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Public Investment in Resource-Abundant Developing Countries

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Abstract

Natural resource revenues provide a valuable source to finance public investment in developing countries, which frequently face borrowing constraints and tax revenue mobilization problems. This paper develops a dynamic stochastic small open economy model to analyze the macroeconomic effects of investing natural resource revenues, making explicit the role of pervasive features in these countries including public investment inefficiency, absorptive capacity constraints, Dutch disease, and financing needs to sustain capital. Revenue exhaustibility raises medium-term issues of how to sustain capital built during a windfall, while revenue volatility raises short-term concerns about macroeconomic instability. Using the model, country applications show how combining public investment with a resource fund—a sustainable investing approach—can help address the macroeconomic problems associated with both exhaustibility and volatility. The applications also demonstrate how the model can be used to determine the appropriate magnitude of the investment scaling-up(accounting for the financing needs to sustain capital) and the adequate size of a stabilization fund (buffer).

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Contents

I. INTRODUCTION

Natural resource revenues have been an important source of fiscal revenue and foreign exchange in many developing countries. The International Monetary Fund lists 29 resource-rich developing countries and 12 prospective countries with identified reserves (International Monetary Fund (2012c)). Among these, the average poverty headcount (living at \$2 a day or below) is about 60 percent, and only 27 percent of total roads are paved.[1] Many of these countries face borrowing constraints and limited tax revenue mobilization. Recent surges in resource revenue may thus provide a valuable source to finance public investment, which is essential for economic development.

Managing revenues from non-renewable resources poses challenges for policymakers. The conventional advice, which is based on the permanent income hypothesis, prescribes that off-the-ground resource wealth should be saved externally in a sovereign wealth fund (e.g., Davis et al. (2001), Barnett and Ossowski (2003), and Bems and de Carvalho Filho (2011)). While this advice preserves resource wealth and avoids instability from spending volatile revenues, it overlooks the current poor living conditions and investment needs in capital-scarce economies. Since mid-2000s, calls for reconsidering the conventional advice and prompting investment spending of resource revenue in developing countries have emerged (e.g., UNCTAD Secretariat (2006), Sachs (2007), Collier et al. (2010), Independent Evaluation Office (2011), Baunsgaard et al. (2012), International Monetary Fund (2012c)). These calls have been supported by theoretical work demonstrating that productive government spending can dominate external saving as an optimal strategy to manage resource revenue in credit-constrained, capital-scarce economies (e.g., Takizawa et al. (2004), Venables (2010), van der Ploeg (2010a), van der Ploeg and Venables (2011), and Araujo et al. (2012)).[2]

Despite the theoretical appeal of investing resource revenue, history has not generally supported the idea that investing resource revenues would promote sustained economic growth. Resource-abundant countries have tended to grow more slowly than others—the so-called natural resource curse.[3] Gelb (1988) studies six oil-exporting developing countries (Algeria, Ecuador, Indonesia, Nigeria, Trinidad and Tobago, and Venezuela) that undertook sizeable investment projects between 1975 and 1978. The overall growth rate of non-oil output was higher after 1974 but quickly slowed after 1978, suggesting that no obvious growth effects lasted after the windfall period. Particularly in Venezuela, much of the oil

[1]Authors' calculation based on the data in Tables 1 and 2 of Appendix 1 in International Monetary Fund (2012c). "Resource-rich" is defined as having the average natural resource revenue or exports at least 20 percent of total fiscal revenue and exports over 2006-2010.

[2]When borrowing costs and debt service are high, another optimal use of resource revenue is to pay down external debt as discussed in Daban and Helis (2010) and van der Ploeg and Venables (2011).

[3]The natural resource curse has been widely studied in the literature, e.g., Gelb (1988), Sachs and Warner (1999), Sachs and Warner (2001), and van der Ploeg (2011b) for a survey. While an average negative correlation exists between growth and the export share of natural resource, some countries, such as Botswana and Chile, have escaped the curse.

windfall (increases over oil revenue from 1962 to 1973) went to public investment, which reached 40 percent on average from 1974 to 1977. Yet the growth rate of per capita non-oil GDP declined in 1976 and became negative in 1979 (Moreno and Shelton (forthcoming)).[4] History then suggests that other factors—aside from potential high public capital returns implied by capital scarcity and the relaxation of credit constraints to finance public investment—can matter for the outcome of investing a resource windfall.

In this paper, we develop a model, in the tradition of the dynamic stochastic general equilibrium (DSGE) literature, to analyze the macroeconomic effects of public investment increases that are mainly financed by natural resource revenues. The model accounts for several important features that are common in developing countries, including public investment inefficiencies, absorptive capacity constraints, weak tax systems, and Dutch disease. Based on this framework, we propose a sustainable investing approach—a combination of raising public investment and saving some of the resources in a resource fund—that fulfills the development needs, preserves resource wealth, and maintains economic stability. This approach stands out then as a policy alternative to grapple with *both* exhaustibility and volatility issues associated with natural resource revenues.

Low public investment efficiency is pervasive among developing countries. Pritchett (2000) and Hurlin and Arestoff (2010) provide estimates of efficiency—defined as the ratio of the change in public capital to investment expenditures—which are generally below 0.5 for countries in sub-Saharan Africa and Latin America. If investment is scaled up quickly (as often observed during a windfall), absorptive capacity constraints—attributed to supply bottlenecks or poor planning—can drive up investment costs further, as discussed in Collier et al. (2010), van der Ploeg (2011a), and Buffie et al. (2012).[5] While empirical evidence on the costs of absorptive capacity constraints is scant, indirect evidence supports a declining investment return as investment accelerates. For instance, Shi (2012) finds that the growth effect became negative after implementing the Western Development Project in West China, where road per capita length grew from 6 percent annually in 1990s to 15 percent after 2003. Following Arestoff and Hurlin's (2006) estimates using Mexican data, we model that investment efficiency falls when investment expenditure levels exceed a threshold value.

The model captures Dutch disease through a learning-by-doing externality in the non-resource traded sector (van Wijnbergen (1984)): rising government spending can impose demand pressures on non-traded goods, leading to a real appreciation and a decline in traded-good production, reducing TFP in this sector. However, in our framework productive public investment can also raise productivity in the non-resource traded sector, counteracting and even eventually reversing the effects of Dutch disease, as suggested in Sachs (2007) and Berg et al. (2010).

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[4]Public investment includes transfers from the Venezuelan Investment Fund to state-owned enterprises. The scope of funding to implement the development strategy contained in the Fifth National Plan was broad, including industrial development projects as well as education, health, electricity, portable water, and highways.

[5]See Chapter II.A in International Monetary Fund (2012d) for the underlying causes resulting in absorptive capacity constraints.

Two key distortions together help explain why natural resource rents deserve special analysis in the context of public investment scaling up. First, in our model—and typically in practice—low-income countries are limited in their ability to access international capital markets. Resource sectors are a major exception: FDI in resource extraction and related sectors is substantial in sub-Saharan Africa, for example, presumably because the high rents provide an incentive to overcome the difficulties implied by sovereign immunity and poor governance. Second, inefficient and weak domestic tax systems amplify the costs of self-financed public investment scaling up and the deferred private consumption and investment that this strategy implies.

Our analysis consists of two country applications, which illustrate the sustainable investing approach.

The first application, to the CEMAC region (the Central African Economic and Monetary Community), stresses the importance of securing financing of recurrent costs for sustaining capital, when exhaustibility is looming in the next 10-20 years.[6] Decisions about whether to invest in domestic capital or to save in a sovereign wealth fund depend not only on the return to capital but also on the economy's absorptive capacity. But more importantly, even when investment is sufficiently productive, the magnitude of the investment scaling-up should be jointly assessed with the fiscal adjustment necessary to sustain capital beyond the windfall. Policy makers and the literature on public infrastructure generally recognize that large-scale public investment programs are important to speed up economic development. However, as emphasized by Heller (1974) and Rioja (2003), on-going expenditures to cover recurrent costs for operation and maintenance (to avoid faster capital depreciation by "filling the potholes") are crucial to have investment projects remain productive in the medium to long term. By making explicit the financing needs to maintain capital, our sustainable investing approach suggests that, when revenue mobilization is difficult or the distorting effects of fiscal adjustments are large, the investment scaling-up should be reduced. With a smaller scaling-up, more resource revenue can be saved in a resource fund, whose return helps finance recurrent costs, thus yielding long-term growth benefits from investing a windfall.

The second application, to Angola, underscores the importance in building a fiscal buffer to invest volatile revenue, as advised in Collier et al. (2010), van der Ploeg (2010b), Cherif and Hasanov (2012), and Van den Bremer and van der Ploeg (2012). Fiscal responses to resource revenue can have a substantial impact on macroeconomic stability (Pieschacon (2011)). Large fiscal expansions from 2006 to 2008 in Angola, prompted by oil revenue surges, left the economy with little buffer when the oil price plummeted in 2008-2009. By using the resource fund as a fiscal buffer, our sustainable investing approach instead can protect the economy from the boom-bust cycles driven by commodity price shocks. Stochastic simulations that account for historical volatility of oil prices demonstrate how our framework

[6]The CEMAC region consists of Cameroon, Central African Republic, Chad, Congo, Equatorial Guinea, and Gabon. See Caceres et al. (2011) and Baker and Nxumalo (forthcoming) for recent economic conditions and oil production activity in the CEMAC region. The average share of oil GDP is 38 percent of GDP in 2010 and is expected to decline to about a quarter of the current production level by 2030.

can assess the adequacy of a buffer given a scaling-up plan and inform allocations between investing and savings in the context of uncertain revenue flows.

Among the burgeoning research on managing resource revenue in developing economies, our paper adds to the literature by constructing a fully-specified dynamic stochastic framework that can be used for policy analysis. The papers previously cited provide useful benchmarks and insights on several issues of investing resource revenue from the perspective of optimal policy. The models used, however, are often simplified for tractability and focus on solving a social planner's problem. Moreover, they often endow governments with a set of fiscal tools that are capable to fully correct any kind of distortions (e.g., internalize the effects of frictions such as absorptive capacity constraints or smooth consumption for hand-to-mouth consumers), but that may not be implementable in reality.[7] Our model, on the other hand, incorporates more fully the consumption, working, saving, investing, and production decisions of private agents, while also focusing on simple and implementable fiscal policies. A relatively detailed specification of fiscal variables makes it feasible to simulate the effects of a given fiscal path or of simple fiscal rules in allocating resource revenues.

II. Model Setup

The model is a small open, real economy that has three production sectors: non-traded goods, (non-resource) traded goods, and a natural resource. It includes the standard friction of investment adjustment costs of the DSGE literature as well as frictions that are common in developing countries, such as public investment inefficiencies and absorptive capacity constraints.

Our interest is in studying the macroeconomic effects of a resource-revenue-financed public investment scaling up in low-income or lower-middle income countries. We examine later alternatives involving greater reliance on tax finance. However, the scope for tax increases in practice is generally limited over the medium term. Despite recent progress, most still face significant challenges (International Monetary Fund (2011)). We also abstract from debt-financed scaling ups. Most governments in low-income and lower-middle-income countries have limited access to external commercial funds, particularly before the discovery of natural resource reserves.[8] Concessional borrowing is possible—and the model can account for it as aid—although this is to a great extent beyond the authorities' control and

[7] For example, van der Ploeg (2010b), Bems and de Carvalho Filho (2011), and Cherif and Hasanov (2012) assume exogenous non-resource income; Venables (2010), Araujo et al. (2012), and van der Ploeg et al. (2012) abstract from government or fiscal specifications; van der Ploeg (2010a) and van der Ploeg and Venables (2011) assume foreign financed private capital.

[8] In particular, low-income countries with IMF-supported programs are subject to debt limit policies on non-concessional borrowing. Recently the IMF has reviewed these policies to reflect better the diversity of low-income countries and their financing patterns, and offer more flexibility depending on countries' debt vulnerabilities and public financial management capacity. See International Monetary Fund (2009) for the guidelines on debt limits in Fund-supported programs.

exogenously given.[9] In addition, reflecting financial development conditions in these economies the model is assumed to have a closed private capital account, as a first approximation.[10]

A. Households

A representative household chooses consumption c_t and labor l_t to maximize expected utility,

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{1}{1-\sigma} (c_t)^{1-\sigma} - \frac{\kappa}{1+\psi} (l_t)^{1+\psi} \right], \tag{1}$$

subject to the budget constraint in units of domestic composite consumption:

$$\left(1+\tau_t^c\right) c_t + b_t = \left(1-\tau_t^l\right) w_t l_t + R_{t-1} b_{t-1} + \Omega_t^T + \Omega_t^N + s_t rm^* + z_t. \tag{2}$$

E_0 denotes the expectations operator conditional on information available at time 0. σ and ψ are the inverses of the elasticities of intertemporal substitution for consumption and labor supply, respectively. κ is the disutility weight on labor. w_t is a real wage index measured in units of consumption, τ_t^c and τ_t^l are the consumption and labor tax rates, rm^* denotes remittances in units of foreign consumption (denoted by $*$), and z_t denotes government transfers. s_t is the CPI-based real exchange rate, and Ω_t^T and Ω_t^N are profits from the traded and non-traded good sectors, respectively. The household holds domestic government bonds b_t, which pay $R_t b_t$ units of composite consumption at $t+1$, with R_t representing the domestic gross real interest rate. Throughout the analysis, we assume that government does not issue additional debt to finance public investment spending ($b_t = b \; \forall \; t$). Households do not have access to foreign loans.[11]

Consumption c_t is a composite of non-traded goods (c_t^N) and traded goods (c_t^T), combined in a constant-elasticity-of-substitution (CES) basket

$$c_t = \left[\varphi^{\frac{1}{\chi}} \left(c_t^N\right)^{\frac{\chi-1}{\chi}} + (1-\varphi)^{\frac{1}{\chi}} \left(c_t^T\right)^{\frac{\chi-1}{\chi}} \right]^{\frac{\chi}{\chi-1}}, \tag{3}$$

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[9] In the natural resource literature, there are papers that allow for government non-concessional debt which is subject to a risk premium, e.g., van der Ploeg and Venables (2011). Empirically this premium is high which implies an almost closed capital account from a borrowing perspective.

[10] See Appendix 1 in International Monetary Fund (2012c) for a list of resource-rich developing countries, and International Monetary Fund (2012a) for a survey of financial development in low-income countries.

[11] A typical low-income country features a large share of hand-to-mouth households, who do not have access to capital and asset markets and consume all their disposable income each period. Because of the assumptions that 1) the private sector faces a closed capital account, 2) firms (not households) own private capital, and 3) the government does not issue additional debt to finance public investment, the forward-looking households behave very similarly to the hand-to-mouth in response to shocks. An alternative setup with a large share of the hand-to-mouth households produces very close results to the one here. For similar reasons, and as discussed in Buffie et al. (2012), allowing the government to finance investment through domestic debt would add little to the analysis.

where χ denotes the intratemporal elasticity of substitution, and φ indicates the degree of consumption home bias. Let the composite consumption be the numeraire of the economy, and assume the law of one price holds for traded goods. Then, s_t is also the relative price of traded goods to composite consumption. The CES basket implies that the price of one unit of composite consumption is

$$1 = \varphi \left(p_t^N\right)^{1-\chi} + (1-\varphi)(s_t)^{1-\chi}, \tag{4}$$

where p_t^N is the relative price of non-traded goods to composite consumption.

1. Aggregate Labor and Wage Rates

Households only supply labor l_t^N and l_t^T to non-resource sectors. There is imperfect labor mobility as reflected by the following CES aggregator for total labor:

$$l_t = \left[\delta^{-\frac{1}{\rho}} \left(l_t^N\right)^{\frac{1+\rho}{\rho}} + (1-\delta)^{-\frac{1}{\rho}} \left(l_t^T\right)^{\frac{1+\rho}{\rho}}\right]^{\frac{\rho}{1+\rho}}, \tag{5}$$

where δ is the share of labor in the non-traded sector in the initial steady state and $\rho > 0$ governs labor sectoral mobility. The real aggregate wage rate is then given by

$$w_t = \left[\delta \left(w_t^N\right)^{1+\rho} + (1-\delta) \left(w_t^T\right)^{1+\rho}\right]^{\frac{1}{1+\rho}}. \tag{6}$$

B. Firms

Firms produce goods in either the non-traded goods sector (N) or the traded goods sector (T), using labor (l), private capital (k) and public capital (K^G). The production in the natural resource sector (O) is assumed to be exogenous, for simplicity.

1. Natural Resource Sector

Since most natural resource production in reality is capital intensive, and much resource investment in low-income countries is financed by foreign direct investment, we can assume the following exogenous process for output in the natural resource sector:

$$\frac{y_t^O}{y^O} = \left(\frac{y_{t-1}^O}{y^O}\right)^{\rho_{yo}} e^{\varepsilon_t^{yo}}, \tag{7}$$

where$\rho_{yo} \leq 1$, $\varepsilon_t^{yo} \sim i.i.d.N(0, \sigma_{yo}^2)$ is the resource production shock and a variable without a time subscript is a variable's value at the initial steady state. We also assume that a country's resource output is relatively small in the world market, and that the international commodity price p_t^{O*} (relative to foreign goods) is exogenous and follows the process

$$\frac{p_t^{O*}}{p^{O*}} = \left(\frac{p_{t-1}^{O*}}{p^{O*}}\right)^{\rho_{po}} e^{\varepsilon_t^{po}}, \tag{8}$$

where $\rho_{po} \leq 1$, $\varepsilon_t^{po} \sim i.i.d.N(0, \sigma_{po}^2)$ is the resource price shock. Resource GDP in units of domestic composite consumption is[12]

$$Y_t^O = s_t p_t^{O*} y_t^O. \tag{9}$$

Resource production is subject to a royalty at a rate of τ^o.[13] Resource revenue collected each period is

$$T_t^O = s_t \underbrace{\left(\tau^o p_t^{O*} y_t^O\right)}_{\equiv T_t^{O*}}. \tag{10}$$

As most resource output in developing countries is exported, we assume that resource output in the model is not consumed domestically.

2. Non-traded Good Sector

The non-traded sector is perfectly competitive. A representative firm uses the technology

$$y_t^N = z^N \left(k_{t-1}^N\right)^{1-\alpha^N} \left(l_t^N\right)^{\alpha^N} \left(K_{t-1}^G\right)^{\alpha^G}, \tag{11}$$

where α^G is the output elasticity with respect to public capital and z^N is a productivity scale parameter. Following neoclassical literature on models with public capital (e.g., Baxter and King (1993) and Kamps (2004)), constant returns to scale are assumed with respect to private production inputs and increasing returns to scale with respect to public capital.[14]

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[12]One way to further simplify the specification is to model the effects of a natural resource sector as foreign transfers that capture resource revenue flows (see, e.g., Dagher et al. (forthcoming)). By making explicit the natural resource GDP, however, the model can be calibrated to better match countries national accounts and fiscal data.

[13]In practice, other instruments or mechanisms, including production sharing contracts, corporate income taxes, and state ownership or participation, may also be used to collect resource revenue (International Monetary Fund (2012b)). Since our analysis concerns only total resource revenue collected, we use one instrument to calibrate the share of resource revenue in total revenue.

[14]Relative to another common specification with constant return to scale to all production factors, this specification has the advantage that α^N can be calibrated to match income shares of labor and private capital of an economy.

Private capital evolves by the law of motion

$$k_t^N = \left(1 - \delta^N\right) k_{t-1}^N + \left[1 - \frac{\kappa^N}{2}\left(\frac{i_t^N}{i_{t-1}^N} - 1\right)^2\right] i_t^N, \tag{12}$$

where $\kappa^N \geq 0$ is the investment adjustment cost parameter.

A representative non-traded good firm maximizes its net present-value profit weighted by the marginal utility of households (λ_t),

$$E_t \sum_{t=0}^{\infty} \beta^t \lambda_t \underbrace{\left[(1-\iota)\left(p_t^N y_t^N\right) - w_t^N l_t^N - i_t^N + \iota p_t^N Y_t^N\right]}_{\equiv \Omega_t^N \text{, profit of the non-traded good sector}}, \tag{13}$$

where ι captures distortions in developing countries that discourage firms from investing and hiring further and Y_t^N denotes the aggregate output of non-traded goods.[15] Implicitly, ι acts like a distorting tax on firms but revenue collected remains in the private sector. For simplicity, these implicit taxes are rebated back to the firms in a lump-sum fashion.

3. Traded Good Sector

The traded good sector is also perfectly competitive and produces by a similar technology to that in the non-traded sector

$$y_t^T = z_t^T \left(k_{t-1}^T\right)^{1-\alpha^T} \left(l_t^T\right)^{\alpha^T} \left(K_{t-1}^G\right)^{\alpha_G}. \tag{14}$$

The productivity z_t^T is subject to learning-by-doing externalities, depending on the last period traded output :

$$\ln z_t^T = \rho_{zT} \ln z_{t-1}^T + d \ln y_{t-1}^T. \tag{15}$$

Like the non-traded good sector, capital evolves according to

$$k_t^T = \left(1 - \delta^T\right) k_{t-1}^T + \left[1 - \frac{\kappa^T}{2}\left(\frac{i_t^T}{i_{t-1}^T} - 1\right)^2\right] i_t^T, \tag{16}$$

and each firm maximizes its weighted preset-value profits,

$$E_t \sum_{t=0}^{\infty} \beta^t \lambda_t \underbrace{\left[(1-\iota) s_t y_t^T - w_t^T l_t^T - i_t^T + \iota s_t Y_t^T\right]}_{\equiv \Omega_t^T \text{, profit of the traded good sector}}. \tag{17}$$

[15] This tax helps match the relatively low investment to GDP ratios observed in developing countries.

C. The Government

Let capital letters denote the aggregate level of a variable (e.g., C_t is aggregate private consumption). The flow government budget constraint is

$$T_t^O + \underbrace{\tau_t^c C_t + \tau_t^l w_t L_t}_{\equiv T_t^{NO}\text{, non-resource tax}} + s_t A^* + s_t (1 + r^*) F_{t-1}^* = p_t^g G_t + Z_t + (R_t - 1) B + s_t F_t^*, \quad (18)$$

where F_t^* is the asset value of a resource fund earning a constant real interest rate r^*, A^* is foreign aid, G_t is government purchases with a relative price to composite consumption goods of p_t^g, and Z_t is aggregate transfers to households.[16]

For simplicity, our specification allows for accumulating external assets but abstracts from external commercial borrowing. Given that the government does not behave optimally, this assumption is akin to assume that the government follows a constant external commercial debt rule and, therefore, does not retire this costly debt during natural resource booms. This is consistent with the fact that the debt relief under the Highly Indebted Poor Countries (HIPCs) Initiative and Multilateral Debt Relief Initiative substantially lowered the debt burdens by about 90 percent relative to pre-decision point levels (see International Development Association and International Monetary Fund (2011)). As a result, the average debt service to GDP of the 36 HIPCs dropped from 3.1 percent in 2000 to 0.9 percent (or 3.9 percent of exports) in 2010. In addition, sovereign capital market access in low-income countries is low, in part due to non-concessional debt limits, especially under IMF-supported programs. Since 2006, only eight low-income countries have placed bonds internationally and total new external commercial debt has remained a small fraction of total new external debt. Concessional borrowing, on the other hand, is considered as aid, and the model can account for it, to some extent, by varying A^*.

The model also makes explicit the challenges that fiscal authorities in developing economies face regarding tax revenue mobilization. In particular note that despite taxing revenues from the non-traded and traded sectors ($\iota p_t^N y_t^N$ and $\iota s_t y_t^T$), the government is unable to use this as an additional source of fiscal revenue. That is, these taxes do not appear as revenues in the budget constraint (18). By assuming that they are rebated to the firms, as can be seen in equations (13) and (17), the model captures the inefficiencies of revenue mobilization in these developing economies. On the other hand, the government collects taxes on revenues from the natural resource sector and they account as a valid financing source for potential fiscal expenditures. Although this seems to be at odds with our assumptions about taxation of the non-resource sectors, it actually reflects some key tax-relevant characteristics of the extractive industries in developing economies. In particular, potentially sizable rents arise in these industries, which are an especially attractive tax base on efficiency grounds, as they generally accrue to foreigners.[17]

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[16]The presence of aid helps better match the actual budget in applications to low-income countries.

[17]Future work could usefully expand on the role of weak revenue systems in sustaining an initial low-public-capital equilibrium. It could be interesting to suppose that consumption and labor taxes are also

1. Investment Efficiency and Absorptive Capacity Constraints

Government purchases consist of expenditures on government consumption G_t^C and public investment G_t^I. We introduce the concept of *effective* public investment ($\tilde{G}_t^I$), which differs from the expenditure concept (G_t^I), by allowing in the model for potential investment inefficiencies and absorptive capacity constraints. As a result, the law of motion of public capital is given by

$$K_t^G = (1-\delta_t^G)K_{t-1}^G + \underbrace{\epsilon_t\left(G_t^I\right) \times G_t^I}_{\equiv \tilde{G}_t^I\text{, effective investment}} \quad , \tag{19}$$

where δ_t^G is the time-varying depreciation rate of public capital, and $0 < \epsilon_t \leq 1$ governs the efficiency of public investment. To capture the idea that lack of maintenance shortens the life of existing capital, we follow Rioja (2003) to model the depreciation rate as a decreasing function of investment expenditure:[18]

$$\delta_t^G = \left\{ \begin{array}{ll} \delta^G \times \frac{\delta^G K^G t-1}{\tilde{G}_t^I}, & \text{when } \tilde{G}_t^I < \delta^G K_{t-1}^G \\ \delta^G, & \text{when } \tilde{G}_t^I \geq \delta^G K_{t-1}^G \end{array} \right\}. \tag{20}$$

Based on the non-parametric estimation results by Arestoff and Hurlin (2006), we assume that investment efficiency takes two values: it falls from ϵ to $\bar{\epsilon}$ when the expenditure level rises above a threshold $\bar{G}^I$. This captures the idea of rising investment costs due to absorptive capacity constraints.[19] Specifically,

$$\epsilon_t\left(G_t^I\right) = \left\{ \begin{array}{ll} \epsilon, & \text{when } G_t^I < \bar{G}^I \\ \bar{\epsilon}, & \text{when } G_t^I \geq \bar{G}^I \end{array} \right\}. \tag{21}$$

Like private consumption, government purchases are a CES basket that includes traded and non-traded goods,

$$G_t = \left[\nu_t^{\frac{1}{\chi}}\left(G_t^N\right)^{\frac{\chi-1}{\chi}} + (1-\nu_t)^{\frac{1}{\chi}}\left(G_t^T\right)^{\frac{\chi-1}{\chi}}\right]^{\frac{\chi}{\chi-1}}, \tag{22}$$

where ν_t denotes the degree of home bias in government purchases. The relative price of government consumption to private consumption is

$$p_t^g = \left[\nu_t\left(p_t^N\right)^{(1-\chi)} + (1-\nu_t)\left(s_t\right)^{1-\chi}\right]^{\frac{1}{1-\chi}}. \tag{23}$$

subject to a similar distortion, with only a fraction of the take appearing in the government's budget constraint.

[18]Rioja (2003) separates investment expenditures between those for new projects and those for maintenance, and the depreciation rate is correlated positively with private capital to capture the intensity of public capital usage and negatively with maintenance expenditures.

[19]Several other approaches exist to model absorptive capacity constraints. Buffie et al. (2012) model this as increasing "prices" of public investment. van der Ploeg (2011a) models this as an internal adjustment cost linked to the public investment management index (PIMI, Dabla-Norris et al. (2011)).

Note that ν_t can be time-varying. In general, a large share of government purchases go to wage bills for paying public servants, implying a relatively high degree of home bias. Since our analysis focuses on allocating additional government spending to public investment, we allow the degree of home bias for additional government spending (ν_g) to be different from its steady-state value (ν). Hence,

$$\nu_t = \nu + \frac{p_t^g G_t - p^g G}{p_t^g G_t} \left(\nu_g - \nu\right). \tag{24}$$

2. Fiscal Policy

Define a resource windfall as a resource revenue that is above its original steady-state level, i.e., $T_t^{O*} - T^{O*}$ in units of foreign goods. Policy specifications below describe the three approaches analyzed in the paper. A resource fund in each approach serves different purposes and hence its evolution is governed by different rules.

- **Saving in a Sovereign Wealth Fund (SWF).** Under this approach, all the resource windfall is saved externally in a SWF. Since spending the additional resource revenue is limited to the interest income of a resource fund ($r^* F_{t-1}^*$ in (18)), then the fund evolves according to

$$F_t^* = F_{t-1}^* + \left(T_t^{O*} - T^{O*}\right). \tag{25}$$

- **The All-Investing Approach.** Here the resource fund stays at its initial level each period $F_t^* = F^* \;\forall\; t$, while public investment expenditures follow the rule

$$G_t^I = G^I + \left(\frac{T_t^O}{p_t^g} - \frac{T^O}{p^g}\right). \tag{26}$$

- **The Sustainable Investing Approach.** Under this approach, a relatively stable scaling-up path of public investment is specified (details of which will be discussed later), commensurate with a country's profile of resource revenue, absorptive capacity, and a development objective. In the case of a short resource revenue horizon, a resource fund is often established for saving purposes. Under this circumstance, we assume that a fixed share ϕ of a resource windfall is saved in a SWF each period, which evolves by

$$F_t^* = F_{t-1}^* + \phi\left(T_t^{O*} - T^{O*}\right). \tag{27}$$

  In the case where a resource fund is built for the stabilization purpose, the saving rate is time-varying. The fund instead evolves by

$$F_t^* = F_{t-1}^* + \left(T_t^{O*} - T^{O*}\right) - \left(\frac{p_t^g G_t}{s_t} - \frac{p^g G}{s}\right), \tag{28}$$

which is broadly similar to equation (27) but can address revenue volatility issues as we will see below.

Under all fiscal approaches considered, different fiscal instruments are allowed to clear the government budget constraint, including transfers and consumption or labor tax rates. Those that do not adjust are set to their initial steady-state levels.

D. Some Market Clearing Conditions and Identities

Since the total demand for non-traded goods is

$$D_t^N = \varphi \left(C_t + I_t^N + I_t^T \right) + \nu (p_t^g)^\chi G_t, \tag{29}$$

the market clearing condition for non-traded goods corresponds to

$$Y_t^N = (p_t^N)^{-\chi} D_t^N. \tag{30}$$

The current account deficit (CA_t^d) can be expressed as

$$CA_t^d = \left(C_t + I_t + p_t^G G_t \right) - Y_t - s_t \left(r^* F_{t-1}^* + RM^* \right), \tag{31}$$

where $I_t = I_t^N + I_t^T$ is total private investment, and $Y_t = p_t^N Y_t^N + s_t Y_t^T + Y_t^O$ is real GDP. Finally, the balance of payment condition is

$$CA_t^d = s_t \left[A^* - \left(F_t^* - F_{t-1}^* \right) \right]. \tag{32}$$

III. Equilibrium and Calibration

The equilibrium system of the model consists of the private agents optimality conditions, the government budget constraint, fiscal policy, market clearing conditions, the balance of payment condition, and the exogenous processes of the shocks (see Appendix I for the definition of the equilibrium and optimality condition). The model is at the annual frequency an applied to the CEMAC region and Angola, as representative cases of the policy challenges associated with natural resource revenue exhaustibility and volatility, respectively. Table 1 summarizes the baseline calibrations for these country applications. The two calibrations share many parameter values, especially those without country specific estimates in the literature.

For both applications, we calibrate the degree of home bias in private consumption and investment to be $\varphi = 0.5$, as in Burstein et al. (2005). For the elasticity of substitution between traded and non-traded goods, we set $\chi = 0.44$, following Stockman and Tesar (1995). We use the estimate by Horvath (2000) for the labor mobility parameter: $\rho = 1$. The risk aversion parameter for households is $\sigma = 2$—an intertemporal elasticity of substitution of 0.5—corresponding to the high end value of most estimates in developing countries

(Agenor and Montiel (1999)). A low Frisch labor elasticity of 0.1 ($\psi = 10$) is assumed, in line with the $0.15 - 0.17$ wage elasticity of labor supply in rural Malawi (Goldberg (2011)). The discount factor $\beta = 0.91$ corresponds to a domestic annual interest rate of 10 percent.

To calibrate the parameters related to the absorptive capacity constraints, we resort to the only empirical evidence we could locate in the literature. Using Mexican data from 1980 to 1994, Arestoff and Hurlin (2006) find that the coefficient of regressing public capital produced (or effective investment in our model) on investment expenditures falls from 0.5 to 0.35 when investment expenditures exceeds 1.6 times of the average level in the sample.[20] Thus, to calibrate (21), we set $\epsilon = 0.5$ and $\bar{\epsilon} = 0.35$, and $\bar{G}^I = 1.6 \times G^I$. This range of investment efficiency ($0.35 - 0.5$) is in line with Pritchett's (2000) estimate for sub-Saharan countries with a linear specification between effective investment and investment expenditures.

For private production, data on factor shares in sub-Saharan Africa suggest that the capital share in non-resource production is about $0.55 - 0.6$ in the non-traded good sector and $0.35 - 0.4$ in the traded good sector.[21] According to the low end of these ranges, then the sectoral labor income shares are $\alpha^N = 0.45$ and $\alpha^T = 0.65$. Both applications set the depreciation rates for private capital to be at 10 percent in non-traded and traded sectors ($\delta^N = \delta^T = 0.1$). Without empirical backing, we assume a minor degree for the learning-by-doing externality: $\rho_{zT} = d = 0.1$. The parameters of investment adjustment costs are set to $\kappa^N = \kappa^T = 25$, both following the calibration in Berg et al. (2010).

Resource production shocks are assumed to be somewhat persistent: $\rho_{yo} = 0.9$ in (7). Since the resource commodity in both applications is oil, we assume that the real oil price follows a random walk without a drift ($\rho_{po} = 1$ in (8)), as estimated by Hamilton (2009) using data from 1970 to 2008. The oil price per barrel in the initial steady state is set to $\$94$ a barrel, matching the 2011 actual average and the WEO price forecast (World Economic Outlook database updated June 2012, International Monetary Fund (2012e)) from 2012 to 2017. Based on the average real return of the Norwegian Government Pension Fund from 1997 to 2011 (Gros and Mayer (2012)), the annual real return of international financial asset is set to 2.7 percent ($r^* = 0.027$).

The rest of the section describes the country specific parameterization to match the national accounts and fiscal data in the calibrated initial steady state of each economy.

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[20] Arestoff and Hurlin (2006) also provide estimates for Colombia. Although the average slope is similar to that of Mexico—about 0.4— the relationship appears to be linear regardless of investment levels. While absorptive capacity constraints in developing countries have long been recognized in the literature (e.g., Horvat (1958), Adler (1965)), Chenery and Strout (1966), and Berg (1983)), empirical evidence, however, is scant, and experience across countries is likely to vary. This suggests more empirical work is needed to better model and calibrate absorptive capacity constraints for individual countries.

[21] See the GTAP5 database, assembled by the Global Trade Analysis Project and the International Food Policy Research Institute. See Buffie et al. (2012) for a summary of other estimates for factor shares of countries in sub-Saharan Africa.

A. The CEMAC Region

Oil production in the CEMAC region reached its peak in mid-2000 at about 400 million barrels a year. By 2010, it had declined to 376.8 million barrels or 37 percent of CEMAC GDP (Caceres et al. (2011)). Based on projections by IMF country teams, oil production is projected to gradually decrease and reach a low level of about 100 million barrels in 2030 (roughly the production level in 1980). We calibrate the initial steady state to have a low level of oil production, about 9 percent of GDP. While the oil production remains high in the starting year of the simulations (2012), the region is on its way to this low level of oil production, making explicit exhaustibility concerns.[22]

The initial steady state is calibrated to match averages of WEO historical data, subject to availability. The trade balance is set to 5.7 percent of GDP based on the average of exports and imports from 1980 to 2000. For private investment, the $1990 - 2010$ average historical share of GDP is 0.17. Together with a 10-percent depreciation rate of private capital, the model implies a distorting factor of $\iota = 0.16$. Government expenditure is set to equal the $2000 - 2010$ average of 20.1 percent of GDP, out of which 6.8 percent is public investment.

As for the return to public capital, there exists a wide range of estimates in the literature. Bai and Qian (2010) estimate the return to various types of infrastructure in China, and obtain a rate of around 10 percent for transport, storage, and postal service in the early 1980s (their Figure 11) and also around 10 percent for railway systems in the early 1990s (their Figure 15). Estimates for investment projects in low-income countries are particularly diverse and changing over time. The median rate of return of the World Bank projects increased from 12 percent in late 1980s to 24 percent in 2008 (International Bank for Reconstruction and Development and the World Bank (2010)). Based on a large project-level disbursement dataset, Kraay (2012), however, finds that World Bank projects have smaller output multipliers in low-income countries. Our baseline calibration for the CEMAC region assumes the elasticity of public capital to output is $\alpha^G = 0.1$. Together with an annual depreciation rate of public capital of 8 percent ($\delta^G = 0.08$), this implies a return to public capital—defined as marginal product of public capital less depreciation—of 13.4 percent. The implied public capital is 42.5 percent of GDP in the initial steady state, roughly the average estimated ratio of public capital to GDP of developing countries in 2003 (based on a sample of 31 developing countries estimated by Cubas (2011)).[23] Because the return to public investment plays an important role in our analysis, we explore the implication of varying α^G from 0.05 to 0.2 for the CEMAC simulations.

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[22]Following the DSGE convention, the starting point of the simulation is a steady state. For developed economies, this steady state is often a balanced growth path that characterizes the long-term average performance of an economy. For developing countries analyzed here, we calibrate this steady state to be an initial state that characterizes the average past performance of the economy.

[23]Our calibrated depreciation rate is much higher than the range of 2.5 to 4.3 percent used for developing countries in the literature (e.g. Hurlin and Arestoff (2010) and Gupta et al. (2011)). Since lack of maintenance on public capital is common in low-income countries (World Bank (1994)), the actual depreciation rate in the CEMAC region is likely to be higher than the typically assumed low rate. Also, a low depreciation rate would imply an unreasonably high capital output ratio for the CEMAC region, inconsistent with actual conditions.

Based on data in International Monetary Fund (2011), the average VAT rate for the CEMAC countries is about 18 percent, so $\tau^c = 0.18$. To target the average of tax revenue to GDP ratio of 0.18 (average of $1990 - 2010$), the labor tax rate is set to 8 percent, $\tau^l = 0.08$. When calibrating the oil tax rate, we set $\tau^o = 0.58$ to match an initial oil revenue share in total revenue of 0.55, roughly the average share from 2000 to 2010. Based on the $1980 - 2000$ average of the government balance, a low level of a resource fund at 1 percent of GDP is assumed in the initial steady state. Also, the average external debt to GDP ratio of the CEMAC region at the end of 2010 implies that public debt at the initial steady state is 11.6 percent of GDP.

Lastly, without empirical support, we assume that the degree of home bias in government purchases has a higher content in non-traded goods, $\nu = 0.6$. For government purchases financed by a resource windfall, the degree of home bias falls to 0.5 ($\nu_g = 0.5$), as increased public investment spending is more likely to fall on traded goods.

B. Angola

For the Angola simulations, the initial steady state is mostly calibrated based on the data of 2011, following Richmond et al. (2012). The oil production in the initial state is set to the 2011 level of 606 million barrels and oil output is 47.5 percent of GDP. Given an oil tax rate of 0.58, the model implies that oil tax receipts are about 80 percent of total government revenue.[24] Since Angola has not saved abroad its oil revenue, the size of the stabilization fund in the initial state is set at a low value of 2 percent of GDP.

Given a high dependence on oil production, Angola has relied on imports to a large extent to meet domestic demand. For private consumption and investment baskets, we assume $\varphi = 0.4$, less than the typical value of 0.5. Moreover, the degree of home bias in government purchases is $\nu = 0.4$ in the initial steady state. For additional government spending above the steady-state level, the degree of home bias is assumed to be even lower as reflected by $\nu_g = 0.2$. Since oil production is almost 50 percent of GDP, the assumption of unusually low degree of home bias is consistent with a rather small non-resource production sector; the model implies that non-oil traded good production is only 17 percent of GDP.

Public investment in the initial steady state is 8.7 percent of GDP, the level in 2011. Given a 7-percent depreciation rate and investment efficiency parameter value of $\epsilon = 0.5$, we choose $\alpha^G = 0.2$ to target a return to public capital of about 10 percent. Government consumption in the initial steady state is 19.5 percent of GDP. As government debt is 34.5 percent of GDP, the model implies that household transfers correspond to 2.8 percent of GDP. Without specific tax rate data, consumption and labor tax rates are both set at 0.1, implying that the non-resource tax revenue is about 20 percent of total revenue. The model implied distorting tax rate is $\iota = 0.2$.

[24] The tax rate in Angola is oil price dependent.:$\tau_t^o = 0.56$ if the crude oil per barrel is less than US\$75; $\tau_t^o = 0.58$ if between US\$75 and US\$100; $\tau_t^o = 0.6$ if between US\$100 and US\$125; and finally, $\tau_t^o = 0.65$ if oil price is above US\$125.

Finally, Angola simulations are conducted under stochastic oil prices since our focus here is on the implications of natural revenue volatility. To calibrate the standard deviation of oil price shocks, the process of (8) with $\rho_{po} = 1$ is estimated using (log) real oil price data from 1980 to 2011. This yields $\sigma^{po} = 0.1$.[25]

IV. Investing with a Short Revenue Horizon

The analysis begins by showing how the model developed in Section II can be used to inform policy decisions when a resource revenue horizon is short. The conventional PIH advice—to save in a SWF—may be attractive when resource revenues are expected to be exhausted within 10 to 20 years. By comparing the macroeconomic outcomes under the approaches of saving in a SWF vs. investing in public capital, we highlight the important factors to consider between the two options. Also, when investment is sufficiently productive, we show how the proposed sustainable investing approach can help determine a scaling-up magnitude that is sustainable after resource revenue is exhausted.

The simulation exercise applies the model to the CEMAC region by taking as given the projection of oil production from 2012 to 2030 by IMF country teams. Since the current oil production is much above the level in the calibrated steady state, the model is solved by a non-linear perfect foresight solution to avoid approximation errors due to linearization. The constant oil price assumption and the perfect foresight solution ignore the role of volatility and uncertainty played in policy decisions, which will be studied in the next section V, conducting stochastic simulations for the Angola application.

A. Saving in a SWF vs. Investing in Public Capital

Figure 1 presents the responses of four scenarios under the two approaches to managing oil revenue in the CEMAC region. Oil production, held at the same levels across all scenarios, is expected to decline from about 380 million barrels a year in 2012 to about 100 million barrels in 2030. The solid lines are responses under saving in a SWF, and the dotted-dashed lines are those under the all-investing approach. Unless indicated in parentheses, the units are in percent deviations from a growth path in absence of oil windfalls from the level in the initial steady state.

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[25]The oil price series is the simple average of three spot prices: Dated Brent, West Texas Intermediate, and Dubai Fateh.

1. The Baseline Scenario

The first column presents the results under the baseline calibration (Table 1). With saving in a SWF, accumulation of windfall (by equation (25)) increases the fund steadily, reaching 132 percent of GDP in the new steady state. The interest income from the SWF enters the regular budget each period and is mainly distributed to households as transfers.[26] As transfers increase, private consumption becomes higher. Despite a temporary windfall, households enjoy a permanent higher level of consumption because of a higher net foreign asset position. In the new steady state, consumption is 5.2 percent higher relative to the path without the windfall. With higher consumption, the wealth effect has a small negative influence on labor inputs.[27] As a result, non-oil GDP experiences a small decline in the new steady state. Public capital does not increase because public investment stays constant at the initial steady state level.

In contrast to saving in a SWF, the all-investing approach invests all windfall in public capital (26), building up a higher public capital stock. At the peak (in 2025), public capital is 26 percent higher relative to the path without the windfall. Higher public capital raises the marginal product of private inputs, resulting in higher non-oil GDP. But higher output also means more income to households, which supports higher private consumption. At the peak (in 2026), consumption is 4.3 percent above the path without the windfall and slightly higher than consumption with saving in a SWF(4.1 percent). Consequently, welfare is also higher under all-investing by 1.0 percent of initial steady-state consumption each period.[28]

2. Absorptive Capacity

Absorptive capacity constraints are a fundamental factor for the benefits of investing all the oil windfall. Column one of Figure 1 shows that despite much more public investment, households only enjoy slightly more consumption with all-investing than with saving in a SWF. This is because the baseline assumes that absorptive capacity constraints are binding, i.e., investment efficiency falls from 0.5 to 0.35 when the expenditure levels are above 60 percent of the initial steady-state level. The second column explores the scenario where

[26]Results are similar when the interest income is used to lower the consumption tax rate.

[27]Given our calibration of a low Frisch labor elasticity (0.1), the influence of negative labor responses on non-resource output is suppressed. An alternative modeling strategy would be to adopt the Greenwood-Hercowitz-Huffmann preference (Greenwood et al. (1988)), which removes the wealth effect. A number of researchers, however, find a negative effect of remittance income on labor supply in developing countries, suggesting some wealth effect still operates; see e.g., Kim (2007).

[28]The welfare is measured by the average consumption change each period—in percent of consumption of the initial steady state—required to equate the present-value welfare in a path with a windfall to that in a path without. The horizon computed is from 2012 to 2040. A high discount factor (more impatient households) would mean that saving in a SWF—which has higher consumption later—has a higher chance to be preferred than all-investing, holding everything else constant.

absorptive capacity constraint does not bind: $\epsilon = 0.5 \; \forall \; t$.[29] Relative to column one, public capital in column two under all-investing rises much higher with the same amount of investment expenditures as the baseline. Consequently, non-oil GDP and private consumption are much higher. Peak consumption in scenario 2 is 8.4 percent higher than under the path without a windfall, compared to 4.3 percent with binding absorptive capacity constraints. Between saving in a SWF and all-investing in scenario 2, on average households enjoy more utility each period relative to saving in a SWF, equal to 3 percent of consumption in the initial steady state.

To assess the costs associated with absorptive capacity constraints, we compute the present-value, cumulative non-oil output multiplier for public investment. Following Mountford and Uhlig (2009), the cumulative multiplier at the end of year k is defined as

$$\frac{\sum_{i=0}^{k}\left(\prod_{j=0}^{i} R_{t+j}^{-1}\right)\triangle Y_{t+i}^{NO}}{\sum_{i=0}^{k}\left(\prod_{j=0}^{i} R_{t+j}^{-1}\right)\triangle p_{t+i}^{g} G_{t+i}^{I}}, \qquad (33)$$

where $\triangle Y_{t+i}^{NO}$ and $\triangle p_{t+i}^{g} G_{t+i}^{I}$ are level changes in non-resource GDP and public investment relative to the pre-windfall values. The discount factors—the product of domestic real rates R_{t+j}s—are constructed from model-implied interest rates along a transition path. Under the baseline with all-investing, the cumulative non-oil output multiplier is 0.41 at the end of 2040, and increases to 0.64 in scenario 2 with non-binding constraints.

While public capital in both scenarios is reasonably productive, the multiplier for public investment is generally low (much smaller than 1), mainly attributed by investment inefficiencies, aside from potential absorptive capacity constraints. Our model assumes that investment efficiency does not improve over time, because generally its underlying factors, such as institutional and governance quality as well as administration and managing capacity, can take a long time to improve. If public investment can be devoted to investing in building up capacity in implementing good investment ("investing in investing" in the terminology by Collier (2009)), the model could be revised to have investment efficiency changing along with investment expenditures in capacity building.

3. Return to Public Capital

In addition to absorptive capacity, another important factor for saving and investing decisions is the return to public capital. The first two scenarios assume that the public capital elasticity of output is $\alpha^G = 0.1$, implying a net annual return of 13.4 percent. In light of a wide variation among public investment projects, the rest two scenarios explore different values for α^G. Scenario 3 (the third column) assumes $\alpha^G = 0.05$, implying an annual return of 2.7

[29] All other parameters are held the same as in the baseline.

percent. Scenario 4 (the last column) corresponds to $\alpha^G = 0.20$ or an annual return of 35 percent, which is much higher than the median return (24 percent) of World Bank projects in 2008 (International Bank for Reconstruction and Development and the World Bank (2010)).

When investment projects are almost un-productive as in scenario 3, households are better off saving in a SWF and consuming the interest income. They enjoy much more consumption throughout most of the horizon relative to the case with all-investing. By the end of 2040, private consumption under saving in a SWF is 4.7 percent above the path without the windfall, while it is only 0.8 percent with all-investing. If instead public investment is quite productive as in scenario 4, households enjoy more consumption before 2035 with all-investing than with saving in a SWF. The welfare with all investing on average is 3.2 percent higher than with saving in a SWF. The cumulative non-resource output multiplier of public investment in 2040 increases from 0.28 when $\alpha^G = 0.05$ to 0.67 when $\alpha^G = 0.2$. When absorptive capacity constraints are also relaxed (keeping $\epsilon = 0.5 \; \forall \; t$, scenario not shown), the multiplier is further increased to 1.12.

The scenarios in Figure 1 highlight the sensitivity of economic outcomes to returns to public capital. While investing a windfall can build much needed public capital for development, when public capital is not sufficiently productive, an economy is better off following the conventional advice to save a windfall in an external fund.

B. Sustaining Public Capital

A frequently ignored issue by the literature that promotes investing is that, when a resource revenue horizon is short, sustaining public capital built with a windfall may be difficult in the long run. In reality, it is also the case that politicians often have preference to new projects instead than allocating budget for operating and maintaining existing capital.[30] This section discusses the financing issue of sustaining public capital under a short revenue horizon. It also introduces the sustainable investing approach as an alternative to ensure long lasting development gains from investing a windfall.

1. The Cost of Fiscal Adjustments

With the all-investing approach, one way to sustain capital is to make fiscal adjustments by cutting government spending or raising non-resource taxes to maintain sufficient investment to replenish depreciated capital. Figure 2 presents the four scenarios (as in Figure 1) with

[30]Heller (1979) documents examples of lost productivity resulting from lack of funding to cover capital recurrent costs:“In Colombia, new tarmac roads have suffered rapid and premature deterioration for lack of maintenance...Throughout West Africa, many new schools have opened without qualified teachers and education materials, or equipment...In the Sahel, pastoral wells constructed for livestock projects have fallen into disrepair...(p. 38).”

all-investing but assumes that transfers to households (solid lines) or the consumption tax rate (dotted-dashed lines) are adjusted to sustain public capital.[31]

Across scenarios, Figure 2 shows that some fiscal adjustments are required to sustain capital after a windfall ends. The argument that increases in non-resource revenue through more public capital ought to be able to finance investment for sustaining capital does not prevail here; even scenario 4 (the high capital return) requires slight adjustment in the long run. In the baseline (first column), the transfers to GDP ratio has to be lowered to 0.9 percent of GDP in the new steady state, from 2.7 percent in the initial steady state. If financed by taxes, the consumption tax rate has to be raised to 0.21 in the new steady state, from 0.18 originally.

With higher public capital relative to the case without sustaining capital (dotted-dashed lines in the first column of Figure 1), non-oil GDP is also higher in the new steady state. Whether households can enjoy more consumption, however, depends on the relative strength of the benefit from more public capital and the cost of fiscal financing. Rows (1) to (3) in Table 2 contain the welfare comparison results. Across the scenarios, households on average enjoy slightly higher welfare when capital is sustained under the baseline and scenario 4. When public capital is less productive (scenario 3), households are slightly better off if capital is not sustained, since the benefits from more capital is small. Similarly, households are also better off with un-sustained capital in scenario 2. Since more capital is built with non-binding absorptive capacity constraints, a higher investment level is required to maintain capital. Hence, fiscal adjustment magnitudes have to be a lot bigger. Transfers as a share of GDP now have to be lowered to -0.01, equivalent to a lump-sum tax of 1 percent of GDP. Alternatively, the consumption tax rate has to be raised to 0.24 in the new steady state. Aside from their negative economic impact, these large adjustments might not be feasible in practice. Given the political economy constraints in implementing large fiscal adjustments, public capital stocks built with windfalls are likely to depreciate over time.

C. Endogenous Depreciation of Public Capital

Our model specification assumes that the depreciation rate of public capital rises when investment is lower than the cost required to replenish capital at a steady-state depreciation rate, equation (20). Figure 1 shows that with all-investing, the depreciation rate rises after 2020 to about 10 percent. This endogenous deprecation rate penalizes volatile public investment trajectories relative to those that preserve capital once built. To show this, Figure 3 plots the same four scenarios as Figure 1 but under a fixed depreciation rate at the steady-state level of 8 percent. Not surprisingly, as public capital declines at a slower rate, non-oil GDP and private consumption are both higher with all-investing, across scenarios. Removing endogenous depreciation does not change the results in 2, because investment rates are maintained at high enough levels to preserve the capital stock. These two effects

[31]Technically, the period of the maximum public capital reached in each scenario simulated in Section A is identified. Then, public investment expenditures required to sustain capital from that point continued are computed. The magnitudes of fiscal adjustment in the consumption tax rate or transfers are endogenously determined by the government budget constraint.

combine to overturn the previous result that sustaining the capital stock through fiscal adjustment as in Figure 2 yields higher welfare in the more optimistic scenarios 1 and 4. To see this, compare row (4) to row (1) in Table 2. In the model, and we believe in practice, strategies that result in volatile capital stocks are less efficient. We return to this point below in discussing the management of natural resource volatility.

D. The Sustainable Investing Approach

One of the main challenges of investing a short-horizon resource windfall is to sustain capital in line with long-run fiscal sustainability. Instead of pursuing two extreme approaches of either saving abroad or investing all domestically, we propose the "sustainable investing approach" that combines these two approaches. The key to preserve resource wealth in the form of physical capital is to choose a sustainable scaling-up magnitude, given a windfall size and other fiscal and structural characteristics of the country. After a windfall is exhausted, interest income from any external savings and additional non-resource revenue can then jointly finance recurrent costs to maintain capital.

To formalize this approach, we specify an investment rule characterized by an initial increase in investment expenditure G_0^I, a scaling-up investment target in the new steady state G_{nss}^I, and an investment speed of adjustment γ.

$$G_t^I = \left(1 - e^{-\gamma t}\right) G_{nss}^I + e^{-\gamma t} G_0^I. \tag{34}$$

When $\gamma = 0$, $G_t^I = G_0^I \; \forall \, t$, and when $\gamma \rightarrow \infty$, public investment jumps to the new steady-state level immediately. Given a saving share ϕ of a windfall, the resource fund evolves by (27). Since oil production is projected to decline over time, and the authorities may have an intention to speed up the investment scaling-up, we choose $G_0^I > G_{nss}^I$, implying a front-loaded path for investment spending. Also, across all cases, we choose $\gamma = 0.15$ to yield a gradual declining investment path, settling at a level sufficient to sustain capital. The simulations presented here assume that the consumption tax rate is the instrument of fiscal adjustment. Results are similar under transfers adjustment.

The solid lines of Figure 4 compare the three cases with different scaling-up magnitudes and saving shares of a resource windfall under the baseline. For facility, the dotted-dashed lines repeat the outcomes of the all-investing approach under the baseline, combined with raising the consumption tax rate to sustain capital. The first column has $G_0^I = 1.6 \times G^I$ and $G_{nss}^I = 1.26 \times G^I$. Under the 0.5 saving rate, the resource fund eventually climbs to 64 percent of GDP. Meanwhile, public capital is 26 percent permanently higher relative to the path without a windfall. Higher public capital leads to permanently higher non-resource GDP, while private consumption is raised by 4.7 percent in the new steady state. During the transition path, as external savings and additional public investment expenditure do not fully exhaust a resource windfall, the government is also able to lower the consumption tax rate, boosting private consumption during the windfall period.[32]

Compared to the all-investing approach, public capital is scaled up at a slower pace and at a lower level under the sustainable investing approach. The moderate investment increase, however, implies that investment efficiency does not worsen. During the first 12 years, ϵ stays at a constant level of 0.5 with sustainable investing, relative to 0.35 under all-investing. In addition, sustainable investing under the scaling-up magnitude of $1.26 \times G^I$ and the saving rate of 0.5 also remove the need for fiscal adjustments after the windfall is exhausted. The interest income from a resource fund finances part of the capital recurrent cost. In the new steady state, the consumption tax rate returns to its initial steady-state level. As a result, consumption is higher relative to that of all-investing, where the consumption tax rate has to be raised to 0.21 permanently. In welfare terms, households enjoy on average more periodic utility—equivalent to 1.1 percent of initial steady-state consumption—with sustainable investing than with all-investing.

To see the implications of a higher scaling-up, the second column assumes that investment in the long run is 40 percent higher than the initial steady-state level. While public capital is now higher at 38 percent (compared to the 26 percent) above the no-windfall path, the interest income derived from the sovereign wealth fund becomes insufficient to support the higher investment. Consequently, to sustain capital, the consumption tax rate has to be raised to about 0.2. Despite more public capital and non-resource GDP, consumption under this higher scaling-up is lower due to a higher consumption tax rate. Periodic utility is on average 0.5 percent lower compared to the earlier case of 26 percent scaling-up.

Finally, the third column presents the case of a lower saving rate ($\phi = 0.2$), while the scaling-up remains at 26 percent. The 20-percent saving rate leads to a smaller resource fund. Since the investment level is the same as that of the case in column 1, more resource windfall can be allocated to reduce the consumption tax rate, resulting in a consumption boom during the windfall period. However, after the windfall, a smaller resource fund yields less interest income. As a result, the consumption tax rate has to be raised to about 0.2 to sustain capital. In the new steady state, private consumption is 1.7 percent lower than under the case with a 50-percent saving rate.

The results in Figure 4 illustrate how the framework can help determine a scaling-up magnitude given a projected windfall path. The choices of $G^I_{nss} = 1.26G^I$ and $\phi = 0.5$ in the first case are pinned down after a sequence of simulations to find the magnitude that does not require fiscal adjustment in the long run.[33] The results are certainly conditioned on

[32]In practice, the government needs not lower the consumption tax rate. It could save more of a resource windfall in a resource fund, distributes it to households as transfers, or even raising government consumption spending. The messages from changing all-investing to the sustainable investing approach remain valid regardless of these minor differences in policy design.

[33]The analysis does not suggest that a scaling-up magnitude that requires fiscal adjustment later is necessarily inferior to the one that does not. It depends on the feasibility of fiscal adjustments in a country, as well as the distorting effect of such adjustments. From the perspective of preserving resource wealth with physical assets, choosing a sustainable scaling-up magnitude, however, is desirable.

assumptions about return to public capital, absorptive capacity constraints, etc. When investment projects are less productive or the costs of absorptive capacity constraints are higher, fiscal adjustments would be larger and thus more difficult to implement. To avoid repeating the history that much of the public capital built under a windfall cannot have long-lasting growth effects, initial planning of an investment scaling-up must account for the future financing needs to sustain capital.

E. Development without the Windfall

The above discussion of financing costs of public investment sheds some light on a fundamental question related to the Lucas paradox (Lucas (1990)): Why is that in a capital-scarce economy, a public investment scaling-up cannot occur in the absence of a resource windfall? In our setup, part of the answer is the closed capital account: foreign capital does not flow easily to finance development. This assumption is common to much of the literature and largely consistent with stylized facts (see UNCTAD (2012)). Of course, the country in our model is able to develop the natural resource, which typically requires substantial investment. While this is implicit in our model, foreign direct investment often provides the mechanism in practice. In fact, foreign investments in low-income countries are to a large extent focused on natural resource extraction. For example, the greatest FDI flows to sub-Saharan Africa in 2011 went to Nigeria, Ghana, Congo, Mozambique, and Zambia and were to a very large extent directed at natural resource extraction.[34] This is presumably related to the fact that the substantial rents from resource extraction make extractive industry foreign investment attractive even in the face of the usual barriers to international capital flows related to sovereign immunity and poor governance in recipient countries.[35]

Even if foreign capital for non-resource public investment is scarce in poor countries, one might imagine that a properly motivated government would finance high-yielding public investments through its own revenue effort. A variety of distortions—some playing a role in the model presented here and many not—can explain why this typically has not happened. We would emphasize two. One is again the financing constraint and closed capital account, which implies that countries would need to go through a reduction in private consumption and investment in order to finance the scaling up. Second is the weak and distortionary domestic tax system (captured here by low effective tax rates and the ineffectiveness of the income tax). Figure 5 compares two scaling-up scenarios without a windfall to one with the windfall. The dashed lines repeat the sustainable investing case in the first column of Figure

[34] See UNCTAD (2012). The analysis of the role of natural resources in poor countries is complicated by some difficult classification problems. Analyses that focus on the importance of natural-resource intensive *countries* miss the importance of new resource discoveries. For example, Mozambique and Ghana are not generally classified as natural-resource-intensive countries, but FDI is directed towards exploration of new gas and oil fields and mining operations. Meanwhile, in terms of *sectors*, investments in services or manufacturing are typically closely related to or play a supporting role in resource extraction (page 41, UNCTAD (2012)).

[35] See International Monetary Fund (2012b), which discusses these issues and in particular how to design fiscal regimes that make use of the resource rents to overcome the various obstacles to attracting and benefiting from FDI.

4, which has a front-loaded investment path with a 26 percent scaling-up. The solid lines undertake the same scaling-up path, but the economy does not experience an oil windfall. The dotted-dashed lines also assume no resource windfall but take a more gradual scaling-up path, reaching the same level in the new steady state. As expected, when scaling-up without a windfall, the consumption tax rate has to adjust substantially. In particular, when public investment is front-loaded (solid lines), the consumption tax rate has to jump drastically from 0.18 to almost 0.27 immediately implying a substantial fall in private consumption. In the gradual scaling-up case (dotted-dashed lines), private consumption does not fall as much, but the consumption increase in the new steady state is still minimal. Without a windfall, welfare is higher if the scaling up is not undertaken. In contrast, with the windfall, welfare is generally higher under either scaling up approach (all-investing or sustainable investing) than with full saving of the windfall (saving in a SWF).[36] From this perspective, the resource windfall represents both a relaxation of the financing constraint and a new tax technology, in that we implicitly assume that low-income countries are in fact able to extract a high percentage of the rents for natural resource extraction.[37]

V. INVESTING VOLATILE RESOURCE REVENUE

The CEMAC application shows that the sustainable investing approach can address the exhaustibility issue when investing under a short revenue horizon. This section demonstrates how this approach can also manage volatility, in the context of the Angola application.[38] Given the long-lasting oil reserve and more potential future findings in Angola, the initial steady state is calibrated to have high oil production. Revenue volatility is introduced by fluctuating oil prices mimicking historical dynamics. Instead of obtaining a non-linear perfect foresight solution as in CEMAC simulations, the equilibrium here is log-linearized and solved by Sims's (2001) method for rational expectations models.

A. The Sustainable Investing Approach to Managing Volatility

With a long revenue horizon and high fiscal dependence on resource revenue, the resource fund analyzed for Angola is a stabilization fund, providing a fiscal buffer to smooth government spending. The policy rule for savings in a resource fund is revised to allow for depositing and withdrawing, as shown in equation (28). For a given path of public investment and government consumption, surplus revenues, $\left(T_t^{O*} - T^{O*}\right) - \left(\frac{p_t^g G_t}{s_t} - \frac{p^g G}{s}\right)$, are saved in a stabilization fund. Conversely, when there is a revenue shortfall, the fund is drawn down to

[36] Among the investing scenarios investigated—all-investing in Figure 1, all-investing with sustaining capital in Figure 2, and sustainable investing in 4, except the scenario of $\alpha^G = 0.05$, where public capital is rather unproductive, welfare measures are all higher than saving in a SWF.

[37] International Monetary Fund (2012b) calculates that developing countries typically achieve effective tax rates in petroleum are on the order of 65 to 85 percent and in mining are 45 to 65 percent.

[38] For Angola's recent economic conditions and oil production activity, see Chapter III.B of International Monetary Fund (2012d) and Richmond et al. (2012).

maintain a level of investment commensurate with the given investment path. In the case of insufficient buffer, investment spending is cut to maintain a non-negative balance in the fund.[39] Technically, we impose an non-negative constraint on the path of F_t^*.

To demonstrate the advantage of the sustainable investing approach in reducing macroeconomic instability, we compare the standard deviations of key variables under this approach with those under the spend-as-you-go approach. The latter follows the one analyzed in Richmond et al. (2012) and is similar to what Angola has practiced until recently. Standard deviations reported in Table 3 are the average of 100 simulations based on different draws of price shock sequences $\{\varepsilon_t^{po}\}$ from the estimated distribution. We take the projection of the oil production quantity in International Monetary Fund (2012d) as given, and a series of production shocks $\{\varepsilon_t^{yo}\}$ is injected to hit the projected quantity path.[40] For our purpose, the analysis concerns about volatility in resource revenues (not the source of volatility). For simplicity we use the same oil production path across simulations.

The spend-as-you-go approach is similar to the all-investing approach analyzed earlier. Instead of assuming that all resource revenues above the initial level go to investment, it is assumed that 60 percent of additional revenues goes to investment and the rest 40 percent goes to government consumption. With sustainable investing, we specify public investment to gradually increase from 8.7 percent of GDP (the actual level in 2011) to 15 percent in 2022. Given a high government consumption to GDP ratio in 2011 of 19.5 percent, we reduce government consumption and fixed it at 18 percent of GDP throughout the simulation horizon. Both the labor and consumption tax rates are set at their initial steady-state levels, while transfers experience small fluctuations to clear the government budget constraint.

Table 3 compares the average standard deviations of public investment expenditure, private consumption, non-oil GDP, and the real exchange rate from 2011 to 2025 in percent deviations from their trend paths. All four variables exhibit more volatility—about $60 - 70$ percent more—with spend-as-you-go. Despite a rather smooth investment path, public investment under the sustainable investing approach can still experience some fluctuations. When large negative revenue shocks hit, the stabilization fund may not have sufficient balance to support a pre-determined investment level, forcing investment expenditures to dip.

In an economy that is highly resource dependent, the fiscal channel through which resource revenue volatility can affect macroeconomic stability is made explicit here. Although the simulations assume that government purchases in Angola have a high share of traded goods ($\nu_g = 0.2$), the increased government purchases still generate some demand pressure on domestic production, driving up overall income and private consumption and investment. Conversely, when oil revenue declines, a procyclical fiscal policy as captured by

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[39]In practice, government consumption or transfers may also be reduced or tax rates may be raised to maintain an investment path. However, given the implementation difficulty in these other fiscal adjustment options, public investment is most likely to be cut, as observed recently in Angola.

[40]In Angola, aside from fluctuating oil price and quantities, oil revenue volatility is also due to unpredictable transfers of oil revenue from the state oil company to the treasury. See Box 6 in Chapter III.B of International Monetary Fund (2012d) for details.

spend-as-you-go can lead to a collapse of overall demand, generating a boom-bust cycle commonly observed in resource-rich economies.[41] Sustainable investing, on the other hand, de-links periodic government spending from resource revenue flows, and thus shield the domestic economy from the disturbance of volatile resource revenues.

B. Allocation between Investing and External Saving

When following the sustainable investing approach, one question remains to answer: how large should a stabilization fund be in an environment of uncertain future revenue? A more aggressive scaling-up leads to faster build-up of public capital and potentially higher economic growth. As more resource revenue is devoted to investment, less can be saved in a stabilization fund, leaving the economy vulnerable to negative shocks. To address this policy question, we show how stochastic simulations can be used to advise the allocation between investment and saving in a stabilization fund.

Figure 6 plots the one- and two- standard deviation (68 and 95 percent) confidence intervals under two investment paths. The left column—the conservative scaling-up path—assumes that public investment and government consumption follow those assumed earlier (Section A). Relative to the left, the right column implements an aggressive scaling-up path. Public investment quickly rises from 9.2 percent in 2011 to 20 percent in 2016 and stays at this level for the rest of the simulation horizon.

The wide interval for oil prices (from $40 to $180 in 2025) captures the notorious fluctuations of oil price movements. Also, the very different performance of the stabilization fund confirms our conjecture that a more aggressive scaling-up plan leaves the economy with a small to little buffer. By the end of 2025, the stabilization fund is on average only 1.1 percent of GDP under the aggressive path, compared to the 37.1 percent under the conservative path. Since the stabilization fund is insufficient most of the time, the mean scaling-up magnitude from 2016 to 2025 at 15 percent also deviates much from the pre-determined 20 percent. In contrast, the conservative path with a much larger buffer allows the realized investment path following closely with the pre-determined path. Without much disruption in the investment pace, the depreciation rate of public capital is also kept low in most cases. The average depreciation rate of the 95-percent upper bound is 0.08 under the conservative path, compared to 0.10 under the aggressive path.

The aggressive path on average accumulates more public capital (40 percent vs. 31 percent above the path without additional oil revenue at the end of 2025), but it also runs a much higher tail risk of accumulating less public capital. The one (two) standard deviation lower band is 7.3 (-27.0) percent with the aggressive path in 2025 vs. 24.8 (-4.0) percent with the conservative path. When oil revenues are hit by a sequence of large negative oil shocks, the aggressive path, which does not have much buffer, cannot sustain investment even at the level

[41]In addition to the experience of Angola from mid-2000's to 2010, Mongolia is another recent example. It experienced a boom-bust cycle with surges and falls in copper prices between 2006 to 2009, which led to a balance-of-payment crisis and an IMF program to stabilize the economy.

to maintain existing capital, and hence public capital can fall below the initial steady state level. Similar to the outcome with spend-as-you-go, large swings in public investment and hence public capital lead to great instability in the economy. As shown in Figure 6, the confidence intervals are wider for non-oil GDP under the aggressive path. The one-standard deviation interval ranges from 5.0 to 22.0 percent above the path without additional oil revenue in 2025, compared to 7.5 to 15.0 percent with the conservative path. Moreover, despite a more stable economy with the conservative scaling-up path, households on average enjoy similar magnitude of consumption as under the aggressive path.

The endogenous depreciation channel plays an important role in linking revenue shocks to macroeconomic volatility. Bad revenue outcomes imply investment well below replacement rates, which result in an increase in depreciation rates, thus amplifying the effect of the negative shock on the capital stock and hence output. This can be seen in the very high upper band for the depreciation rate in the case of aggressive scaling up in Figure 6, which is one of the reasons for the substantially worse lower band for public capital, GDP, and so on. On the other hand, if the depreciation rate is fixed at the initial 7 percent as shown in Figure 7, the lower bands of public capital are much less negative than those in Figure 6, and hence much improved performance of non-oil GDP and consumption in the lower bands.

The comparison of the two specific investment paths suggests that scaling up too much and too fast (as the aggressive path) could subject the economy to more instability, lowers investment efficiency, and there is no guarantee that its growth impact can outperform a more conservative scaling-up path. Our analysis can be extended to alternative investment paths under different parameter calibrations for a more thorough assessment in the adequacy of a stabilization fund.

VI. Conclusion

Natural resource revenues provide an opportunity to accelerate economic development in capital-scarce economies that face financial and fiscal constraints. However, these revenues also pose significant challenges to policymakers as they can be exhaustible and volatile. Using a DSGE-type small open economy model, we propose a "sustainable investing approach"—combining investment with a resource fund—as a way to grapple with both exhaustibility and volatility. The approach makes possible to achieve development goals by scaling up public investment while maintaining economic stability. To illustrate, we calibrate and apply the model to the CEMAC region and Angola. In the CEMAC, resource production is declining and therefore the revenue horizon is short. The conversion of the windfall into permanently higher incomes is the key policy concern. In Angola, a highly resource-dependent economy with large reserves, managing (price) volatility is a priority.

The sustainable investing approach explicitly accounts for the financing needs involved in operating and preserving capital. The current literature on managing natural resources seems to neglect the fact that even if a government manages to build productive public capital by implementing good projects (implying high efficiency and absorptive capacity), its return will diminish over time unless revenues are available to cover recurrent costs. The failure to preserve public capital and cover recurrent costs has been an important theme in public economics of development at least since Heller (1974) and remains of great practical significance. With limited revenue mobilization, our analysis implies that the size of the scaling-up plan should be jointly considered with an economy's ability to finance future costs to sustain capital and to the distorting effects of fiscal adjustments.

In cases where exhaustion lies beyond the horizon but resource revenue volatility looms large, sustainable investing avoids procyclical fiscal policy and minimizes the disruption in macroeconomic stability. Scaling up public investment too high and too fast, for example following the path of resource revenues themselves—subjects the economy to more instability, lowers investment efficiency, and risks higher depreciation rates. There is no guarantee that growth outcomes will be superior to a more conservative scaling-up path. In addition it makes the economy more prone to boom-bust cycles. Sustainable investing, on the other hand, de-links periodic government spending from resource revenue flows, through a stabilization fund, and thus shields the domestic economy from the disturbance of volatile resource revenues.

A number of extensions could usefully be considered. We focus on public investment in physical capital; the analysis can be extended to other types of investment, such as health and education to build human capital, which also improve the productivity of private inputs in production. We study some simple and implementable government rules; a fuller consideration of rule-based optimal policy, while not trivial in such a complex model, would clearly be useful.[42] In addition, the model could readily be adapted to address short-run policy issues by introducing, for instance, nominal rigidities. Finally, natural resource booms can relax borrowing constraints, which may induce debt stability problems.[43] As developing economies become more able to tap international bond markets, a detailed study of the interaction of natural resource revenues with fiscal rules that allow for accumulation of commercial debt is in order.

[42]An intermediate step might be to rework the "sustainable investing" fiscal rule for short-revenue horizon scenarios in (27) to imply a time-varying savings rate ϕ with a view to smoothing government (or total) consumption. A rule somewhat along these lines is used in the application of this framework to Angola (see Richmond et al. (2012).

[43]Manzano and Rigobon (2007), for instance, argue that during the 1970s, when commodities' prices were high, natural resource abundant countries used them as collateral for debt. As the 1980's witnessed an important fall in the prices, these countries faced debt crises. In this regard, the previously mentioned natural resource curse might be related to a debt overhang.

Table 1. **Baseline Parameter Calibration**

parameters	CEMAC	Angola	notes
σ	2	2	inverse of intertemporal elasticity of substitution for consumption
ψ	10	10	inverse of Frisch elasticity of labor supply
φ	0.5	0.4	degree of home bias in private consumption
χ	0.44	0.44	elasticity of substitution between traded and non-traded sectors
δ	0.45	0.56	share of labor supplied to non-traded sector
ρ	1	1	elasticity of substitution between the two types of labor
β	0.91	0.91	the discount factor
α^N	0.45	0.45	labor income share in non-traded sector
α^T	0.65	0.65	labor income share in traded sector
α^G	0.10	0.20	output elasticity of public capital
d, ρ_{ZT}	0.1	0.1	learning-by-doing externalities
ι	0.18	0.20	firms' production distortion parameter (model implied)
κ^N, κ^T	25	25	investment adjustment cost
δ^N, δ^T	0.1	0.1	depreciation rate for K^N, K^T
δ^G	0.08	0.07	depreciation rate for public capital
ϵ	0.5	0.5	public investment efficiency
$\frac{Y^O}{GDP}$	0.09	0.475	oil GDP/GDP
ν	0.6	0.4	home bias of government purchases
ν_g	0.5	0.2	home bias of government purchases above the level in initial state
τ^l	0.08	0.1	effective labor tax rates
τ^c	0.18	0.1	effective consumption tax rates
s^B	0.116	0.347	debt-to-GDP ratio in initial state
$\frac{Z}{GDP}$	0.025	0.028	transfers/GDP in initial state
$\frac{G^C}{GDP}$	0.133	0.195	GC/GDP in initial state
$\frac{G^I}{GDP}$	0.068	0.087	GI/GDP in initial state
$\frac{F^*}{GDP}$	0.01	0.02	stabilization fund/GDP in initial state
r^*	0.027	0.027	annual real return to a resource fund
ρ_{yo}	0.9	0.9	AR(1) coefficient in oil production quantity
σ_{po}	–	0.1	standard deviation of oil price shock

Table 2. **Welfare Comparison with All-Investing.** See footnote 28 for the definition of welfare measure

scenarios	baseline $\alpha^G = 0.1$	scenario 2 $\alpha^G = 0.1, \epsilon = 0.5 \forall t$	scenario 3 $\alpha^G = 0.05$	scenario 4 $\alpha^G = 0.2$
(1) not sustaining K^G	3.36	6.42	2.28	5.59
(2) sustaining K^G, transfer adj	4.50	6.13	2.18	6.06
(3) sustaining K^G, τ^c adj	4.49	6.06	2.16	6.07
(4) not sustaining K^G, constant δ^G	4.70	6.80	2.43	6.15

Table 3. **Stabilization Effects of the Sustainable Investing Approach.** Average standard deviation in percent from a de-trended path based on 100 simulations.

Variables	Spend-as-You-Go	Sustainable Investing
public investment	16.2	7.4
non-resource GDP	1.2	0.7
private consumption	1.0	0.6
real exchange rate	2.2	1.4

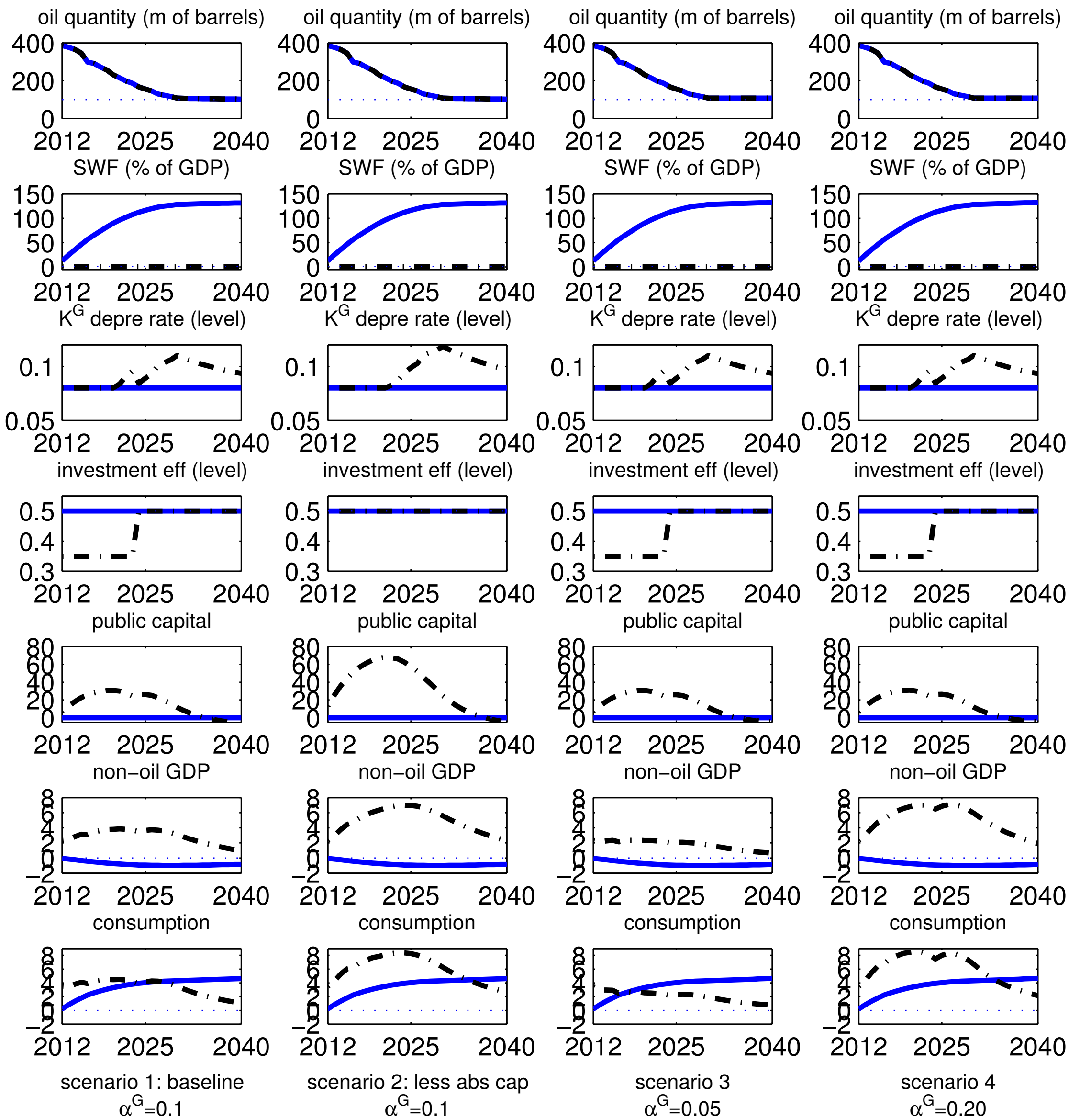

Figure 1. **CEMAC application: saving in a SWF (solid lines) vs. all-investing (dotted-dashed lines).** Y-axis is in percent deviation from the path without a windfall unless stated otherwise.

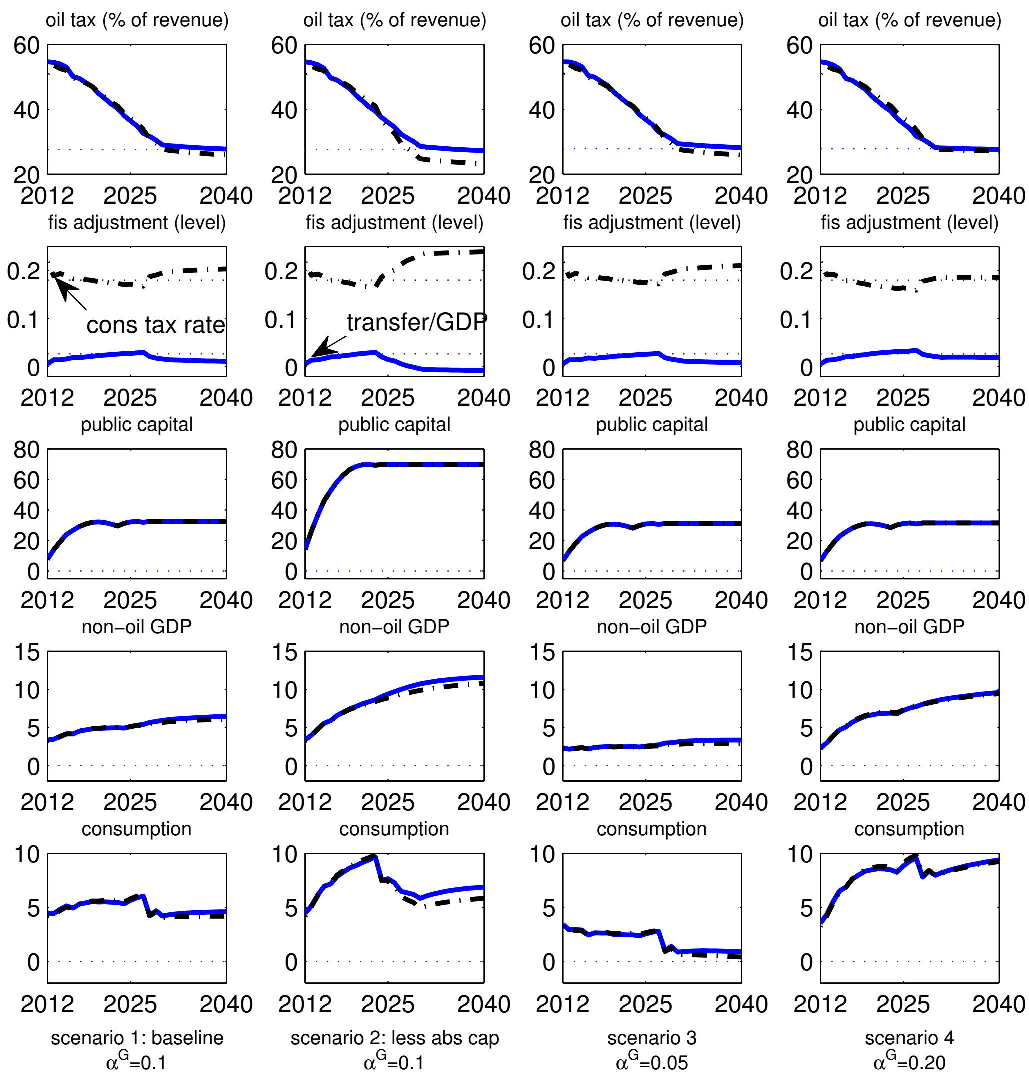

Figure 2. **CEMAC application: all-investing and sustaining public capital by fiscal adjustments through consumption taxes or transfers.** Y-axis is in percent deviation from the path without a windfall unless stated otherwise.

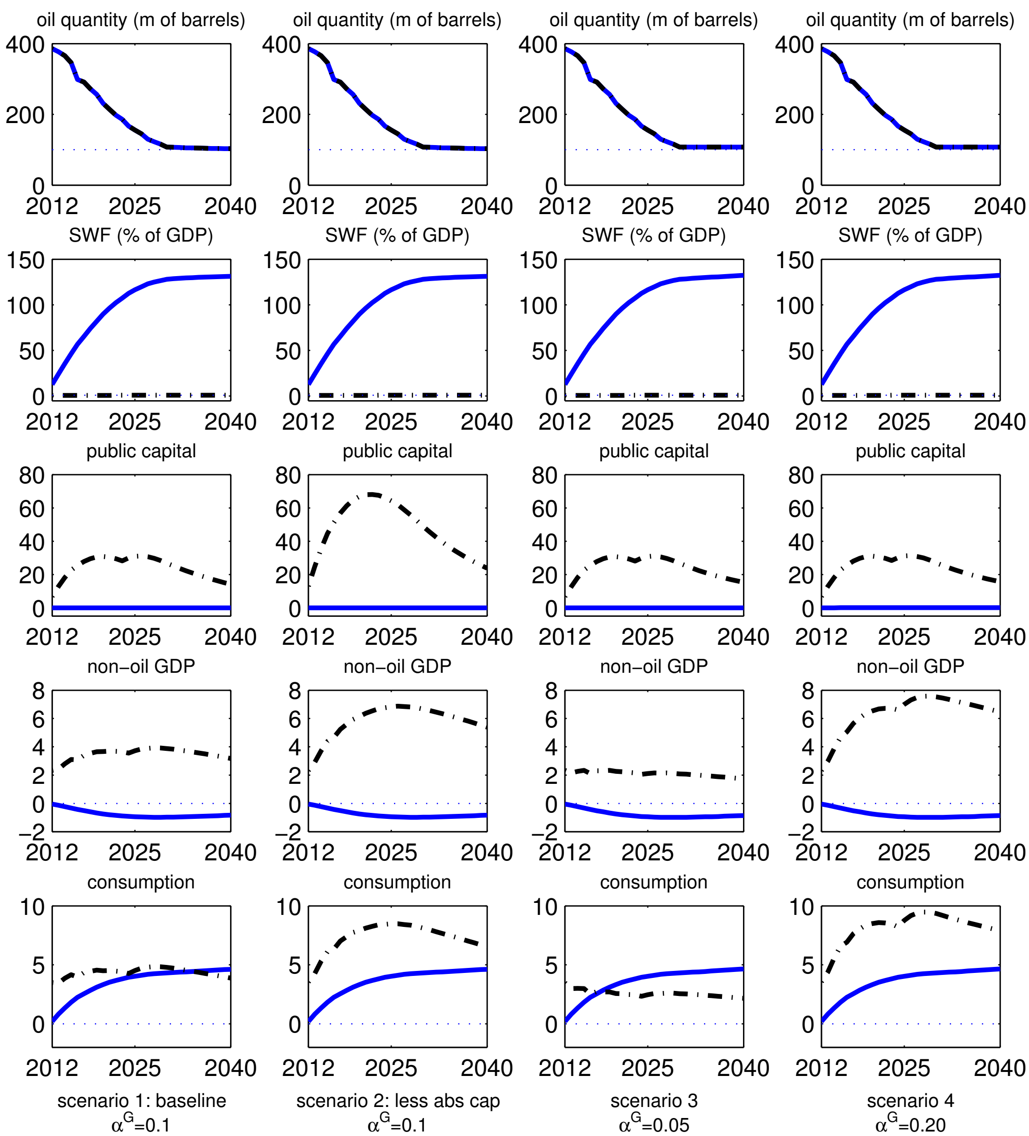

Figure 3. **CEMAC application with constant depreciation rate of public capital: saving in a SWF (solid lines) vs. all-investing (dotted-dashed lines).** Y-axis is in percent deviation from the path without a windfall unless stated otherwise.

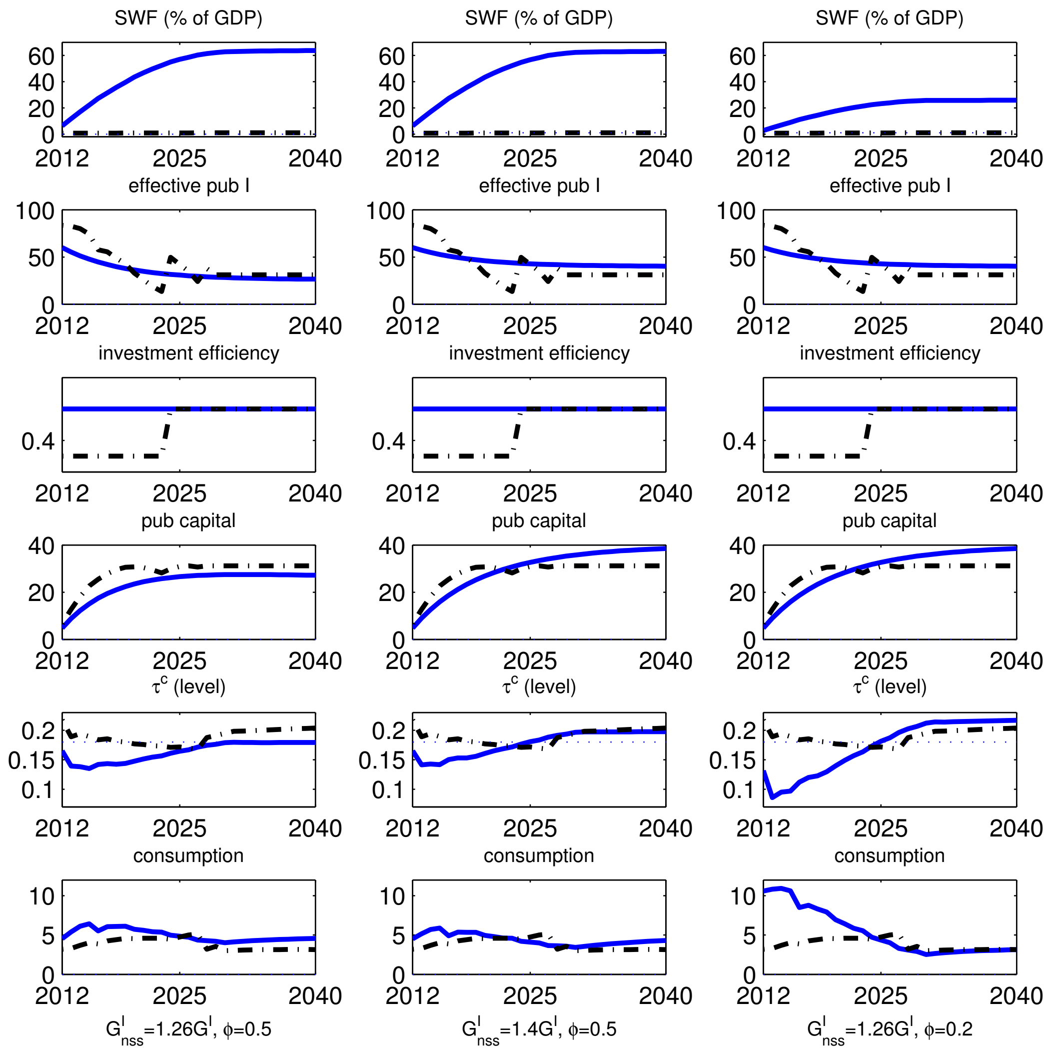

Figure 4. **CEMAC application: sustainable investing approach.** Y-axis is in percent deviation from the path without a windfall unless stated otherwise.

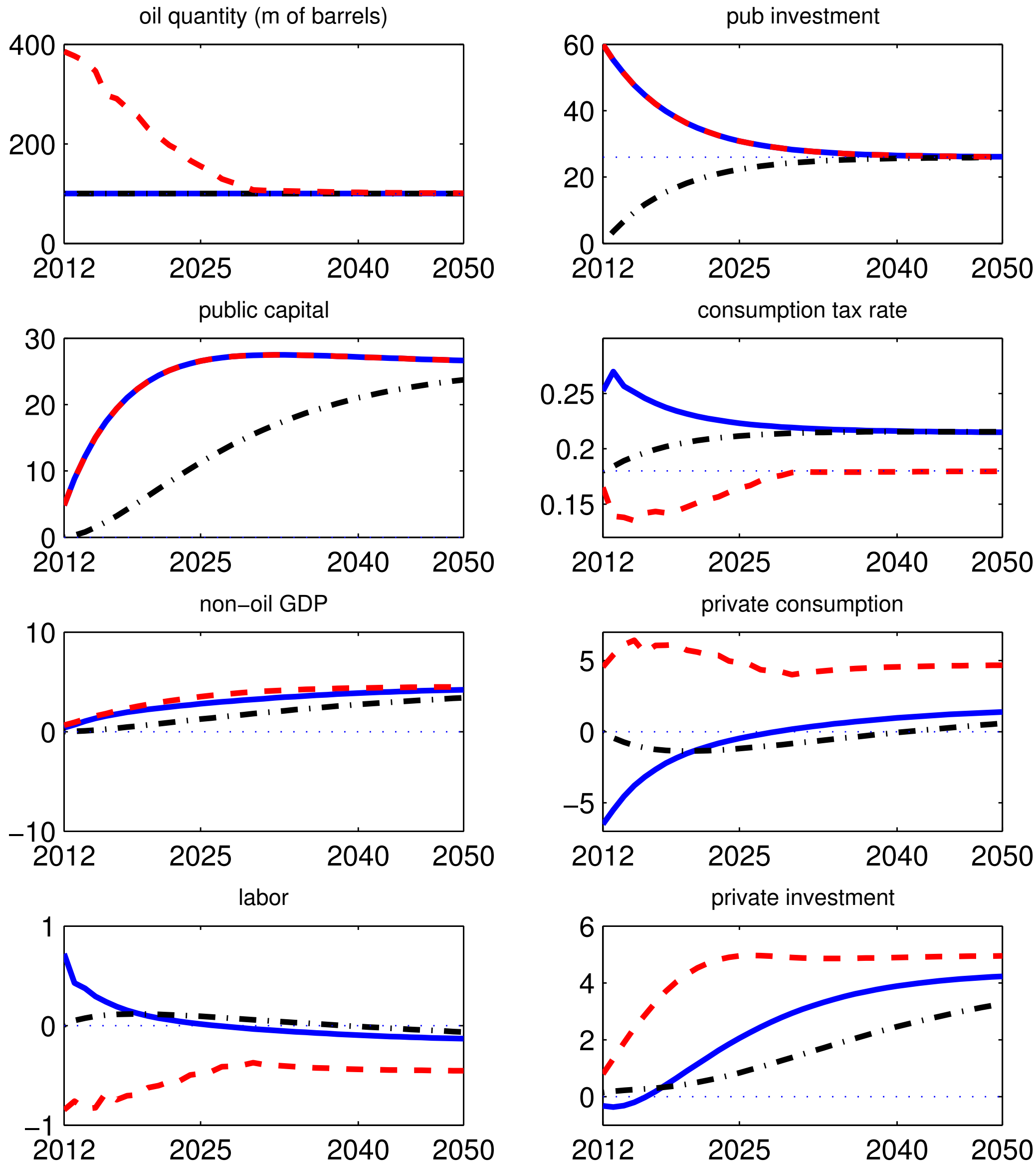

Figure 5. **CEMAC application: investing without a Resource Windfall.** Solid and dotted-dashed lines assume a front-loaded and a gradual scaling-up path without a windfall, respective; dashed lines assume a front-loaded scaling-up with a windfall. Y-axis is in percent deviation from the path without a windfall unless stated otherwise.

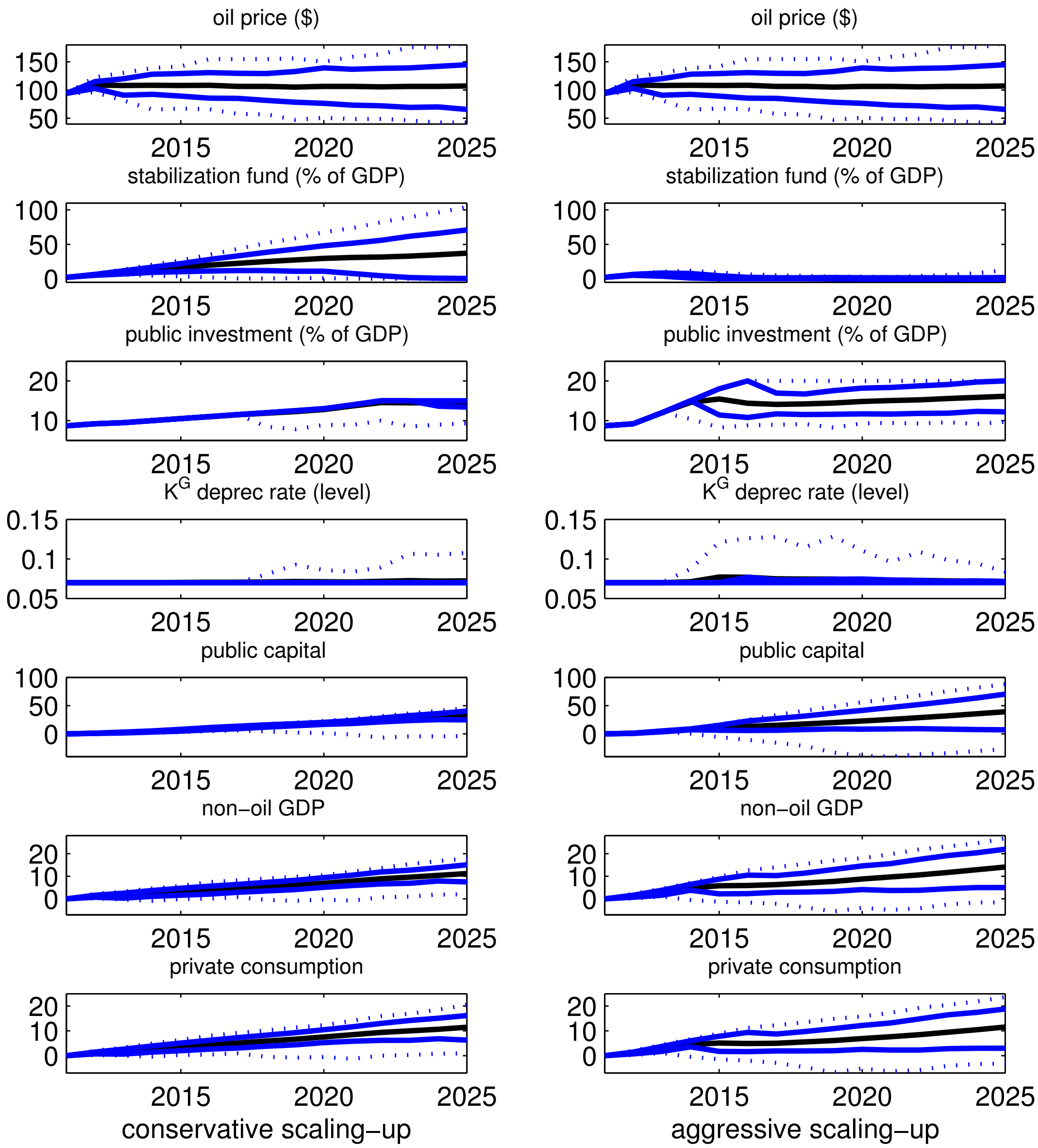

Figure 6. **Angola application: conservative vs. aggressive scaling-up under sustainable investing.** Y-axis is in percent deviation from the path without a windfall unless stated otherwise. The middle solid lines are mean responses based on 100 simulations. The bands in solid lines are one-standard-deviation intervals, and the bands in dotted lines are two-standard-deviation intervals.

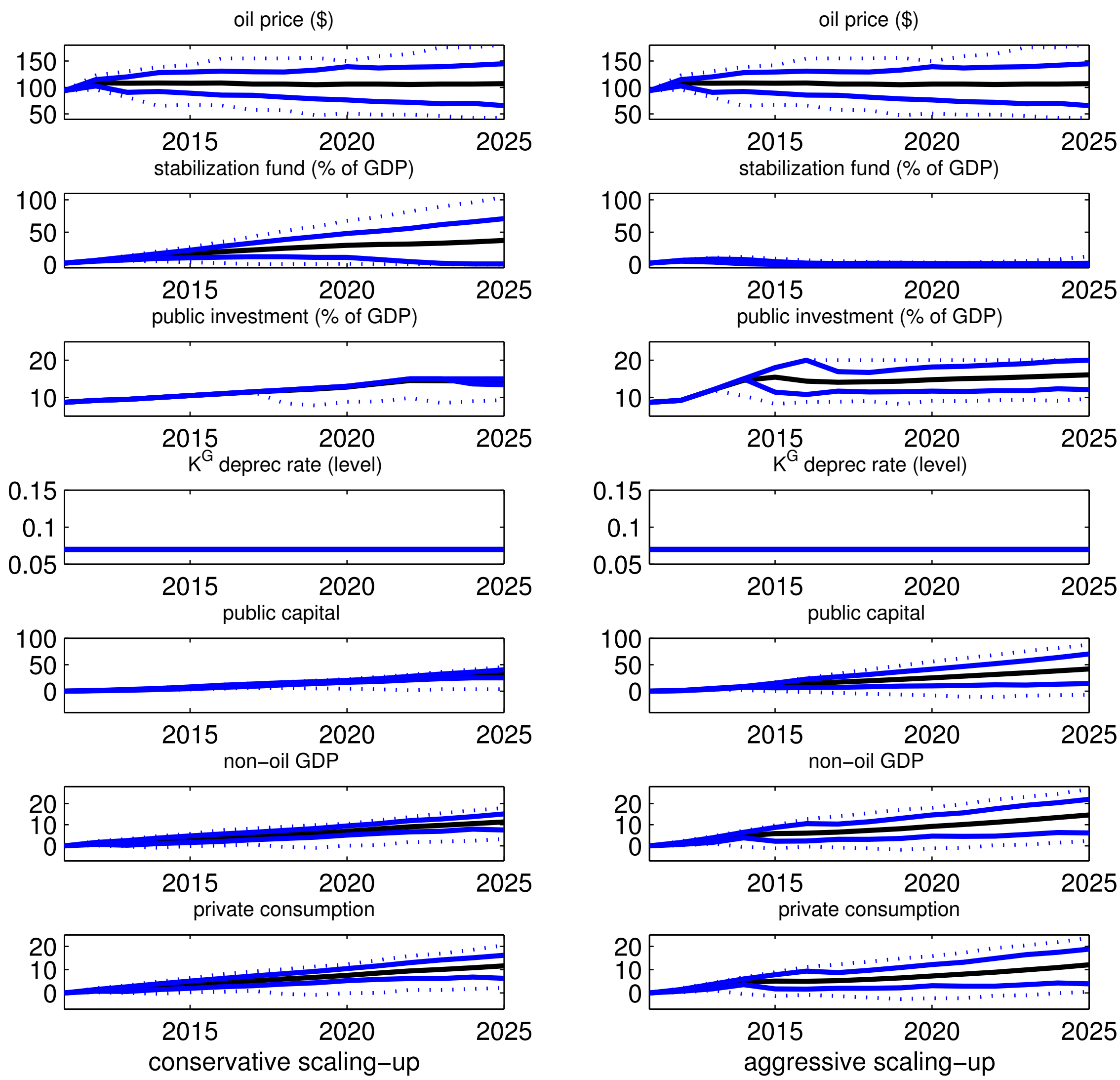

Figure 7. **Angola application: conservative vs. aggressive scaling-up with constant depreciation rate (δ^G).** Y-axis is in percent deviation from the path without a windfall unless stated otherwise. The middle solid lines are mean responses based on 100 simulations. The bands in solid lines are one-standard-deviation intervals, and the bands in dotted lines are two-standard-deviation intervals.

Appendix I. Equilibrium and Optimality Conditions

The unique competitive equilibrium consists of the households' decision $\{c_t, l_t, b_t\}_{t=0}^{\infty}$, the firms' decisions $\left\{i_t^N, i_t^T, k_t^N, k_t^T, l_t^N, l_t^T\right\}_{t=0}^{\infty}$, prices $\left\{R_t, w_t^N, w_t^T, p_t^N, s_t, p_t^g\right\}_{t=0}^{\infty}$, and the state of the economy, including predetermined capital, bond, and a resource fund, the realization of shocks at t, and agents' expectations of future variables, such that (i) the optimality conditions (described below) hold, (ii)the transversality conditions for debt and capital hold, (iii) the goods, capital, labor, and bond markets clear, and (iv) the government budget constraint (18) is cleared each period.

Let λ_t, λ_t^N, and λ_t^T be the Lagrangian multipliers for the maximization problems of households, non-traded firms, and traded firms. Define the Tobin's q as $q_t^N = \frac{\lambda_t^N}{\lambda_t}$ and $q_t^T = \frac{\lambda_t^T}{\lambda_t}$. The first order conditions of all the optimization problems in the model are listed next.

$$\lambda_t(1+\tau_t^c) = (c_t)^{-\sigma} \tag{I.1}$$

$$\lambda_t = \beta E_t\left(\lambda_{t+1} R_t\right) \tag{I.2}$$

$$\kappa\left(l_t\right)^{\psi} = \lambda_t\left(1-\tau_t^l\right) w_t \tag{I.3}$$

$$\lambda_t^N = \beta E_t\left\{\frac{\lambda_{t+1}}{\lambda_t}\left[\left(1-\delta^N\right)\lambda_{t+1}^N + \left(1-\alpha^N\right)(1-\iota)\, p_{t+1}^N \frac{y_{t+1}^N}{k_t^N}\right]\right\} \tag{I.4}$$

$$l_t^N = \delta\left(\frac{w_t^N}{w_t}\right)^{\rho} l_t; \quad l_t^T = \delta\left(\frac{w_t^T}{w_t}\right)^{\rho} l_t \tag{I.5}$$

$$\frac{1}{q_t^N} = 1 - \frac{\kappa^N}{2}\left(\frac{i_t^N}{i_{t-1}^N}-1\right)^2 - \kappa^N\left(\frac{i_t^N}{i_{t-1}^N}-1\right)\frac{i_t^N}{i_{t-1}^N} + \beta\kappa_N E_t\left\{\frac{q_{t+1}^N\lambda_{t+1}}{q_t^N\lambda_t}\left(\frac{i_{t+1}^N}{i_t^N}-1\right)\left(\frac{i_{t+1}^N}{i_t^N}\right)^2\right\} \tag{I.6}$$

$$l_t^N = \left[\frac{\alpha^N(1-\iota)\, p_t^N z^N \left(k_{t-1}^N\right)^{1-\alpha^N}\left(K_{t-1}^G\right)^{\alpha^G}}{w_t^T}\right]^{\frac{1}{1-\alpha^N}} \tag{I.7}$$

$$\lambda_t^T = \beta E_t\left\{\frac{\lambda_{t+1}}{\lambda_t}\left[\left(1-\delta^T\right)\lambda_{t+1}^T + \left(1-\alpha^T\right)(1-\iota)\, s_{t+1}\frac{y_{t+1}^T}{k_t^T}\right]\right\} \tag{I.8}$$

$$l_t^T = \left[\frac{\alpha^T (1-\iota) s_t z_t^T \left(k_{t-1}^T\right)^{\alpha^T} \left(K_{t-1}^G\right)^{\alpha^G}}{w_t^T} \right]^{\frac{1}{1-\alpha^T}} \tag{I.9}$$

$$\frac{1}{q_t^T} = 1 - \frac{\kappa^T}{2} \left(\frac{i_t^T}{i_{t-1}^T} - 1 \right)^2 - \kappa^T \left(\frac{i_t^T}{i_{t-1}^T} - 1 \right) \frac{i_t^T}{i_{t-1}^T} + \beta \kappa_T E_t \left\{ \frac{q_{t+1}^T \lambda_{t+1}}{q_t^T \lambda_t} \left(\frac{i_{t+1}^T}{i_t^T} - 1 \right) \left(\frac{i_{t+1}^T}{i_t^T} \right)^2 \right\} \tag{I.10}$$

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