PUBLIC INVESTMENT IN RESOURCE ABUNDANT LOW-INCOME COUNTRIES

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Abstract. *Natural resource revenues provide a valuable source to finance public investment in low-income countries. Conventional wisdom, however, advises to save most windfalls abroad to preserve wealth. We develop a dynamic stochastic general equilibrium model to study the tradeoffs between saving resource revenues abroad in a sovereign wealth fund and investing them domestically in public capital. Public investment may be highly desirable in capital-scarce countries, but several concerns are present, including Dutch disease, growth sustainability, absorptive capacity constraints, and risks to macroeconomic stability. By scaling up investment gradually and securing funding for recurrent capital costs, we show that this investing approach can address those concerns, preserve resource wealth and contribute to economic development.*

Keywords: natural resource; public investment; public infrastructure; low-income countries

JEL Codes: Q32; E22; F43; O41

1. Introduction

Natural resource revenues have been an important source of fiscal revenues and foreign exchange in many low-income countries. The International Monetary Fund (IMF) identifies 19 low-income countries as hydrocarbon and mineral rich, most of them located in Sub-Saharan Africa (International Monetary Fund (2010)). As

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more discoveries in Africa are likely in the future, managing resource revenues will become increasingly important in many low-income countries.[1]

Managing revenue windfalls from non-renewable resources poses challenges for policymakers. Conventional wisdom based on the permanent income hypothesis (PIH) prescribes that off-the-ground resource wealth should be mostly saved in a sovereign wealth fund (SWF), consisting of international financial assets (e.g., Davis et al. (2001), Barnett and Ossowski (2003), and Bems and de Carvalho Filho (2011)). While this principle minimizes the instability associated with a volatile income stream and preserves resource wealth for future generations, it overlooks the investment needs in capital-scarce, credit-constrained countries. This paper studies the macroeconomic effects of different approaches in managing resource revenues in low-income countries. In particular, it focuses on a comparison of two options: placement abroad in a SWF and public investment spending at home.

Low-income countries are often credit-constrained, facing difficulties in financing public investment essential for economic development. Capital scarcity in these countries suggests that the rate of return to capital is possibly high. When the resource revenue horizon is short, a windfall presents a window of opportunity to translate resource wealth into developmental gains. As productive public capital builds up, productivity in the private sector would increase, raising income, reducing poverty, and even enlarging the non-resource tax base. Since mid-2000s, these potential benefits have called for reconsideration of the policy advice on managing resource revenues in low-income countries (UNCTAD Secretariat (2006), Sachs

[1] Africa is often perceived to be resource abundant, but the average value of known reserves in African landmass is only one fifth of that in the OECD landmass, suggesting the potential of much more future findings (The World Bank (2006) and Collier and Venables (2008)).

(2007), Collier et al. (2010), and the Natural Resource Charter (2010)). While consumption smoothing along the PIH principle may still be desirable, the prospect of using resource wealth to build much needed public infrastructure is worth studying in more detail.

To see whether developing countries should deviate from saving a resource windfall in a SWF, several studies have used models that feature capital scarcity and high borrowing costs as in low-income countries. When government spending can enhance private productivity, Takizawa et al. (2004) show that an economy with a below steady-state capital stock can benefit from running a higher non-resource primary deficit than what is implied by the PIH. Venables (2010) shows that if resource wealth improves credit worthiness and lowers borrowing costs, capital-scarce countries should boost public investment spending following a resource windfall. van der Ploeg and Venables (2011) demonstrate additional benefits from front-loading resource-financed investment, to reduce distortions caused by higher tax rates, which are otherwise required in the absence of resource wealth.

Despite the theoretical appeal of the idea, history does not generally suggest that investing resource windfalls would promote sustained economic growth in developing countries. Natural resource abundant countries tend to grow more slowly than others—the so-called natural resource curse.[2] Sachs and Warner (1999) identify four Latin American countries (Bolivia, Ecuador, Mexico, and Venezuela) that experienced a significant natural resource boom over 1970 to the mid-1980s. Only Ecuador had a higher real GDP level after the boom ended but the after-boom

[2]The natural resource curse has been widely studied in the literature (e.g., Gelb (1988), Sachs and Warner (2001), and Stevens (2003)). As surveyed by van der Ploeg (2011b), while an average negative correlation exists between growth and the export share of natural resource, many countries have escaped the curse, such as Botswana and Chile.

growth rate was not higher. Among the six oil-exporting developing countries (Algeria, Ecuador, Indonesia, Nigeria, Trinidad and Tobago, and Venezuela), despite sizeable investment undertaken between 1975 and 1978, the overall growth rate of non-oil output was higher after 1974 but quickly slowed after 1978 (Gelb (1988)). On average, public investment in these countries grew more than twice as fast as non-oil output during 1974-1978, yet no obvious supply-side effects of growth lasted after the windfall period.[3] Spending resource revenues domestically also generates volatile government expenditure paths, jeopardizing macroeconomic stability. Comparing the effects of oil price shocks in Mexico and Norway from mid-1980s to 2006, Pieschacon (2009) finds that the spending approach adopted by the former generated much more volatile macro dynamics than the SWF adopted by the latter.

This paper adds to the literature on managing natural resource revenues in developing or low-income countries. In light of history, it suggests that other factors—aside from high returns to capital and reduced distortion in financing public investment—can matter for the outcome of investing a resource windfall. The analysis begins by comparing two stylized approaches—the conventional "saving in a SWF" and the more recent recommendation of "investing in public capital"—to highlight the key differences between the two. Under the stylized saving approach the macroeconomic dynamics are minimal, avoiding instability, because most resource revenues do not flow into the domestic economy. Also, the annuity income from a SWF supports higher consumption indefinitely, in line with the PIH.

[3] Venezuela conducted the largest investment program in its history between 1974 to 1977, but its economy was one-third smaller relative to the size it would have been had it continued to grow at the pre-1973 rate (Gelb (1988)).

The stylized investing approach, on the other hand, spends the windfall on public investment as it accrues. Our simulation shows that during the windfall period, the economy experiences fast growth but traded-good production also shrinks for a prolonged period due to a real exchange rate appreciation, with some negative effects on productivity in that sector (Dutch disease). The effectiveness of public investment, as summarized by non-resource output multipliers, also tend to be low, because of rising costs due to absorptive capacity constraints. Moreover, when public investment scales up quickly and no additional non-resource revenues are available to cover capital recurrent costs, public capital eventually returns to the pre-windfall level. This implies that the growth benefits derived from investing a resource windfall do not last, at least under the stylized approach considered here. Given the volatile nature of resource prices, it also implies a volatile spending path that can disrupt stability.

To address all these concerns, we propose an alternative, "sustainable investing approach." By slowing down the scaling-up speed and securing financing to cover recurrent costs of public capital, we show that the approach minimizes instability and reduces the costs of absorptive capacity constraints. In addition, Dutch disease effects can be mitigated through a less appreciated real exchange rate. The sustainable investing approach is broadly consistent with the PIH principle in the sense that consumption is permanently higher. Instead of solely increasing its holding of foreign financial assets, the economy adopting this approach preserves exhaustible natural resource wealth in the form of a permanently higher stock of public capital.

An interesting feature of the “sustainable investment approach” is that it combines elements of both domestic investment and external savings. Under this approach, the increase in investment is gradual relative to the resource windfall. The non-invested revenue plus any increase in non-resource tax revenues is accumulated in an external “investment fund,” which is then drawn on once the resource revenue dries up. In addition, provided the sustained (or long-term) increase in public capital is not too large relative to the windfall, the investment fund is never depleted. Instead, the interest revenue derived from the fund finances the recurrent costs of maintaining the higher capital stock. This helps avoid having to raise taxes in the long run, an important issue given the difficulties low-income countries often face in mobilizing additional domestic revenue (International Monetary Fund (2011)).

Our analysis complements several recent papers that search for optimal policy to invest a resource windfall (van der Ploeg (2011a), Cherif and Hasanov (2012), and Araujo et al. (2012)), but also differs in two distinctive aspects. First, instead of pursuing optimal policy exercises, our analysis is based on simple policy rules in a fully-specified DSGE model, which may have a practical appeal for policy implementation. Analytical frameworks for conducting optimal policy analysis typically have to be simple to make a central planner’s problem tractable. These frameworks, for instance, abstract from endogenous labor supply, have exogenous private investment decisions, or have very simplified fiscal specifications. Despite their simplicity, the policy implications from this line of work—to gradually ramp up public investment as in van der Ploeg (2011a) and Araujo et al. (2012), or to build a sizable holdings of safe, liquid assets as in Cherif and Hasanov (2012)—are consistent with our formulation of the sustainable investing approach.

Second, our analysis stresses the policy design required to sustain public capital created from a windfall. Although both financial assets and physical capital can preserve a country's wealth, they differ in some fundamental ways. Through proper portfolio management, the return uncertainty of financial assets can be minimized, and an infinite stream of annuity income can be derived. Physical capital, on the other hand, depreciates intrinsically. Unless revenues are made available to cover recurrent costs for operation and maintenance, investment projects cannot continue to be fully productive (Heller (1974)), and their returns will diminish over time or even vanish. When deciding to invest a resource windfall, our framework can inform whether the magnitude of a scaling-up can be supported for a given windfall size and the structure of government revenue. Moreover, if the scaling up of public investment is too large relative to the windfall, the model's relatively detailed fiscal specification allows to gauge the macroeconomic feedback associated with the fiscal adjustment required to sustain capital. In our simulation of such a scenario, fiscal adjustments are implemented by raising the consumption tax rate, and the bulk of the feedback effects fall on private consumption.

The model used here has a similar structure to Berg et al. (2010). To reflect the mismanagement problems that can be pervasive in the public sectors of low-income countries, it builds in lower public investment efficiency than what is normally assumed for developed countries (Pritchett (2000)). It also features learning-by-doing externalities in the traded-good sector to capture potential Dutch disease (van Wijnbergen (1984)). Finally, the absorptive capacity constraints are modeled by rising costs of public investment during an investment scaling-up. The higher costs reflect supply bottlenecks or waste resulted from inexperienced or unskilled administrators and workers. They aggravate the already low investment efficiency in low-income countries, resulting in even less effective public investment produced for a given expenditure amount.

2. Model Setup

The model is a small-open, real economy that has a closed private capital account. The government cannot borrow but can hold international financial assets. These extreme capital account assumptions are meant to capture financing difficulties faced by low-income countries. They also reflect our interest in studying a resource-windfall-financed (not debt-financed) scaling-up of public investment.

2.1. **Households.**

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

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

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

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

σ and ψ are the inverses of the elasticity of intertemporal substitution for consumption and labor supply. 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 real exchange rate, the price of the foreign consumption basket relative to the domestic basket. Ω_t^T and Ω_t^N are profits from the traded and non-traded good sectors, respectively. The household holds inflation-indexed domestic government bonds b_t, which pay $R_t b_t$ units of composite consumption at $t+1$. R_t is the domestic gross real interest rate. Throughout the analysis, we assume that government does not issue additional debt to finance public investment spending ($b_t = b \; \forall \; t$).[4]

The composite consumption c_t consists of non-traded goods (c_t^N) and traded goods (c_t^T), combined in a CES basket

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

where χ denotes the intratemporal elasticity of substitution, and φ indicates the degree of consumption home bias. Let composite consumption be the numeraire of the economy, and assume the law of one price hold 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.

Total labor effort is

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

where (l_t^T, l_t^N) denotes labor supplied to the traded and non–traded sector, δ is the steady-state share of labor in the non-traded sector and $\rho > 0$ is the elasticity of substitution—a higher ρ implies more sectoral labor mobility. The real wage index

[4]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 (with only forward-looking households).

is

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

where w_t^N and w_t^T are the real wage rates in each sector. Note that as resource extraction is very capital intensive, we assume it does not employ any labor.

2.2. **Firms.** The economy consists of three sectors: a non-traded sector (denoted by a superscript N), a (non-resource) traded sector (by T), and a natural resource sector (by O for oil). As the vast majority of resource production in low-income countries is exported, we assume that resource output is solely for exports.

2.2.1. *Non-traded Good Sector.* The non-traded sector is perfectly competitive. A representative non-traded firm produces by the technology

$$y_t^N = z^N\left(k_{t-1}^N\right)^{1-\alpha^N}\left(l_t^N\right)^{\alpha^N}\left(K_{t-1}^G\right)^{\alpha^G}, \tag{7}$$

where K_t^G is public capital, and α^G is the output elasticity with respect to public capital. Following the modeling convention of public capital in the neoclassical literature (e.g., Baxter and King (1993) and Kamps (2004)), we assume constant returns to scale with respect to private production inputs and an increasing return to scale with respect to public capital.

Private capital evolves by the law of motion

$$k_t^N = \left(1-\delta^N\right)k_{t-1}^N + \left[1 - \frac{\kappa^N}{2}\left(\frac{i_t^N}{i_{t-1}^N} - 1\right)^2\right]i_t^N, \tag{8}$$

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),

$$E_t \sum_{t=0}^{\infty} \beta^t \lambda_t \underbrace{\left[(1-\iota) \left(p_t^N y_t^N \right) - w_t^N l_t^N - i_t^N + \iota p_t^N Y_t^N \right]}_{\equiv \Omega_t^N \texttt{, profit of the non-traded good sector}}, \tag{9}$$

where ι captures distortions in low-income countries that discourage firms from investing and hiring further. Implicitly, ι acts like a distorting tax on firms but for simplicity the revenues collected are rebated back to the firms in lump-sum fashion. Y_t^N denotes the aggregate output of non-traded goods.

2.2.2. *Traded Good Sector.* The traded good sector is also perfectly competitive and produces by the technology

$$y_t^T = z_t^T \left(k_{t-1}^T \right)^{1-\alpha^T} \left(l_t^T \right)^{\alpha^T} \left(K_{t-1}^G \right)^{\alpha_G}. \tag{10}$$

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

$$\ln z_t^T = \rho_{zT} \ln z_{t-1}^T + d \ln y_{t-1}^T. \tag{11}$$

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

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

and each firm maximizes its weighted preset-value profits,

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

2.2.3. *Natural Resource Sector.* We assume that the country's natural resource output is relatively small in the world market, and that the international commodity price—relative to the foreign consumption basket (p_t^{O*})—is exogenous. p_t^{O*} follows the process

$$\frac{p_t^{O*}}{p^{O*}} = \left(\frac{p_{t-1}^{O*}}{p^{O*}}\right)^{\rho_{po}} e^{\varepsilon_t^{po}}, \tag{14}$$

where $\varepsilon_t^{po} \sim i.i.d.N(0, \sigma_{po}^2)$ is the resource price shock.

We abstract from modeling investment decisions in resource production. Recent increases in resource extraction in many African countries has been mainly driven by foreign direct investment (FDI) in response to demand in other countries such as China. For this reason, the FDI in the resource sector is also assumed exogenous, following the process

$$\frac{FDI_t^*}{FDI^*} = \left(\frac{FDI_{t-1}^*}{FDI^*}\right)^{\rho_{FDI}} e^{\varepsilon_t^{FDI}}, \tag{15}$$

where $\varepsilon_t^{FDI} \sim i.i.d.N(0, \sigma_{FDI}^2)$ is the FDI shock.

The capital in the resource sector evolves according to the law of motion,

$$K_t^O = \left(1 - \delta^O\right) K_{t-1}^O + FDI_t^*. \tag{16}$$

Resource output is produced with the technology

$$Y_t^O = z^O \left(K_{t-1}^O\right)^{\alpha^O}, \tag{17}$$

where z^O is the total factor productivity for the resource sector.

The government has three sources of resource revenues: royalties, dividends, and the interest income from a SWF (F_t^*). Royalties are levied based on production quantity at a rate τ^o. Since intermediate inputs and other costs in resource production are omitted here, the resource sector's net profit is

$$\Omega_t^{O*} = (1 - \tau^o)\, p_t^{O*} y_t^O. \tag{18}$$

Let ι^{div} be the dividend share that the government receives. The total resource revenues collected each period is

$$T_t^O = s_t \left[\tau^o p_t^{O*} y_t^O + \iota^{div} \Omega_t^{O*} + (i^* - 1) \rho_F F_{t-1}^* \right], \tag{19}$$

where $\rho_F < 1$ capture the loss of the real value of the principle F_{t-1}^* due to inflation from $t-1$ to t. $(i^* - 1) \rho_F$ can be seen as the net foreign real interest rate, assumed to be constant.[5]

2.3. **The Public Sector.** The government's flow budget constraint is

$$T_t + B_t + s_t A^* + s_t \rho_F F_{t-1}^* = p_t^G G_t + Z_t + R_{t-1} B_{t-1} + s_t F_t^*, \tag{20}$$

where B_t is total government debt outstanding, A^* is foreign aid, G_t is government purchases, and Z_t is aggregate transfers to households. Since additional borrowing is not allowed, B_t is set to their steady-state level every period. Total government receipts T_t include labor income taxes, consumption taxes, and resource revenues:

$$T_t = \tau_t^c C_t + \tau_t^l w_t L_t + T_t^O. \tag{21}$$

Government purchases consist of expenditures on government consumption (G_t^C) and public investment (G_t^I), which includes absorptive capacity constraints costs. For a given expenditure, the *effective* public investment produced is $\tilde{G}_t^I$. Specifically,

$$\tilde{G}_t^I = \left[1 - b \left(\frac{G_t^I}{G^I} - 1 \right)^2 \right] G_t^I, \quad b \geq 0, \tag{22}$$

where G^I is the public investment expenditure in the pre-windfall steady state. b governs the severity of absorptive capacity constraints. When $\frac{G_t^I}{G^I} > 1$, $b > 0$,

[5]The model does not have the nominal side. $\rho_F < 1$ is a short cut to capture the characteristic that the real value per capita of a financial principle falls over time due to inflation and population growth. The model does not have population growth. Hence, ρ_F is only calibrated to the inverse of inflation.

and when $\frac{G_t^I}{G^I} \leq 1$, $b = 0$. Also, let ϵ be the historical (or steady-state) public investment efficiency. The law of motion of public capital K_t^G is

$$K_t^G = (1-\delta^G)K_{t-1}^G + \epsilon \tilde{G}_t^I, \quad 0 < \epsilon \leq 1, \tag{23}$$

where δ^G is the depreciation rate of public capital.[6]

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

$$G_t = \left[\nu^{\frac{1}{\chi}} \left(G_t^N\right)^{\frac{\chi-1}{\chi}} + (1-\nu)^{\frac{1}{\chi}} \left(G_t^T\right)^{\frac{\chi-1}{\chi}}\right]^{\frac{\chi}{\chi-1}}, \tag{24}$$

where ν denotes the degree of home bias in government purchases. The relative price of government purchase to composite consumption is

$$p_t^G = \left[\nu \left(p_t^N\right)^{(1-\chi)} + (1-\nu)\left(s_t\right)^{1-\chi}\right]^{\frac{1}{1-\chi}}. \tag{25}$$

2.3.1. *Fiscal Policy.* We assume that the government follows simple rules in terms of constant shares to allocate a windfall. Resource windfalls are defined as the incremental resource revenue received above the pre-windfall level T^O. For a given saving share ϕ, the SWF in units of foreign goods evolves according to

$$F_t^* - F^* = \rho_F \left(F_{t-1}^* - F^*\right) + \left[\phi \underbrace{\left(\frac{T_t^O}{s_t} - \frac{T^O}{s}\right)}_{\texttt{resource windfall}}\right].^7 \tag{26}$$

[6]Several other approaches exist to model absorptive capacity constraints. Buffie et al. (2011) 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)). This implies a time-varying PIMI, which falls when investment ramps up. Our approach captures that less effective public investment can be delivered for a given inflow of resource revenues. The concept of PIMI—related to governance quality and managing capacity of institutions—is embedded in ϵ of (23).

[7]Note that interest earnings of the SWF at t is included in T_t^O; see (19).

For the windfall that is not saved, the government can allocate it among government consumption, public investment, and transfers to households, or use it to pay down debt or lower taxes. Our analysis focuses on the option of public investment.

Two stylized approaches are considered:

(1) **"Saving in a SWF."** To mimic the conventionally recommended policy advise, the stylized saving approach sets $\phi = \frac{1-\rho_F}{\rho_F(i^*-1)}$ to ensure a sufficient proportion of the resource windfall is put aside each period to generate a permanent stream of annuity income.[8] The windfall not saved in a SWF, together with any increase in non-resource tax revenues (due to an expanded tax base), is distributed among households as transfers. Because households have limited access to capital and asset markets, this means that unsaved windfall is largely consumed. All other fiscal policy variables—government consumption, public investment, and tax rates—are set to their pre-windfall levels.

(2) **"Investing in Public Capital."** The stylized investing approach sets $\phi = 0$ in (26), and all resource windfalls are used to boost public investment. Public investment expenditures follow the process,

$$G_t^I = G^I + \left(\frac{T_t^O}{p_t^G} - \frac{T^O}{p^G} \right). \tag{27}$$

We detail the formulation of the sustainable investing approach in Section 6.

2.4. **Some Market Clearing Conditions and Identities.** Let capital letters denote the aggregate quantity of a macroeconomic variable. The total demand for

[8]Mathematically, $\phi = \frac{1-\rho_F}{\rho_F(i^*-1)}$ creates a unit root in (26) and moves the economy to a new steady state with a permanently higher net foreign asset position.

non-traded goods is

$$D_t^N = \varphi\left(C_t + I_t^N + I_t^T\right) + \nu(p_t^G)^\chi G_t. \tag{28}$$

Note that all investment in the resource sector uses traded goods only. The market clearing condition for non-traded goods is

$$Y_t^N = (p_t^N)^{-\chi} D_t^N. \tag{29}$$

Current account deficits (CA_t^d) are computed as

$$CA_t^d = \left(C_t + I_t + p_t^G G_t\right) - p_t^N Y_t^N - s_t Y_t^T - s_t p^{O*} Y_t^O - s_t\left[\left(i^* - 1\right)\rho_F F_{t-1}^* + rm^*\right], \tag{30}$$

where total investment $I_t = I_t^N + I_t^T + I_t^O$. The balance of payment condition is

$$CA_t^d = s_t\left[A^* + FDI_t^* - \left(1 - \iota^{div}\right)\Omega_t^{O*} - \left(F_t^* - \rho_F F_{t-1}^*\right)\right]. \tag{31}$$

Lastly, the total output of the economy in units of composite consumption is

$$Y_t = p_t^N Y_t^N + s_t Y_t^T + s_t p_t^{O*} Y_t^O. \tag{32}$$

3. Equilibrium, Solution Methods, and Calibration

The equilibrium system of the model consists of optimality conditions (see Appendix A), the government budget constraints, fiscal policy, market clearing conditions, the balance of payment condition, and the exogenous processes of shocks. Most of the analysis focuses on the scenarios of a resource boom driven by a one-time, large FDI shock. The equilibrium is solved nonlinearly from a pre-windfall steady state to another steady state, where the resource production returns to the pre-windfall level. Appendix B conducts stochastic simulations, where the economy is subject to frequent shocks in both resource production and prices. The equilibrium for the stochastic simulation exercise is log-linearized and solved by Sims's (2001) method. The model is at the quarterly frequency, calibrated to an average resource-abundant low-income country in Sub-Saharan Africa. Table 1 summarizes the baseline calibration.

The characteristics of resource revenues are roughly calibrated to the average of 13 low-income, resource abundant countries in Africa identified by the International Monetary Fund (2010).[9] In the baseline calibration, the resource windfall is 5 percent of GDP and 25 percent of total revenues. Following Buffie et al. (2011), the net domestic quarterly real rate is set to be 0.025 (or an annual rate of 10 percent). We assume that the SWF earns a quarterly real rate of 0.011 (or an annual real return of 4.5 percent), which is slightly above the average of historical real returns on stocks and 3-10 year T-bills in the U.S.

To simulate an FDI-driven resource boom, we set $\rho_{FDI} = 0.95$ and $\sigma_{FDI} = 552.5$ in (15) to produces a gradual increase in resource production, which on average doubles the pre-windfall level over a 10-year period. This production profile is typical for an African country that has made recent discovery.[10] The specific share of the resource windfall saved in a SWF can vary, depending on the assumption on the real return of a SWF (see Section 2.3.1). In the baseline, $\phi = 0.8991$ for the stylized saving approach.

In the pre-windfall steady state, the government is assumed to invest 4 percent of GDP in public capital. The efficiency parameter of public investment ϵ in (23)

[9]These countries had resource revenues on average contributed at least 25 percent to total government revenues over 2000 to 2007, and/or their exports made up at least 25 percent of the value of total exports of goods (Annex 1, International Monetary Fund (2010)).

[10]For example, see the projection of Ghana's oil windfall in Dagher et al. (forthcoming), which began production in 2011 and is expected to exhaust the current discovery in early 2020s.

is set to 0.4, in line with the estimate by Pritchett (2000) for low-income countries. Combined with a quarterly depreciation rate of 2.5 percent ($\delta^G = 0.025$), it yields a public capital to GDP ratio of 0.64 and a quarterly net return to public capital of 5.1 percent (or an annual return of about 22 percent), consistent with the median rate of return on World Bank projects around 2001 in sub-Saharan Africa (The World Bank (2010)).[11] This baseline calibration reflects the assumption that capital scarcity implies a high return to public investment, relative to savings in a SWF.

To model absorptive capacity constraint, we set $b = 0.3$ in the baseline. The convex cost function in (22) implies rapidly rising costs as public investment scales up. Under $b = 0.3$, a 10-percent increase in public investment expenditures implies absorptive capacity constraint costs are only 0.3 percent of total expenditures. However, when public investment expenditures double from the pre-windfall level, the costs rises to 30 percent of total expenditures. Since there is little empirical evidence to support our calibration, different values of b are investigated. Another parameter relevant to low-income countries is the production distortion parameter (ι). This distortion acts as a tax on firms, reflecting a hidden cost to conducting business in low-income countries. Given a quarterly depreciation rate of private capital and the private investment-output ratio, we set $\iota = 0.07$.

Finally, we assume a low Frisch elasticity of labor supply. A high Frisch elasticity implies that households would reduce work efforts substantially when receiving additional government transfers. Given the poor living conditions in low-income

[11]The net return to public capital in the model is defined as the weighted sum of marginal product of public capital in both non-traded and traded good sectors less depreciation, where the weights are the ratios of each sector's output to total non-resource GDP.

countries, the wealth effect, if present, is likely to be small. Thus, we assume the Frisch labor elasticity is 0.1 ($\psi = 10$), much below the typical 0.5 used in macroeconomic models.[12]

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

The analysis begins by illustrating the very different macroeconomic dynamics under two stylized approaches for managing a resource windfall: saving in a SWF vs. investing in public capital. A one-time, persistent FDI shock drives up resource production. Policy rules follow those described in Section 2.3.1. Figure 1 presents the transition dynamics starting from the pre-windfall steady state. The solid lines depict the responses under saving in a SWF, and the dotted-dashed lines are under investing in public capital. The x-axis denotes the number of years after the initial increase in FDI. The units in the y-axis are percentage deviations from the original steady state unless otherwise denoted in parentheses.

4.1. **Saving in a SWF.** In response to an increase in FDI, resource output and thus government revenues rise gradually. Under the baseline calibration, the stylized saving approach has the government save about 90 percent of the windfall in a SWF each period. In the new steady state, the SWF is about 400 percent of quarterly GDP (or 100 percent of annual GDP). Since resource revenues are defined to include interest earnings from the SWF, resource revenues are also permanently higher, reaching 9 percent of GDP. Public capital, on the other hand, remains at the pre-windfall level because none of the resource revenues is allocated for public investment.

[12]Goldberg (2011) estimates that the wage elasticity of labor supply in the rural Malawi ranges from 0.15 to 0.17.

Under the stylized saving approach, current account movements are mainly driven by activity in the resource sector. The rising current account deficits at the beginning are due to the FDI surge. As resource output—all exported—grows, the deficits fall. In the longer term, the SWF earns a constant stream of foreign interest income, and the current account turns into a surplus of 5 percent of GDP, compared to 1 percent in the pre-windfall level.

Overall, non-resource production experiences small movements, yet consumption becomes permanently higher by 0.5 percent because the government transfers annuity income to households. Higher consumption, in turn, induces households to cut labor supply, lowering the marginal product of non-resource investment. As a result, non-resource investment falls slightly. In the new steady state, lower labor and investment result in a tiny decline of non-resource output by 0.06 percent.

The stylized saving approach modeled here is a conservative way to manage a resource windfall: Resource revenues are not spent until received, and the spending proportion is restricted to the extent that a permanently higher position of net foreign assets can be guaranteed.[13]

4.2. **Investing in Public Capital.** The stylized external saving approach just analyzed produces minimal macroeconomic activity because most resource income is directly deposited into foreign denominated assets. In contrast, the responses under the stylized investing approach are sizable, as shown by the dotted-dashed lines in Figure 1. Another distinctive difference is that the economy now returns

[13]The stylized saving approach mimics the "bird-in-hand " rule in practice. The strict PIH rule involves borrowing against expected future resource revenues to immediately boost current consumption. The bird-in-hand rule, on the other hand, does not use future resource revenues as collateral; it withdraws a fixed, small share out of a SWF for spending each year.

to the pre-windfall steady state, instead of converging to a new steady state as in the stylized saving case.

In this scenario, the government allocates the received windfall to public investment. Consequently, public capital rises substantially following the path of resource output. At the peak (25 years after the windfall starts), public capital is 35 percent above the pre-windfall level, or 0.8 for the ratio of public capital to GDP (rising from 0.64 in the pre-windfall steady state). Higher public capital raises the marginal product of private inputs, resulting in a peak increase in non-resource investment by 5.6 percent and in non-resource GDP by 4.2 percent, 27 years after the windfall starts. Higher output also translates into more income, supporting higher consumption; peak consumption is 3.9 percent above the pre-windfall level, much higher than 0.5 percent under stylized saving.

While the response of non-resource output is quite positive, the traded good sector experiences a substantial decline for the first 20 years. Spending a large amount of foreign exchange from the resource windfall makes the real exchange rate appreciate, reaching 3.7 percent 5 years after the windfall starts (compared to only 0.3 percent under stylized saving). The real exchange rate appreciation lowers the price that traded-good firms receive in units of domestic consumption, discouraging production. With mild learning-by-doing externalities assumed in the baseline, the decline of the traded output reaches the trough of 5.5 percent below the pre-windfall level about 9 years after the shock. Although traded-good output later rebounds due to more productive public capital, the substantial and prolonged decline of traded production—and some decline in productivity—reflects the concern of Dutch disease.[14]

As mentioned above, despite the rapid scaling-up in public investment, the economy returns to the pre-windfall state. The stylized investing approach does not allocate non-resource revenues to finance public investment; the increase of the non-resource revenues (due to the tax base expansion from the investment surge) is distributed as transfers to households. As resource production declines, the expenditure on public investment falls accordingly. Without continuous funding for public investment, capital built with the windfall eventually depreciates. The under-financing of recurrent costs results in the stock of public capital falling back to the pre-windfall level.

A somewhat surprising result under the investing approach is the negative labor response. While higher public capital raises the marginal product of labor, inducing households to supply more labor, the wealth effect points in the opposite direction. As income rises, households take more leisure and reduce labor supply. The net effect is a labor decline, more than under the saving approach, suggesting a stronger wealth effect from a public investment surge at least in the medium run.[15]

Overall, the analysis of the two stylized approaches indicates that investing a windfall yields better outcomes in terms of higher real non-resource GDP, higher

[14]The Dutch disease dynamics presented here are typical for spending foreign exchange inflows associated with a natural resource discovery or an aid surge (e.g., see Berg et al. (2010) and van der Ploeg and Venables (2010).

[15]Given our calibration of a low Frisch labor elasticity (0.1), the influence of negative labor responses on non-resource output is reduced. 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).

consumption, and more leisure at least for the first 70 some years. The welfare gain under the investing approach equals 1.2 percent of consumption each period relative to the path without the windfall. This result echoes the view that capital-scarce countries are better off by front-loading public investment to improve the living conditions of current generations, even if the increase in public capital is not sustained. To check the robustness of this conclusion, sensitivity analysis is conducted next.

5. Sensitivity Analysis: Growth Effects of Public Investment

The rosy picture under the stylized investing approach in Figure 1 is obtained assuming public capital has a much higher return than the SWF (22 percent vs. 4.5 percent at annual rates). Since a great uncertainty exists regarding the output effect of public investment in low-income countries,[16] we also investigate a less optimistic view of the return to public capital. We focus on two important parameters for determining the growth effects of public investment: the output elasticity of public capital (α^G) and the parameter governing the severity of absorptive capacity constraints (b).

5.1. **Productivity of Public Capital.** Table 2 contains the welfare results for the first 100 years after the windfall, under the baseline and three other parameterizations. The welfare measures in Table 2 (and throughout the paper) refer to the permanent change in consumption required to equate the welfare with the windfall to the welfare without the windfall (the path the economy would have

[16] Kraay (2012) obtains very small output effects for the World Bank spending using lending data of 6,529 projects for 29 low-income countries from 1985 to 2009. Also see Buffie et al. (2011) for a summary on the estimates of the rate of returns on infrastructure projects in low-income countries.

stayed on in the original steady state). Thus, a more *negative* number indicates *higher* welfare in the windfall scenario.

Table 2 shows that, under the baseline calibration, the stylized investment approach dominates the stylized external savings. However, it also shows that, by modifying the assumption on returns to domestic and foreign assets, the welfare comparison outcome can be easily reversed. Scenario 2 has the output elasticity of public capital $\alpha^G = 0.05$ and the annual SWF return of 5 percent, compared with $\alpha^G = 0.1$ and a SWF return of 4.5 percent in the baseline. Households now enjoy higher welfare when saving in a SWF. In the extreme case where public capital is completely unproductive (scenario 4 with $\alpha^G = 0$), the stylized investing approach only slightly outperforms the scenario without a windfall, and households are much better off by saving in a SWF.

Figure 2 plots the impulse responses of key macroeconomic variables across the four scenarios. Each column compares the stylized saving approach (solid lines) with the stylized investing approach (dotted-dashed lines) under a set of return assumptions. For reference, the first column (scenario 1) repeats the baseline. In scenario 2, since the annual return to the SWF is higher than in the other cases (by 0.05 percentage point), the accumulation into the SWF need not be as high. With a higher SWF return, consumption is also higher—equal to 0.9 percent above the pre-windfall steady state level, compared to 0.5 percent under the baseline. As α^G gradually decreases (moving from left to right columns), spending the windfall on public investment has a smaller and smaller effect on non-resource GDP and consumption. The negative labor response due to wealth effects also diminishes. When public investment becomes unproductive (scenario 4), the labor response turns positive because the substitution effect from a higher wage rate (resulting from a stronger government demand on non-traded goods) dominates the overall labor response.

In sum, both welfare comparison and impulse responses show that the better economic outcomes in Figure 1 under the investing approach are fragile to the assumptions on the rate of return of public capital. Although capital scarcity presents a strong case for low-income countries to invest a resource windfall, unless public capital can be sufficiently productive, increasing government spending can only generate short-lived effects. Under those circumstances, households are better off by saving the windfall in a SWF.

5.2. **Absorptive Capacity Constraints.** Aside from the output elasticity of public capital, another crucial factor is the country's absorptive capacity constraint. Figure 3 presents two calibrations: Solid lines have less severe constraints ($b = 0.2$); dotted-dashed lines have more severe ones ($b = 0.33$). The path of public investment *expenditures* is identical under the two scenarios, but private investment, consumption, and non-resource output are all lower when the constraints are more severe. The smaller labor decline under more severe constraints is due to weaker wealth effects on labor supply as a result of a smaller increase in non-resource output. It is no surprise that less severe constraints ($b = 0.2$) yield higher welfare (-2.6) than the baseline case ($b = 0.3$, with a welfare measure of -1.8).

To quantify the output effect due to different absorptive capacity constraints, we compute the present-value, cumulative non-resource output multiplier for public investment. Following Mountford and Uhlig (2009), the multiplier k quarters after an increase in public investment is defined as

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

where $\triangle Y_{t+i}^{NO}$ and $\triangle p_{t+i}^{G} G_{t+i}^{I}$ are level changes in non-resource output 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. The multipliers are cumulative over 40 years. Table 3 summarizes the results.

Table 3 also reports a "leak" measure—the maximum ratio of the absorptive capacity constraint costs to investment expenditures, or $1-\frac{\tilde{G}_t^I}{G_t^I}$—under various b values. It shows that more severe absorptive capacity constraints are associated with higher costs and a smaller non-resource output multiplier. Despite a relatively high returns to public capital ($\alpha^G = 0.1$), absorptive capacity constraints could significantly lower the fiscal multiplier of public investment.

Our results highlight the importance of accurate assessments in public investment projects of both the rate of return and the absorptive capacity constraint. One caveat worth noting is that these simulations are conducted under no uncertainty and hence may not fully account for the benefits of saving abroad. In addition to providing a permanent income stream, a SWF can also serve as a stabilization buffer, enabling households to enjoy a smoother consumption path over negative economic shocks. Accounting for these additional benefits of saving further suggests that public investment scaling-up in low-income countries should be pursued with caution.

6. Preserving Resource Wealth by Investing a Windfall

The PIH-based advice emphasizes the advantages of preserving wealth to sustain a permanently higher level of consumption. The conventional PIH advice is to sustain consumption through the annuity income of financial assets. Since investing is also a form of saving and higher consumption can be supported by a higher public capital stock, the PIH framework in principle can accommodate public investment by transforming resource wealth into physical assets instead. The main challenge is to maintain a permanently higher stock of public capital from investing a temporary stream of income, so output and consumption can be permanently raised. This section proposes a "sustainable investing approach." The key to preserve wealth is to choose a sustainable scaling-up magnitude given a windfall size and other fiscal characteristics of the country.

The sustainable investing approach combines investing with external saving. To secure financing of recurrent costs for maintaining capital after a resource revenue flow stops, an "investment fund" is established to store part of the windfall, similar to a SWF.[17] Instead of distributing annuity income to households to directly raise private consumption, the annuity income plus any increases in non-resource taxes are set aside to finance public investment.

To formalize this approach, let the scaling-up of public investment in the new steady state be G^I_{nss}, and γ be the adjustment speed to the new steady-state public

[17]In practice, institutional factors may argue against fragmentation in the form of a separate investment fund, which may weaken overall fiscal planning and control. The creation of an investment fund here can be thought of as an intellectual construct to help illustrate the benefits of the sustainable investing approach. See Baunsgaard et al. (2012) on the institutional consideration of setting resource funds.

investment. Public investment expenditures follow the process

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

When $\gamma = 0$, $G_t^I = G^I \; \forall \, t$, and $\gamma \to \infty$, public investment jumps to the new steady-state level immediately. The investment fund evolves following the same process as (26) for a SWF, except that $\left(T_t^O - T^O\right)$ is now replaced by $(T_t - T)$. When a scaling-up magnitude is beyond what can be supported by a given windfall and additional non-resource revenues, a fiscal adjustment—raising the consumption tax—is implemented to ensure fiscal sustainability; other fiscal variables are set to the pre-windfall levels.[18]

To see examples of implementing the sustainable investing approach, let $\gamma = 0.1$ in (34). Figure 4 compares the two scenarios with different new steady-state public investment levels. Solid lines have $\frac{G_{nss}^I}{G^I} = 1.2$ (a 20-percent increase), dashed lines have $\frac{G_{nss}^I}{G^I} = 1.8$ (an 80-percent increase). For reference purposes, the responses under the stylized investing approach are repeated (dotted-dashed lines). We first compare between the responses under $\frac{G_{nss}^I}{G^I} = 1.2$ and the stylized investing approach to demonstrate the advantages of the sustainable investing approach. Later, we use $\frac{G_{nss}^I}{G^I} = 1.8$ to illustrate a scenario where a scaling-up is too large to be sustainable, unless substantial fiscal adjustments are made. The last part of this section discusses generalizing the sustainable investing approach in practice.

6.1. **Advantages of a Sustainable Investing Approach.** Comparing to stylized investing, the sustainable investing approach entails a slower and smoother path of scaling up. The real exchange rate appreciates but the magnitude is greatly

[18]A country may resort to borrowing when the magnitude of the scaling-up is beyond what the windfall can support. However, a fiscal adjustment will still be needed at some point to ensure fiscal sustainability, unless very large supply-side effects can be generated from the investment.

reduced: The maximum appreciation is only 0.4 percent (vs. 3.7 percent under stylized investing). Traded-good production also declines less, by a peak of 0.3 percent 4 years after the shock. Moreover, output rebounds much faster. This shows that when a windfall is spent at a much slower pace, Dutch disease effects can be mitigated.

Another conspicuous difference is that the growth benefits of investing a resource windfall in public capital is now sustained. When $\frac{G^I_{nss}}{G^I} = 1.2$, the new steady state has non-resource GDP 2.2 percent and consumption 1.7 percent above the pre-windfall level. This long-term growth effect results from a permanently higher public capital stock, generating an increase in the marginal product of private capital and labor. In the new steady state, public capital is 18.6 percent higher than the pre-windfall level, raising the public capital-to-GDP ratio from 0.64 to 0.74. Higher public capital elevates households' income and consumption. Like the stylized saving and investing approaches, labor falls because the wealth effect dominates the substitution effect from a higher marginal product of labor. The absorptive capacity constraints costs as a share of investment expenditures also drop dramatically from an average of 30 percent to 1 percent for the first 20 years. As a result, the non-resource output multiplier for public investment substantially raises to 1.1, compared to 0.56 under stylized investing with the baseline calibration.

Overall the welfare measure of the sustainable investing approach with $\frac{G^I_{nss}}{G^I} = 1.2$ is -0.7, implying lower welfare than that under the stylized investing approach (-1.8, Table 2). There are two possible reasons for this ranking. First, since standard welfare calculations are computed in terms of present-value utility, which under our current calibration heavily discounts utility gains in the distant future, it is no surprise that stylized investing outperforms welfare gains from the sustainable investing approach: consumption climbs up at a faster pace under the former. If the policy objective is to increase consumption for all generations, by discounting the consumption of future generations by less, then the sustainable investing approach would be preferred instead. Second, it is possible that the investment path specified by (34) is too gradual relative to the economy's need for public capital, even if absorption constraints are severe. A more rapid increase in investment may therefore be preferred, although in the absence of fiscal adjustment the additional public capital that can be sustained in the long run would have to be lower.

We now compare the new approach with the SWF case. Solid lines in Figure 5 plots the sustainable investing approach with $\frac{G^I_{nss}}{G^I} = 1.2$, and dotted-dashed lines repeat the stylized SWF saving. While the latter yields higher consumption for the first 10 years, the former approach is able to support higher consumption in the long run. Under sustainable investing, public capital is 20 percent higher than the pre-windfall level, non-resource GDP is also higher, and consumption is 1.7 percent above the pre-windfall level, compared to 0.5 percent under the stylized saving. The welfare measure is -0.7, slightly outperforming stylized saving in a SWF (-0.6). Like the sensitivity analysis in Section 5, the comparisons result surely depend on the return to public capital. If public capital turns out to be less productive, say $\alpha^G = 0.05$ (vs. $\alpha^G = 0.1$ in the baseline), the welfare measure becomes -0.2, and agents are better off just saving abroad.

Finally, the gradual scaling-up and smooth investment path proposed by the sustainable investing approach has the advantage of minimizing macro volatility due to a volatile resource income stream. The analysis so far abstracts from resource price volatility. Appendix B conducts an exercise to compare volatility of key economic variables under the stylized investing and the sustainable investing approach in a context of volatile international prices. It shows that smoothing investment expenditures substantially reduces volatility of non-resource output.

6.2. **The Size of Scaling-up and Recurrent Costs.** The preceding analysis has a moderate scaling up of public investment in the new steady state (only 20 percent higher than the the pre-windfall level). As the consumption tax rate does not rise (Figure 4), this implies that the combination of the resource windfall and the savings of additional non-resource tax revenues produces a self-sustainable scaling-up; i.e., no fiscal adjustment is needed to finance higher recurrent costs. If the public investment plan is more ambitious however, say an 80-percent increase ($\frac{G^I_{nss}}{G^I} = 1.8$, dashed lines in Figure 4), then the consumption tax rate has to gradually rise from 10 percent to 13 percent (permanently) to maintain public capital.

Under $\frac{G^I_{nss}}{G^I} = 1.8$, the economy ends up with more public capital and induces more non-resource investment, producing higher non-resource GDP. A higher GDP, however, does not deliver more consumption, because a larger public capital stock means more capital depreciation and a higher consumption tax rate to finance investment. During the first 12 years, consumption even falls in response to a higher consumption tax rate. As more public capital raises the marginal return to private inputs, higher income later turns consumption to the positive territory. The welfare measure under $\frac{G^I_{nss}}{G^I} = 1.8$ is 0.4, compared to -0.7 under $\frac{G^I_{nss}}{G^I} = 1.2$. Despite more output being produced, a higher share of the additional output goes to replenish depreciated capital. Moreover, the positive welfare measure under higher scaling-up indicates that households are indeed worse off relative to the path without a windfall because they have to reduce initial consumption and work harder.

Given the assumed windfall size, the above scenario is an example of "over" scaling-up, in the sense that private consumption over the transition path is indeed lower than under alternative scaling-up magnitudes (e.g., a 20-percent). Even when non-resource revenues can be made available, the benefits from a higher capital stock should be weighed against its recurrent costs plus any distortions brought by higher tax rates or the incidence of reductions in other government spending items. Our model provides a coherent framework for assessing these benefits and costs along a transition path and at a steady state.

6.3. **Generalizing the Sustainable Investing Approach.** The investment trajectories we have laid out for analyzing the sustainable investing approach appear to be conservative. Subject to the functional from in (34), the approach suggests a monotonically increasing path of public investment until it reaches a permanently higher level. Also, under the assumption of no fiscal adjustment, the increase in investment is relatively small, especially during the early years (see the 20-percent scaling-up in Figure 4).

In practice, investment projects can be lumpy. In addition, donors' support and borrowing access may also be available as the windfall arrives. For example, if a country considers using both resource windfalls and aid to build a 500 million dollar highway with a recurrent cost of 50 million each year, then the scaling-up can be made possible by the higher aid, provided the absorptive capacity constraints do not rise substantially. One principle to guide public investment in such scenarios is that the front-loading of the investment does not result in an overshooting of public capital; i.e., public capital rises and then declines along the path. When this occurs, it implies that the new capital cannot be sustained, and less frontloading would be preferable.

Our modeling framework provides a conservative benchmark to implement the sustainable investing approach. Given the difficulty in mobilizing revenues in low-income countries, the sustainable approach guarantees that recurrent costs will be financed. Otherwise, an investment project that relies on collecting more future domestic revenues—e.g., through higher tax rates or a rosy projection of large supply-side effects of public investment—may not be feasible and the capital may not be sustained. Similar concerns apply to non-concessional external borrowing. As shown in Buffie et al. (2011), when commercial borrowing is used to finance an investment scaling-up, it poses greater risks for both capital sustainability and fiscal sustainability.

7. Conclusion

Natural resource revenues relax the financial constraints of low-income countries and provide an opportunity to speed up economic development. This paper studies different approaches of investing a resource windfall in low-income countries and compares their outcome with the often–recommended external saving approach. While saving in a SWF minimizes economic instability and preserves resource wealth, its opportunity cost can be high, as returns to investment are likely higher than those of external financial assets. In line with recent literature, we find that investing a resource windfall can generate higher welfare. This result, however, depends crucially on the return to public capital and absorptive capacity constraints of an economy. In addition, investing domestically a large, volatile flow of resource revenues raises Dutch disease and stability concerns.

To address these concerns, this paper proposes a "sustainable investing approach." It emphasizes that when determining the magnitude of a scaling-up, the financing of future recurrent costs should be accounted for, so that the growth benefits from investing can be sustained. The approach also prescribes a gradual scaling-up to address absorptive capacity constraints, prevalent in low-income countries. As public investment is ramped up gradually, Dutch disease and absorptive capacity constraints are much relieved, and economic instability is minimized. Since consumption is permanently higher, this approach is broadly in line with the PIH principle. Instead of preserving exhaustible resource wealth by accumulating external financial assets, the sustainable investing approach converts resource wealth into a permanently higher stock of domestic public capital.

In reaching these conclusions, we have calibrated the model to a "typical" low-income country in sub-Saharan Africa. With a more country-specific calibration, the framework may be useful in illustrating the macroeconomic consequences of different policy choices. Some lessons from the current calibration, however, are broadly applicable. These include the merits of the sustainable investing approach relative to the two extremes (saving in a SWF and investing all of the resource windfall as it accrues). Also, the analysis underscores the complications involved in converting resource wealth into public capital. One set of complications involves various costs associated with that conversion, namely absorptive capacity constraints and Dutch disease considerations. Another is the fiscal issue. The return on financial assets owned by the government accrues to the government. However, the gross return on public capital accrues in the first place to private agents (by raising private productivity), while the government remains responsible for maintenance and depreciation. Even if public capital is highly productive and absorptive capacity is high, tax rates in typical low-income countries are sufficiently low that the government may not be able to capture enough of these returns to finance recurrent costs without tax rate increases. The potentially disruptive implications of these rate increases are an important consideration when determining the magnitude of the scaling-up.

A number of extensions could usefully be considered. The paper focuses 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 productivity of private production inputs in low-income countries. The paper focuses on some simple government rules; a fuller consideration of optimal policy, while not trivial in as complex a model as this, would clearly be useful. And the model abstracts from the implications of nominal rigidities and thus short-run macroeconomic concerns; the model could readily be adapted to address these issues as well.

Appendix A. Optimality Conditions

This appendix contains the first order conditions of all the optimization problems in the model. 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 $q_t^T = \frac{\lambda_t^T}{\lambda_t}$.

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

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

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

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

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

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

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

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

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

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

Appendix B. Coping with Commodity Price Fluctuation

The analysis in the text focuses on a resource windfall driven by an FDI surge and abstracts from resource price volatility. The advantage of the sustainable investing approach in improving economic stability can be better demonstrated if the economy also experiences fluctuating commodity prices, as in reality. To show this, we pursue stochastic simulations assuming that the economy is subject to both commodity price and quantity (FDI) shocks. Following the estimated results from oil price data, $\sigma_{PO} = 0.138$ and $\rho_{po} = 0.97$ in (14), and set $\sigma_{FDI} = 1$.[19] Based on the simulated data for an 80-year horizon, Table 4 summarizes the average percent standard deviations from the path without shocks using 100 simulated data sets for the main macroeconomic variables. The experiments are controlled such that the two economies following different investing approaches experience identical values in shocks.

[19]The quarterly series of crude oil prices (in logarithm) from 1980 to 2010 is fitted to estimate (14). Data are seasonally adjusted using the X12 program. Oil prices are the average of three spot prices (Dated Brent, West Texas Intermediate, and the Dubai Fateh) per barrel in U.S. dollars. The setting of $\sigma_{FDI} = 1$ is somewhat arbitrary to simply generate some quantity fluctuations.

The results show that the sustainable investing approach greatly reduces the volatility of public investment expenditures from 1.5 percent to 0.18 percent. As a result, the volatilities of non-resource output and investment also decrease, by a factor of four. Consumption and labor volatilities do not improve mainly due to the policy rule that the consumption tax rate alone does all fiscal adjustments. Stability can be further improved if government borrowing is allowed to smooth the fiscal adjustment process.

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Table 1. **Baseline Calibration**

parameters	values	notes
σ	2	inverse of intertemporal elasticity of substitution for consumption
ψ	10	inverse of Frisch elasticity of labor supply
φ	0.51	degree of home bias in consumption
χ	0.89	elasticity of substitution between traded and non-traded sectors
δ	0.65	share of labor supplied to non-traded sector
ρ	1	elasticity of substitution between the two types of labor
β	0.976	the discount factor
α^T, α^N	0.7	labor income share
α^O	0.9	resource production coefficient
α^G	0.1	output elasticity of public capital
d, ρ_{ZT}	0.1	learning-by-doing externalities
ι	0.067	firms' production distortion parameter
κ^N, κ^T	25	investment adjustment cost
$\delta^N, \delta^T, \delta^O$	0.025	depreciation rate for K^N, K^T, and K^O
δ^G	0.025	depreciation rate for public capital
e	0.4	efficiency of public investment
b	0.3	absorptive capacity constraints
ι^{div}	0.4	government share of resource dividends
$\frac{y^O}{GDP}$	0.1	resource GDP/GDP
$\frac{A^*}{GDP}$	0.03	Aid/GDP
ν	0.7	home bias of government purchases
τ^l, τ^c	0.1	effective labor and consumption tax rates
τ^o	0.1	resource royalty rate
s^B	0.1	steady-state government debt/quarterly GDP
$\frac{Z}{GDP}$	0.029	steady-state transfers/GDP
$\frac{G^C}{GDP}$	0.14	steady-state GC/GDP
$\frac{G^I}{GDP}$	0.04	steady-state GI/GDP
$\frac{\texttt{non-resource tax}}{GDP}$	0.135	steady-state non-resource tax/GDP
$\frac{F^*}{GDP}$	0.005	steady-state sovereign wealth fund/quarterly GDP
ρ_{FDI}	0.95	AR(1) coefficient in the FDI
σ_{FDI}	552.2	standard deviation of the FDI shock

Table 2. **Welfare Comparison.** Welfare is computed over 100 years. Welfare measures are percent changes in consumption to equate the welfare between a windfall scenario and a no-windfall scenario. A more negative number indicating higher welfare.

Scenarios	**Stylized Saving in SWF**	**Stylized Investing**
1. $\alpha^G = 0.1$, SWF return: 4.5% (baseline)	−0.6	−1.8
2. $\alpha^G = 0.05$, SWF return: 5%	−1.1	−1.0
3. $\alpha^G = 0.02$, SWF return: 4.5%	−0.6	−0.5
4. $\alpha^G = 0$, SWF return: 4.5%	−0.6	−0.2

Table 3. **Absorptive Capacity Constraints and Investment Multipliers.** Leak measure reports maximum $1 - \frac{\tilde{G}_t^I}{G_t^I}$. The multiplier is non-resource GDP, cumulative at the end of 40 years.

b	**leak measure**	**multiplier**
0.2 (less severe)	0.32	0.75
0.3 (baseline)	0.48	0.56
0.33 (more severe)	0.53	0.49

Table 4. **Stabilization Effects of the Sustainable Investing Approach.** The numbers are the average standard deviations for the percentage deviations of a variable over 100 simulated data.

Variables	**Stylized Investing**	**Sustainable Investing**
public investment	1.50	0.18
real non-resource GDP	0.12	0.03
consumption	0.12	0.11
private non-resource investment	0.19	0.05
labor	0.04	0.04

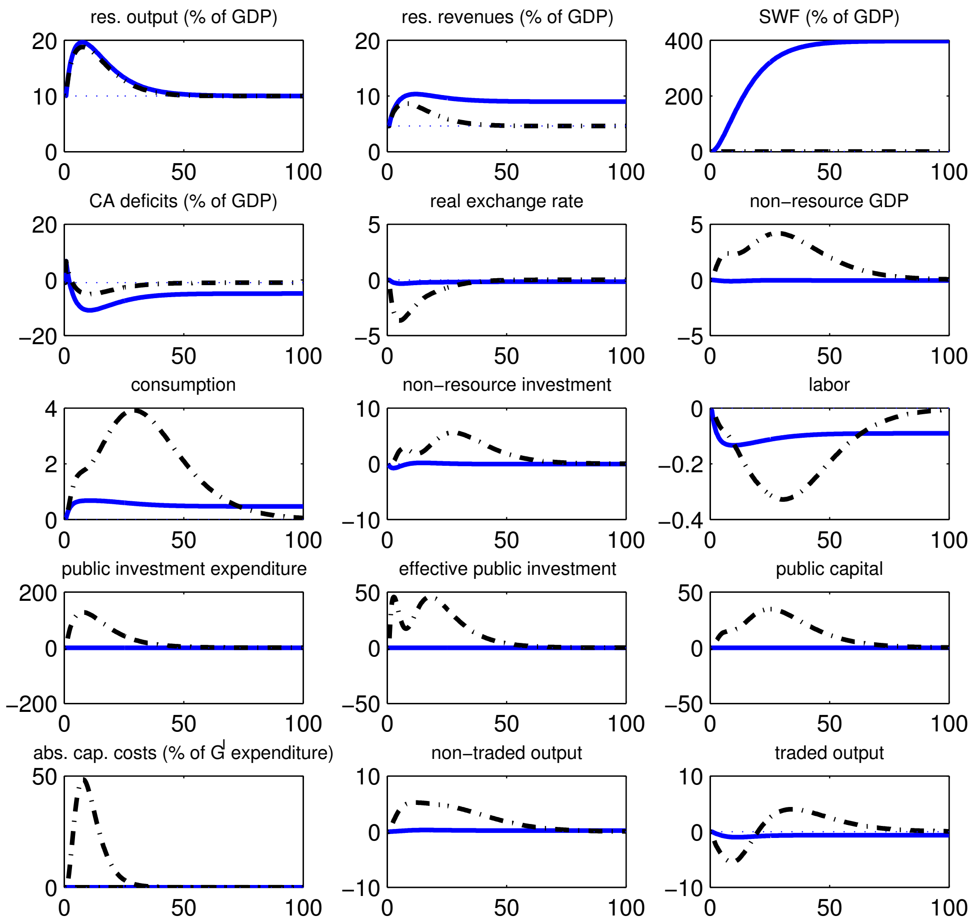

FIGURE 1. **Responses to a resource windfall: two stylized approaches.** Solid lines: saving in a SWF; dashed lines: investing in public capital. The x-axis is in numbers of years after the resource windfall starts. The y-axis is in percent deviation from the pre-windfall steady state unless stated otherwise.

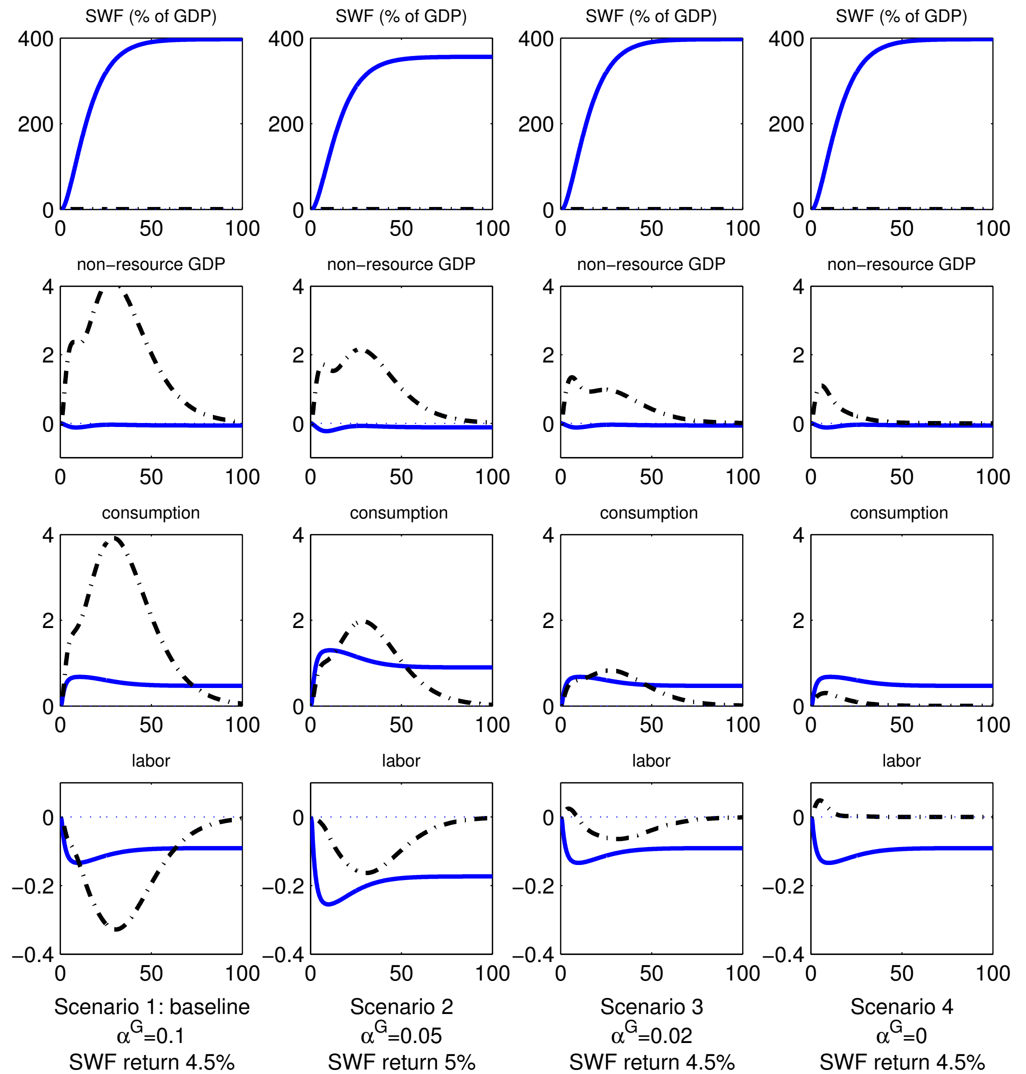

FIGURE 2. **Responses to a resource windfall: sensitivity analysis.** Solid lines are under the stylized saving approach, and the dotted-dashed lines are under the stylized investing approach. The x-axis is in numbers of years after the resource windfall starts. The y-axis is in percent deviation from the pre-windfall steady state unless stated otherwise.

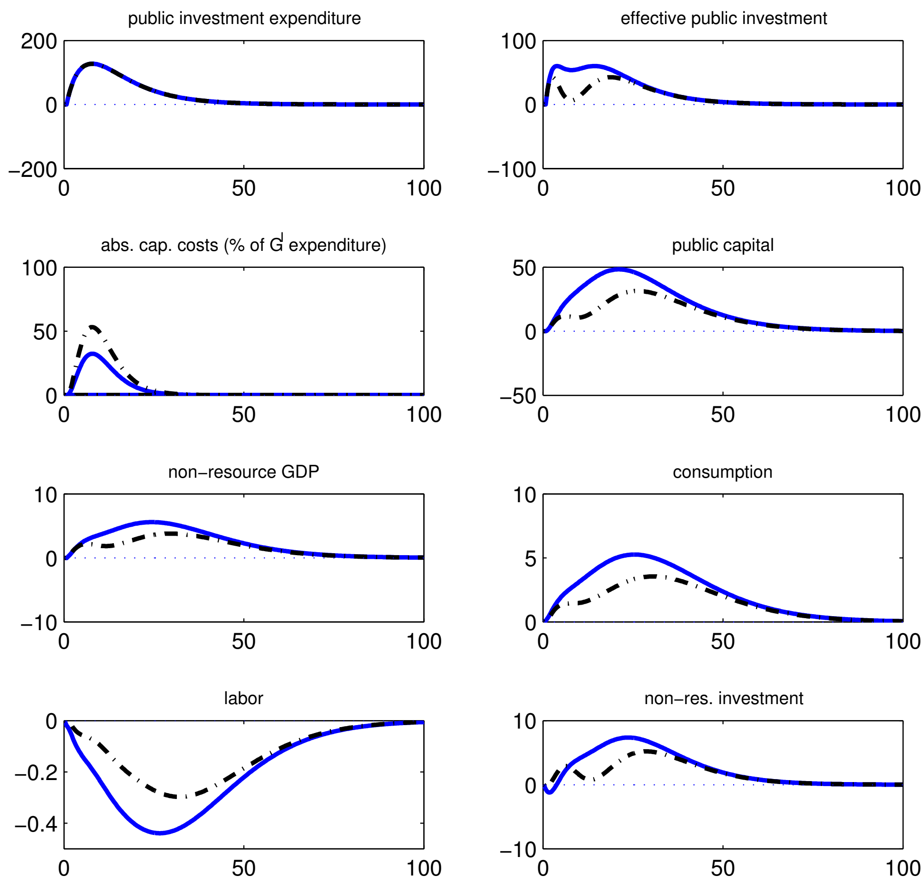

FIGURE 3. **Responses to a resource windfall: different absorptive capacity constraint costs.** Solid lines: less severe constraints ($b = 0.2$); dashed lines: more severe constraint ($b = 0.33$) The x-axis is in numbers of years after the resource windfall starts. The y-axis is in percent deviation from the pre-windfall steady state unless stated otherwise.

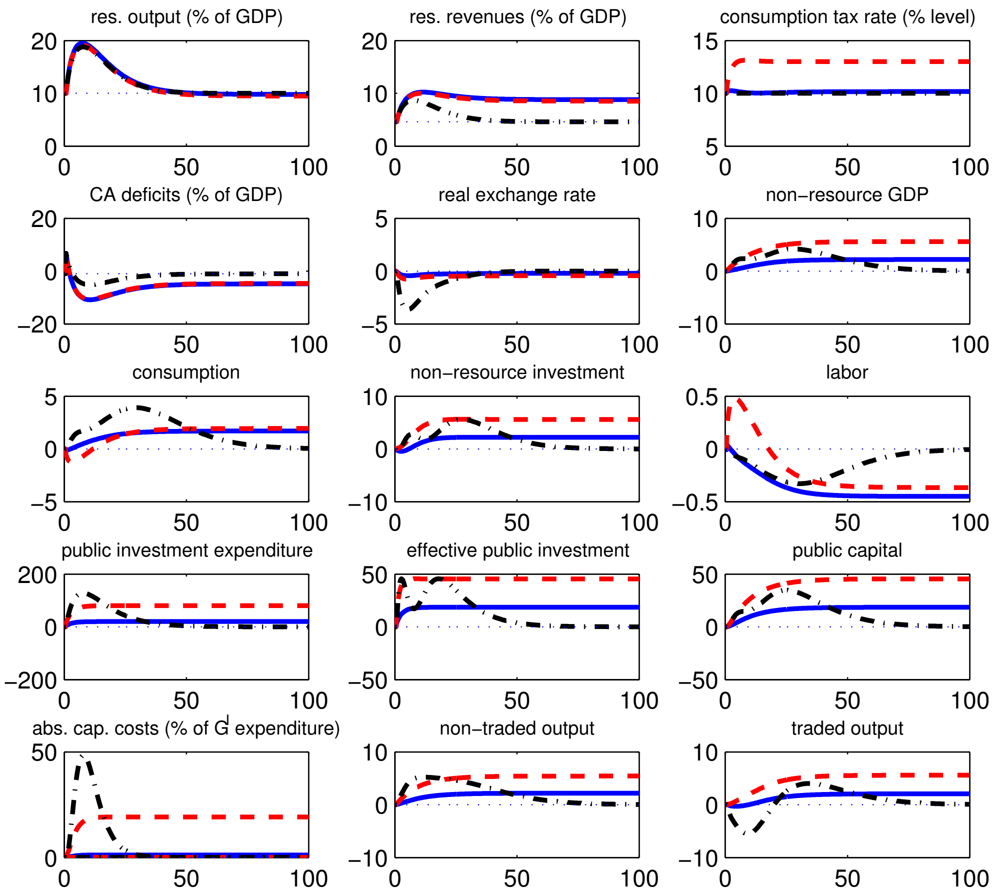

FIGURE 4. **Responses to a resource windfall: sustainable investing approach.** Solid lines: $\frac{G^I_{nss}}{G^I} = 1.2$; dashed lines: $\frac{G^I_{nss}}{G^I} = 1.8$; dotted-dashed lines: stylized investing in public capital ($\frac{G^I_{nss}}{G^I} = 1$). The x-axis is in numbers of years after the resource windfall starts. The y-axis is in percent deviation from the pre-windfall steady state unless stated otherwise.

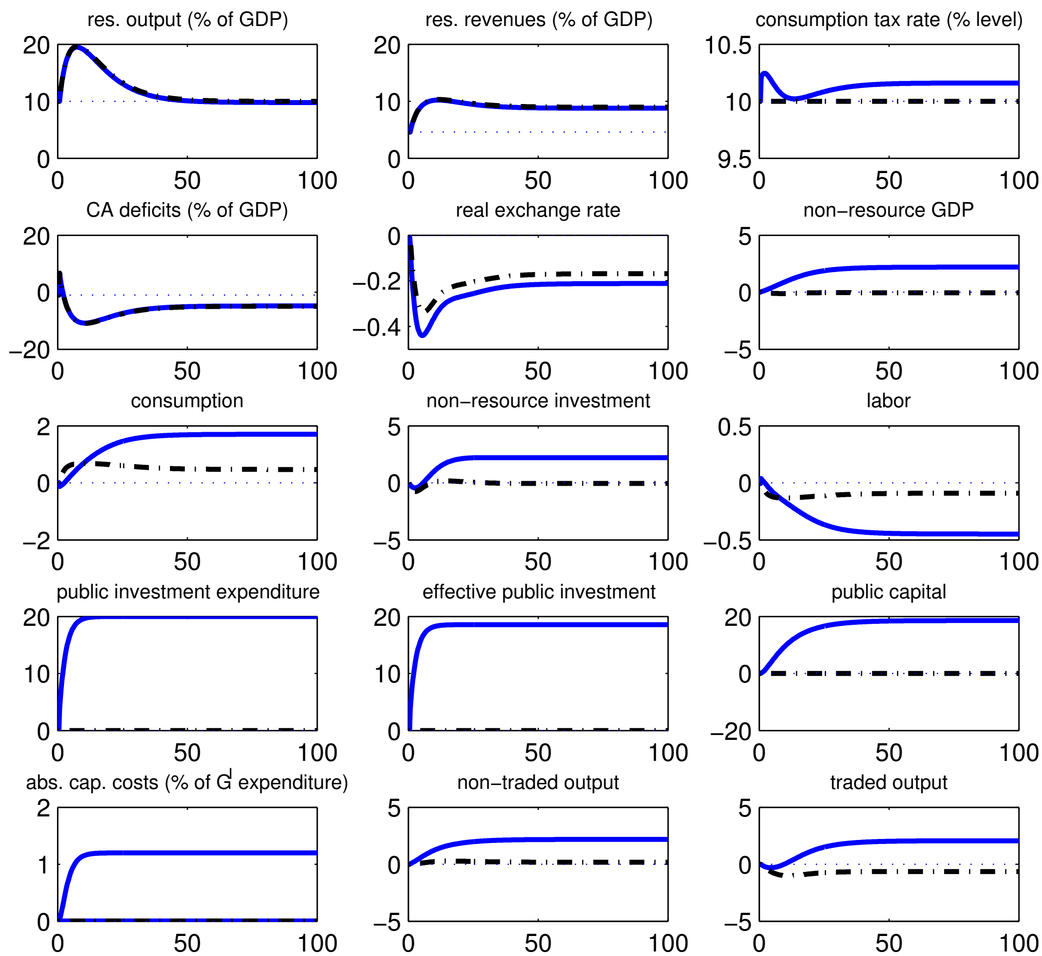

FIGURE 5. **Responses to a resource windfall: sustainable investing vs. saving in a SWF.** Solid lines: sustainable investing ($\frac{G^I_{nss}}{G^I} = 1.2$); dotted-dashed lines: stylized saving in SWF ($\frac{G^I_{nss}}{G^I} = 1$). The x-axis is in numbers of years after the resource windfall starts. The y-axis is in percent deviation from the pre-windfall steady state unless stated otherwise.