11.9% of GDP from t=5 to t=24, the level achieved under Simulations 1 and 2.
7	**Crumbling fiscal control**	As Scenario 1 but accompanied by increase in tax leakages and a deterioration in O&M expenditures relative to efficient scale.
8	**Poor resource management**	As Scenario 7 but with higher and sustained level of consumption transfers combined with decline in world oil prices.
9	**Partial cost recovery**	As Scenario 1 with user costs levied on consumers at 20% of full recurrent cost of installed public capital.
10	**Deferred investment pulse**	As Scenario 1 but investment pulse delayed until t=10; cumulative gross public investment equal to 50% of oil windfall after consumption transfers; public investment increased from 7.6% in t=9 to 14.7% from t=11 to t=24; no sovereign borrowing.

Table 3: Comparative Performance

Simulation		Total Non-oil GDP [excess over trend]	Private Consumption [excess over trend]		Required tax revenue (% non-oil GDP)		Public debt % Total GDP: Total		Public debt % Total GDP: External Non-Concessional		Public debt % Total GDP: Domestic	
	Initial Level				12.8%		29.0%		0.0%		11.0%	
1	T=7	2.0%	-1.5%		18.4%		46.4%		11.9%		17.4%	
	T=15	7.5%	5.7%		14.4%		41.2%		17.1%		12.6%	
	Long-run	6.4%	3.9%		14.4%		19.4%		0.0%		12.7%	
	Extremum		-1.5%	(7)	18.6%	(9)	50.4%	(11)	20.5%	(12)	17.8%	(8)
2	T=7	2.9%	-0.1%		16.9%		52.7%		19.8%		15.7%	
	T=15	6.8%	4.3%		16.0%		55.3%		28.5%		14.6%	
	Long-run	6.4%	3.9%		14.4%		19.5%		0.0%		12.8%	
	Extremum		-0.1%	(7)	17.4%	(9)	63.3%	(11)	34.1%	(12)	16.2%	(9)
3	T=7	5.1%	-5.1%		22.9%		60.1%		19.8%		23.2%	
	T=15	11.3%	1.9%		21.5%		62.0%		28.5%		21.3%	
	Long-run	11.7%	7.1%		15.7%		20.6%		0.0%		13.8%	
	Extremum		-5.1%	(7)	23.7%	(9)	70.9%	(11)	34.1%	(12)	24.1%	(9)
4	T=7	-0.2%	-9.0%		22.7%		59.5%		19.8%		22.5%	
	T=15	3.9%	-5.4%		23.6%		64.2%		28.5%		23.4%	
	Long-run	-0.1%	-4.6%		16.8%		21.7%		0.0%		14.9%	
	Extremum		-9.2%	(8)	24.9%	(13)	72.6%	(12)	34.1%	(12)	25.1%	(13)
5	T=7	0.7%	0.5%		15.7%		43.2%		11.9%		14.1%	
	T=15	4.0%	5.9%		11.9%		39.1%		17.1%		9.8%	
	Long-run	4.1%	2.5%		13.9%		19.0%		0.0%		12.2%	
	Extremum		0.0%	(0)	15.9%	(8)	46.9%	(11)	20.5%	(12)	14.3%	(8)
6	T=7	3.5%	0.9%		15.9%		57.4%		25.8%		14.6%	
	T=15	5.8%	2.7%		17.8%		66.1%		37.1%		16.8%	
	Long-run	8.4%	5.2%		14.9%		20.2%		0.0%		13.5%	
	Extremum		0.0%	(0)	17.9%	(17)	73.8%	(12)	44.4%	(12)	16.9%	(17)
7	T=7	-3.5%	-5.8%		18.2%		46.3%		11.9%		17.2%	
	T=15	-0.9%	-1.4%		14.7%		42.5%		17.1%		13.2%	
	Long-run	-7.9%	-9.9%		16.0%		21.2%		0.0%		14.5%	
	Extremum		-9.9%	(∞)	18.7%	(8)	50.7%	(12)	20.5%	(12)	17.8%	(8)
8	T=7	-4.4%	-6.5%		21.1%		49.3%		11.9%		20.3%	
	T=15	-3.6%	-4.9%		20.2%		48.6%		17.1%		19.3%	
	Long-run	-13.1%	-14.5%		23.3%		29.0%		0.0%		22.2%	
	Extremum		-14.5%	(∞)	23.3%	(∞)	55.1%	(11)	20.5%	(12)	21.2%	(9)
9	T=7	2.3%	-1.5%		17.9%		45.9%		11.9%		16.8%	
	T=15	7.9%	6.2%		13.1%		40.4%		17.1%		11.1%	
	Long-run	6.8%	4.3%		13.6%		18.6%		0.0%		11.9%	
	Extremum		-1.5%	(7)	18.0%	(8)	49.3%	(10)	20.5%	(12)	16.9%	(8)
10	T=7	-1.9%	-0.5%		16.0%		31.5%		0.0%		14.3%	
	T=15	5.5%	1.6%		14.9%		25.7%		0.0%		13.5%	
	Long-run	10.0%	6.1%		15.3%		20.9%		0.0%		14.2%	
	Extremum		-0.5%	(7)	16.0%	(7)	31.8%	(6)	0.0%		14.3%	(7)

Notes: [1] Extremum denotes maximum *decline* in private consumption; maximum required tax rate and maximum public debt. Figures in parenthesis indicates year from t=0 at which extremum is achieved, where ∞ denotes at new steady state.

The International Growth Centre (IGC) aims to promote sustainable growth in developing countries by providing demand-led policy advice based on frontier research.

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