Optimal Public Investment in Resource-Rich Low-Income Countries

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January 30, 2017

Abstract

Recent studies have found that resource-rich low-income countries are better off investing their resource revenues domestically rather than saving them abroad in a Sovereign Wealth Fund (SWF). This paper finds an optimal rule-based policy of raising public capital and an associated public investment path, by modifying a perfect foresight general equilibrium model of Berg et al. (2013) in several respects: The policy rule is expressed in terms of public capital. Absorptive capacity constraint, related to public investment costs to build home-grown capital, is characterized by a single parameter. External saving is an additional fiscal instrument, and there is a variable share of resource revenues to accumulate the SWF. The policy rule for public capital is pinned down by two parameters – a new steady state level of increased public capital and its adjustment speed – that are searched in a range to maximize a household's utility. The study finds that a front-loaded public investment path is optimal given an initial one-period resource windfall, absorptive capacity constraints in the economy, and capital scarcity. This result also holds under less productive public capital, while a scenario of no resource windfall produces the welfare loss due to a steady increase of consumption tax to finance public investment.

Keywords: public investment, public capital, absorptive capacity constraints, optimal policy, resource windfall, SWF

JEL Classification: E22, F43, O41, Q32

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1 Introduction

Resource-rich low-income countries are often considered as the most vulnerable economies in the world for three basic reasons. First, they are exposed to volatile external shocks: commodity world price fluctuations, capital inflows/outflows, and geological discovery/depletion of natural resources. Second, they are prone to a natural resource curse due to weak institutions, high income inequality, inefficient governance, and Dutch Disease problems (Van der Ploeg, 2011). Third, their current generation is poor, living in an environment of capital scarcity, an underdeveloped financial system and high absorptive costs for investment to build home-grown capital. In such specific conditions, finding an optimal rule-based policy to manage resource windfalls with a sustainable development objective is crucial, but challenging.

Several studies have recently concluded that resource abundant developing economies are better off investing their resource windfalls domestically rather than saving them abroad in a Sovereign Wealth Fund for future generations (Berg, Portillo, Yang & Zanna, 2013; Van der Ploeg & Venables, 2011; Collier, Van der Ploeg, Spence & Venables, 2010). This is due to the lack of growth-inducing domestic capital such as infrastructure and human capital, which have higher social value and returns than foreign assets in those economies. The fact of poor, impatient, and credit constrained current households, who need to consume now, suggests a policy focus of benefiting them, as opposed to saving for future individuals, who may well be in a relatively wealthier position given a sustainable development path over time.

This paper utilizes the perfect foresight general equilibrium model of Berg et al. (2013), who find that the sustainable domestic investment of resource windfalls is preferable to saving them abroad. However, in drawing this conclusion, they arbitrarily compare a 26 percent increase in public investment to 40 percent at given adjustment speed based on a constant share of resource revenues saved in the SWF. The objective of this study is to find an optimal policy rule of increasing public capital and an adjustment speed of the capital based on the variable share of savings in the SWF. Since public capital is a stock variable, the associated optimal public investment path can be obtained accordingly.

In section two, the model is outlined representing households, producers of traded and non-traded goods, natural resource sector, and fiscal policy. Section three describes the calibration of parameters, the list of which is provided in Appendix A. Section four discusses the findings of optimal policy for public capital and public investment at different absorptive capacity constraints. Sensitivity analysis to a reduced output elasticity of public capital is presented in section five, including a scenario of no resource windfall shock. Section six concludes.

2 Model

The model is a small open, real economy with no external public or private debt, but with foreign direct investment (FDI) in a natural resource sector. This "closed" assumption of a financial account captures the limited access of low-income countries to foreign funds and facilitates the study of an increase of public investment solely financed by a resource windfall rather than by external borrowing. The domestic public debt is fixed to avoid a drop in a household's consumption due to increased savings in the government bonds than finance the scaling-up of public capital.

The model has a representative household, who consumes and pays consumption tax, supplies labor and pays fixed labor tax, owns firms of traded and non-traded goods, holds a constant amount of government bonds and receives fixed remittances from abroad and fixed transfers from the government budget. The producers of traded and non-traded goods are perfectly competitive, who differ in terms of their total factor productivity (TFP) and have public capital as an additional input in their Cobb-Douglass production function. The natural resource sector is assumed to be capital-intensive with its real FDI shock, thus there is no labor input in this sector to avoid the complications from possible labor mobility. Public investment is productive, effectively accumulating public capital and yet containing absorptive capacity constraints.

2.1 Households

A representative household maximizes its expected utility by choosing composite consumption C_t and labor L_t:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{1}{1-\sigma} C_t^{1-\sigma} - \frac{\kappa}{1+\psi} L_t^{1+\psi} \right] \tag{1}$$

subject to the budget constraint:

$$(1+\tau_t^c)C_t + B = (1-\tau^l)w_t L_t + RB + \Omega_t^T + \Omega_t^N + s_t RM^* + Z, \tag{2}$$

where σ and ψ are the inverses of the elasticity of intertemporal substitution for consumption and labor, τ_t^c and τ^l are the consumption and labor tax rates, Ω_t^T and Ω_t^N are the real profits transferred from the producers of traded and non-traded goods, s_t is a CPI-based real exchange rate, RM^* is remittances in the units of foreign consumption (denoted by an asterisk), Z is the government transfers, B is the government bonds, and R is the domestic real interest rate.

The composite CES consumption bundle C_t includes traded (C_t^T) and non-traded (C_t^N) goods:

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

where φ is a consumption home-bias parameter and χ is the intratemporal elasticity of substitution between traded and non-traded goods. Composite consumption is set as a numeraire for the economy, so that by the assumed law of one price for traded goods, s_t is also the relative price of traded goods to composite consumption, while p_t^N is the relative price of non-traded goods to composite consumption:

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

Labor supply of a household consists of labor efforts made in the traded (L_t^T) and non-traded (L_t^N) sectors with ρ as an elasticity of substitution; thus, there is imperfect labor mobility between these two sectors:

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

A real wage index combines the real wage rates in each sector:

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

2.2 Producers of traded and non-traded goods

The Cobb-Douglass production function of sector $j \in \{T, N\}$ includes public capital K_{t-1}^G as an additional input with its output elasticity of α^G:

$$Y_t^j = z_t^j(K_{t-1}^j)^{1-\alpha^j}(L_t^j)^{\alpha^j}(K_{t-1}^G)^{\alpha^G} \tag{7}$$

The law of motion for private capital has quadratic investment adjustment costs with a relevant parameter $\kappa^j > 0$:

$$K_t^j = (1-\delta^j)K_{t-1}^j + \left[1 - \frac{\kappa^j}{2}\left(\frac{I_t^j}{I_{t-1}^j} - 1\right)^2\right] I_t^j \tag{8}$$

The traded and non-traded sectors are perfectly competitive and differ in terms of their TFP. There is a constant TFP parameter z^N for the non-traded sector and learning-by-doing externalities are in the TFP of the traded sector:

$$z_t^N = z^N, \qquad \ln z_t^T = \rho_{zT} \ln z_{t-1}^T + d \ln Y_{t-1} \tag{9}$$

A firm maximizes its net present-value profits, weighted by the marginal utility of household λ_t:

$$E_0 \sum_{t=0}^{\infty} \beta^t \lambda_t \underbrace{[p_t^j Y_t^j - w_t^j L_t^j - I_t^j]}_{=\Omega_t^j} \tag{10}$$

through choosing labor, capital, and investment subject to the capital accumulation equation (8).

2.3 Natural resource sector

The natural resource production is assumed to be a capital-intensive sector and has capital input:

$$Y_t^o = z_t^o (K_{t-1}^o)^{\alpha^o}, \tag{11}$$

which is accumulated by the FDI denominated in foreign consumption goods.

$$K_t^o = (1 - \delta^o) K_{t-1}^o + FDI_t^* \tag{12}$$

The only shock in the model is a real FDI shock transmitting through the resource output:

$$\ln FDI_t^* = \rho_{FDI} \ln FDI_{t-1}^* + \varepsilon_t^{FDI} \tag{13}$$

The profits of the resource sector include royalties levied on production quantity at a rate τ^o:

$$\Omega_t^{o*} = (1 - \tau^o) P_t^{o*} Y_t^o \tag{14}$$

The resource sector is owned by foreigners and government: the dividend share of resource profits that the government receives is denoted by ι^{div}. The resource revenues consist of royalties and dividends:

$$T_t^o = s_t [\tau^o P_t^{o*} Y_t^o + \iota^{\text{div}} \Omega_t^{o*}] \tag{15}$$

2.4 Fiscal policy

The government collects its resource revenues, non-resource revenues representing consumption and labor taxes, and interest income from the SWF. Fiscal expenditures include transfers, interest payments on bonds, and government purchases which are a sum of public consumption and public investment. Thus, the government budget constraint is as follows:

$$ES_t = T_t^o + \underbrace{\tau_t^c C_t + \tau^l w_t L_t}_{T_t^{NO}} + s_t r^* SWF_{t-1}^* - Z - (RB - B) - p_t^G \underbrace{(G_t^C + G_t^I)}_{G_t}, \quad (16)$$

where a residual variable ES_t indicates the external savings that accumulate in the SWF. The external savings themselves are a time-varying share of resource revenues ϕ_t.

$$SWF_t^* = \rho_{swf} SWF_{t-1}^* + \frac{ES_t}{s_t}, \quad ES_t = \phi_t T_t^o, \quad \phi_t = \phi \frac{T_t^o}{T^o} \quad (17)$$

The policy rule to be examined for the optimal increase of public capital $\frac{K_{nss}^G}{K^G}$ and adjustment speed γ is as follows:

$$K_t^G = (1 - e^{-\gamma t}) K_{nss}^G + e^{-\gamma t} K^G, \quad (18)$$

where K_{nss}^G is a new steady state public capital, while K^G is an initial steady state level of public capital.

Public capital accumulation involves the effective public investment $\epsilon \widetilde{G}_t^I$ with its absorptive capacity constraint costs pinned down by the parameter $b > 0$:

$$K_t^G = (1 - \delta^g) K_{t-1}^G + \epsilon \widetilde{G}_t^I, \qquad \widetilde{G}_t^I = \left[1 - b \left(\frac{G_t^I}{G^I} - 1\right)^2\right] G_t^I \quad (19)$$

Similar to private consumption, government purchases are the CES bundle of traded and non-traded goods with a variable degree of home-bias ν_t:

$$G_t = \left[\nu_t^{\frac{1}{\chi}} (G_t^N)^{\frac{\chi-1}{\chi}} + (1 - \nu_t)^{\frac{1}{\chi}} (G_t^T)^{\frac{\chi-1}{\chi}}\right]^{\frac{\chi}{\chi-1}} \quad (20)$$

This parameter is time-varying, according to Berg et al. (2013), to distinguish the home-bias of additional public spending (ν_g) from its steady state value (ν), since the analysis focuses on the allocation of additional public spending to public investment:

$$\nu_t = \nu + (\nu_g - \nu) \frac{p_t^G G_t - p^G G}{p_t^G G_t} \quad (21)$$

The relative price of government purchases to composite consumption is accordingly as follows:

$$p_t^G = \left[\nu_t (p_t^N)^{1-\chi} + (1 - \nu_t) s_t^{1-\chi}\right]^{\frac{1}{1-\chi}} \quad (22)$$

2.5 Market clearing conditions

The market clearing condition for the non-traded sector requires that its supply is equal to demand:

$$Y_t^N = (p_t^N)^{-\chi} \underbrace{[\varphi(C_t + I_t^N + I_t^T) + \nu_t (p_t^G)^{\chi} G_t]}_{D_t^N} \tag{23}$$

The aggregate output consists of traded, non-traded, and resource sectors' output:

$$Y_t = s_t Y_t^T + p_t^N Y_t^N + s_t P_t^{o*} Y_t^o \tag{24}$$

The current account deficit includes the domestic absorption, output, remittances, and interest income of SWF:

$$CA_t^d = (C_t + \underbrace{I_t^T + I_t^N + I_t^o}_{I_t} + p_t^G G_t) - Y_t - s_t[RM^* + r^* SWF_{t-1}^*] \tag{25}$$

The balance of payments is specified by the following variables: current account deficit, FDI, foreign share of resource profits, and the difference of SWF assets.

$$CA_t^d = s_t[FDI_t^* - (1 - \iota^{\text{div}})\Omega_t^{o*} - (SWF_t^* - \rho_{swf} SWF_{t-1}^*)] \tag{26}$$

The equilibrium system of equations consists of solutions to the household's and firms' optimization problems, private and public capital accumulation equations, government budget constraint, fiscal policy, SWF accumulation, price equations, market clearing conditions, balance of payments equation, and FDI process. The dynamics of the model are driven by a large temporal FDI shock, so that resource output eventually reverts to its pre-windfall level. The equilibrium is solved non-linearly from the initial pre-windfall steady state to a new steady state of increased public capital.

3 Calibration

The model is calibrated on annual data for the CEMAC region (Central African Economic and Monetary Community), which includes Cameroon, Central African Republic, Chad, Congo, Equatorial Guinea, and Gabon. The FDI shock persistence is set to 0.8 with a standard deviation of 6.26 to double the resource output-to-GDP ratio over the next ten years. The domestic real interest rate is 10 percent, giving a discount factor of 0.91 associated with the presence of impatient households. The SWF earns a real return of 2.7 percent, whereas public capital, due to its scarcity, has a higher net return of 9.12 percent at its annual depreciation rate of 10 percent and output elasticity of 0.1. As a sensitivity test, the return on public capital lower than the SWF's interest rate (1.47 percent) is also examined, by changing its output elasticity to 0.06. The tightness of absorptive capacity constraints b is varied across 0.1, 0.2, and 0.3 to observe the differences in optimal increase of public investment. The remaining parameters are consistent with the calibration of Berg et al. (2013) for the CEMAC region and listed in Appendix A.

4 Results

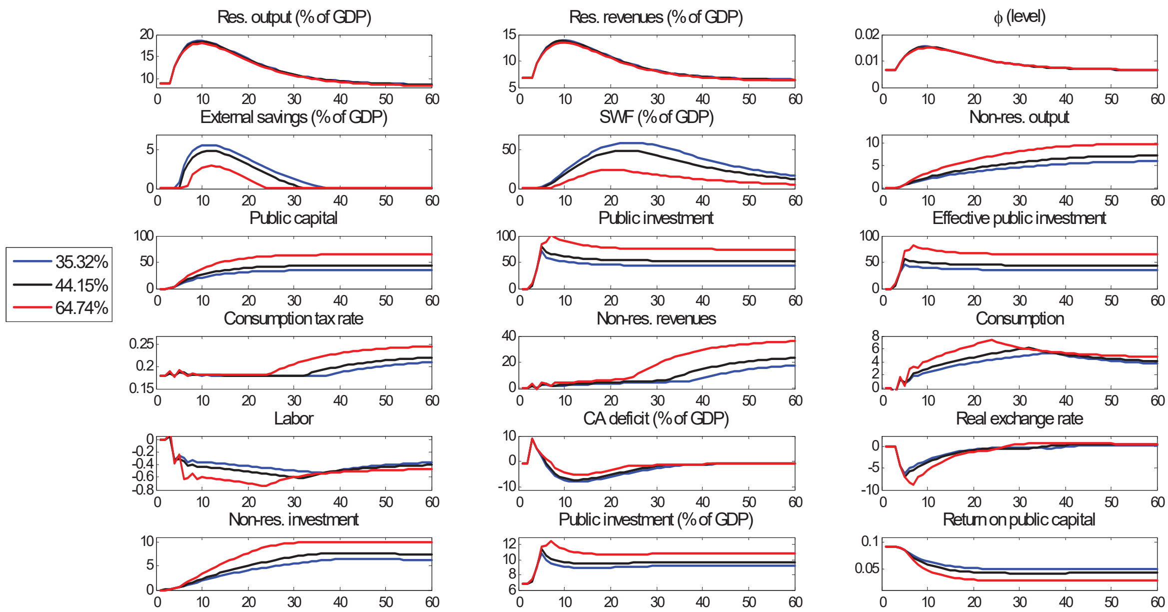
The optimal policy parameters to increase public capital specified by equation (18) are found in two steps. First, the search of welfare-maximizing public capital at a new steady state K^G_{nss} is implemented based on a discounted sum of household's utility. Second, given this optimal level of public capital, the utility-maximizing adjustment speed γ is found over a 100 year period. These two steps are repeated at each absorptive capacity constraint b, which characterizes the tightness of public investment costs in the economy. Technically, the non-linear model is solved in such a way that external savings eventually clear the government budget constraint, and public investment adjusts to avoid an initial hike in consumption tax rate.

Table 1. **Main results** ($\alpha^G = 0.1$)	$b = 0.1$	$b = 0.2$	$b = 0.3$
Effective public investment per $1 invested	0.6613	0.6613	0.6604
Optimal increase of public capital	64.74%	44.15%	35.32%
Optimal adjustment speed	0.16	0.14	0.14
Optimal increase of public investment at new SS	74.4%	52.6%	43.4%
Overshooting magnitude of public investment	102%	79%	71.1%
Overshooting magnitude of effective public investment	81.1%	56.7%	45.2%
Consumption tax rate increase at new SS	39.4%	27.9%	23.2%
St dev of consumption growth over first 10 years	1.36	0.75	0.76
Welfare gain w.r.t. original pre-windfall steady state	3.2%	2.5%	2.1%

The main results are summarized in Table 1. The parameter $b = 0.3$ can be interpreted as $0.6604 effective public investment accumulating public capital per $1 invested. As absorptive capacity constraints become less tight (b declines), the effective public investment per $1 invested increases and the optimal levels of public capital and public investment rise, which are highest at $b = 0.1$. The adjustment speed to reach a new increased level of public capital appears to be at its value which produces an overshooting public investment path that turns out to be optimal across all b. This suggests that front-loaded public investment is preferred thanks to a resource windfall in low-income countries with their capital scarcity and underdeveloped domestic financial market.

In order to finance public investment in the long run, the consumption tax rate has to rise, since the resource windfall is an initial one-period shock. In terms of welfare gain, which is measured as a percentage increase in consumption from the original pre-windfall steady state, the loose absorptive capacity constraint delivers the best outcome. Yet consumption is very volatile in the first several years given the higher magnitude of optimal overshooting public investment at $b = 0.1$.

Figure 1. **Optimal rates of public capital increase**

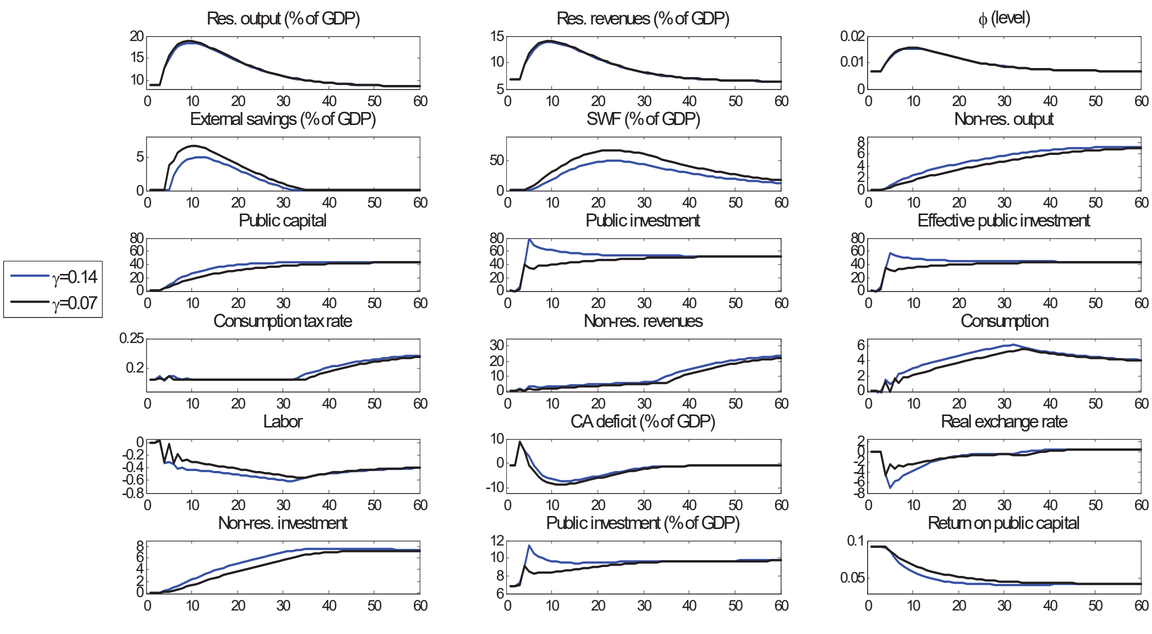


Y-axis is in percent deviation from the initial steady state unless denoted otherwise.

A temporary FDI shock hits the economy in Figure 1, with different absorptive capacity constraints and their respective optimal rates of public capital increase according to Table 1. In response to the shock, a resource output-to-GDP ratio doubles to 18 percent and resource revenues rise to 14 percent of GDP during the next ten years. The saving share of resource revenues ϕ_t, though quite small, yet generates a large increase of external savings in the SWF. A blue solid line depicts the lowest increase of public capital associated with the tight absorptive capacity constraint, and therefore an excess of resource windfall is saved more in the SWF rather than invested domestically. A black dashed line corresponds to the dynamics under $b = 0.2$ as a middle case. A red dotted line, associated with a loose absorptive capacity constraint and thus high accumulation of public capital, shows the welfare preferred case, as it delivers permanently higher consumption and permanently lower labor (higher leisure) than the other two lines.

The consumption tax rate, as a part of non-resource revenues, increases in the later period, since external savings eventually deplete to maintain public investment. The current account deficit initially rises due to a temporal FDI shock, but then declines as resource output and savings in the SWF expand. The magnitude of public capital increase affects the extent of exchange rate appreciation: the more the government invests, the more the exchange rate appreciates. Return on public capital, meanwhile, depends on its availability: capital scarcity generates its higher return and vice versa (the blue solid line versus the red dotted line in Figure 1).

Figure 2. **Different adjustment speed**



Y-axis is in percent deviation from the initial steady state unless denoted otherwise.

Figure 2 compares the impulse-response functions across two adjustment speeds at $b = 0.2$. A blue solid line illustrates the optimal overshooting public investment path ($\gamma = 0.14$), while a black dashed line shows no overshooting dynamics relative to a new steady state level ($\gamma = 0.07$). Consumption and labor under non-optimal public investment appear to be more volatile than they are under a preferable front-loaded policy. In terms of welfare gain, the optimal public investment policy is equivalent to a 2.5 percent increase in consumption from the original pre-windfall steady state, while the non-overshooting path at $\gamma = 0.07$ produces a welfare gain of 1.9 percent.

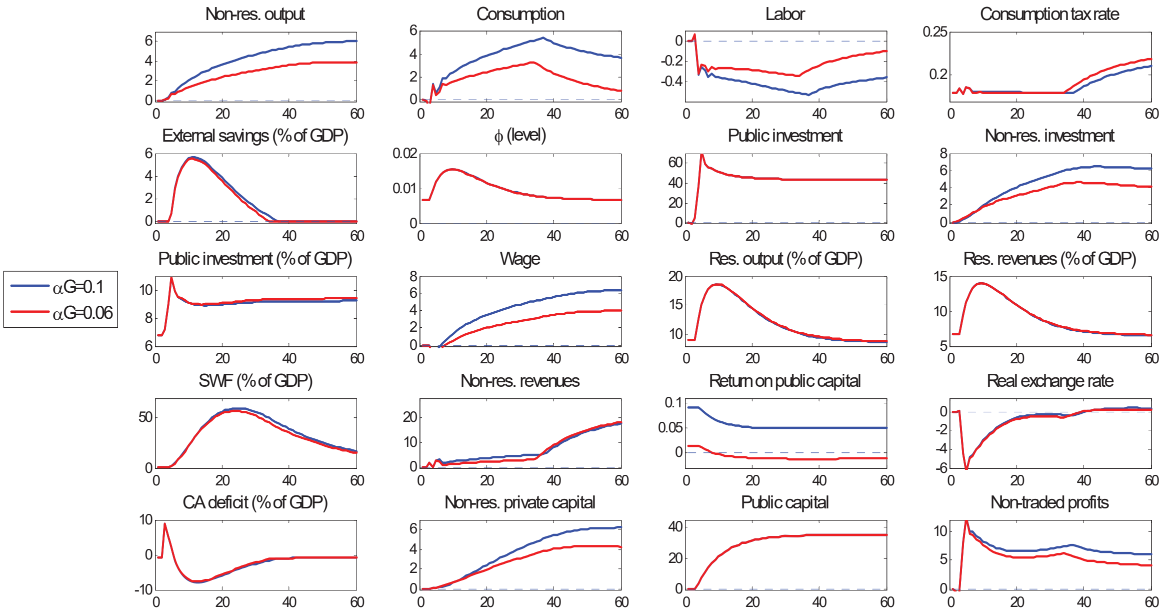
5 Sensitivity analysis

This section examines two cases. Public capital is less productive compared to the baseline model and, thereafter, there is no resource windfall in the first place. If public capital has its output elasticity of $\alpha^G = 0.06$, as opposed to a baseline $\alpha^G = 0.1$, and its return is therefore lower than the SWF's interest rate by 1.23 percentage points, then the government should accumulate less capital, but at a faster adjustment speed (see Table 2). This is because, over time, the return on public capital decreases as it is expanded by public investment; thus, the overshooting public investment path is still preferred. However, relatively volatile consumption takes place at the tight absorptive capacity constraint $b = 0.3$ as opposed to $b = 0.1$ in Table 1. This is because public capital, being less productive, does not need to increase much, but should adjust to that level fast.

Table 2. **Sensitivity analysis:** $\alpha^G = 0.06$	$b = 0.1$	$b = 0.2$	$b = 0.3$
Effective public investment per $1 invested	0.695	0.694	0.694
Optimal increase of public capital	26.1%	20.36%	16.06%
Optimal adjustment speed	0.29	0.28	0.28
Optimal increase of public investment at new SS	27%	21.5%	17.1%
Overshooting magnitude of public investment	59.3%	45.7%	38.4%
Overshooting magnitude of effective public investment	53.7%	39.6%	32.3%
Consumption tax rate increase at new SS	16.3%	13%	10.3%
St dev of consumption growth over first 10 years	0.84	0.91	0.98
Welfare gain w.r.t. original pre-windfall steady state	1.1%	0.9%	0.8%

Figure 3 contrasts the dynamics of a public capital increase by 35.32 percent at $b = 0.3$ according to Table 1 versus its behavior under a reduced output elasticity, $\alpha^G = 0.06$. A solid blue line shows that relatively productive public capital generates more non-resource output, consumption, and wages, since labor also becomes productive allowing households to have more leisure. However, the consumption tax rate is higher in the long run under $\alpha^G = 0.06$, because more tax revenues are needed to finance the same level of public investment, as low output, due to less productive public capital, creates fewer fiscal revenues.

Figure 3. **Different output elasticity of public capital**



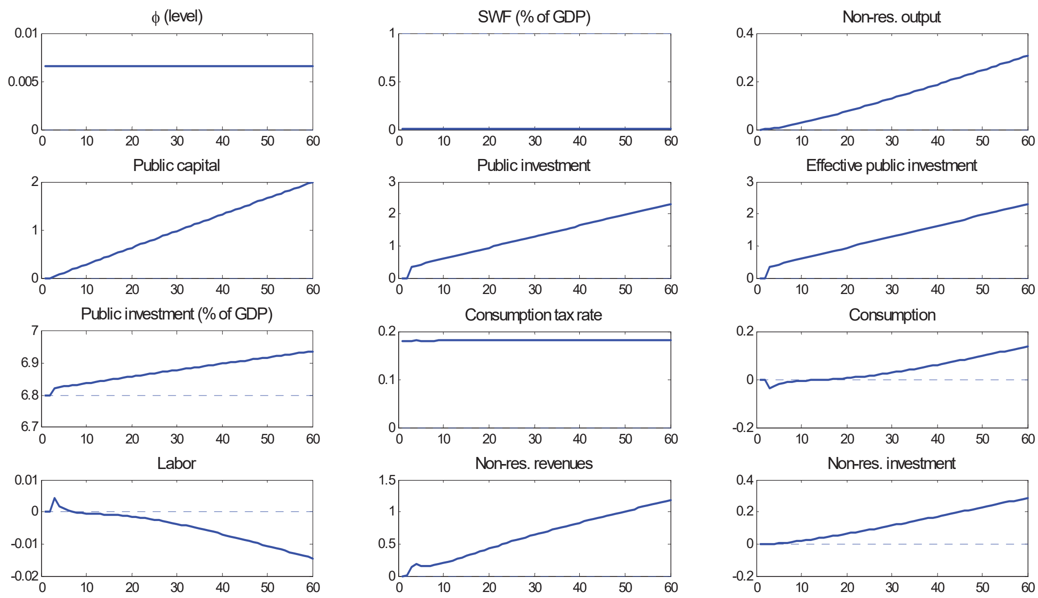
Y-axis is in percent deviation from the initial steady state unless denoted otherwise.

In order to compare the main results with a scenario of no initial resource windfall, a version of zero FDI shock is simulated within the same framework. Table 3 summarizes the results without a resource windfall across different absorptive capacity constraints. The percentage increase of public capital is the same as in the baseline version with FDI shock, but the adjustment speed is significantly lower, suggesting a gradual increase of public investment, instead of its earlier overshooting path, due to the absence of an initial resource windfall.

Table 3. **No resource windfall:** $\alpha^G = 0.1$	$b = 0.1$	$b = 0.2$	$b = 0.3$
Effective public investment per \$1 invested	0.6882	0.6887	0.6888
Optimal increase of public capital	64.74%	44.15%	35.32%
Optimal adjustment speed	0.001	0.001	0.001
Optimal increase of public investment at new SS	41%	28.4%	23%
Consumption tax rate increase at new SS	20.7%	14.3%	11.6%
St dev of consumption growth over first 10 years	0.024	0.017	0.014
Welfare gain w.r.t. original steady state	-0.01%	-0.001%	-0.003%

Negative numbers for welfare gain mean that a scenario of no resource windfall is worse than the original steady state without any increase of public capital. This is due to the absence of external savings as an additional fiscal buffer to finance public investment initially, and the only instrument is consumption tax, which is distortionary for the welfare contributing consumption component.

Figure 4. **Dynamics under no resource windfall**



Y-axis is in percent deviation from the initial steady state unless denoted otherwise.

Figure 4 shows the dynamics of public capital increase by 35.32 percent at $b = 0.3$ with its adjustment speed of 0.001. The saving share of resource revenues ϕ_t is at its constant calibrated value, while the SWF is zero. The gradual scaling up of public investment is financed by a steady increase of the consumption tax rate, which reduces consumption in the beginning and is thus not welfare improving.

Table 4. **No resource windfall:** $\alpha^G = 0.1$, $\beta = 0.98$	$b = 0.1$	$b = 0.2$	$b = 0.3$
Effective public investment per $1 invested	0.6613	0.6613	0.6604
Optimal increase of public capital	64.74%	44.15%	35.32%
Optimal adjustment speed	0.019	0.024	0.024
Optimal increase of public investment at new SS	74.4%	52.6%	43.4%
Consumption tax rate increase at new SS	40.6%	28.75%	23.9%
St dev of consumption growth over first 10 years	0.44	0.38	0.31
Welfare gain w.r.t. original steady state	-0.51%	-0.42%	-0.35%

Table 4 is produced at a higher discount factor $\beta = 0.98$, than the baseline one $\beta = 0.91$, which corresponds to a real interest rate of 2 percent. A high discount factor implies that households are patient and value the future more today, than impatient households with their low discount factor. The former case, giving preferences for savings and investments, suggests a significantly high optimal increase of public investment in Table 4 relative to Table 3, which appears to be identical to the main results with a resource windfall in Table 1. The more households are patient, the more public investment is preferred, but since there is no resource windfall, consumption tax increases to finance the public investment; thus, welfare gain falls more. In other words, under no resource windfall, the economy is worse off than in its initial steady state without any public investment, suggesting that it matters how fiscal expenditures are financed. Commodity-rich economies can benefit and improve their welfare by investing returns from their natural resources domestically, using a front-loaded public investment policy.

6 Conclusion

This paper examines the optimal fiscal policy to accumulate public capital through investing resource revenues domestically rather than saving them abroad in the SWF of resource-rich low-income countries. The model is a modified version of Berg et al. (2013) in several respects: Fiscal policy rule is expressed in terms of public capital as a stock variable, while the public investment path is obtained from capital. The tightness of absorptive capacity constraints is captured by a single parameter b in the equation for effective public investment. External saving is a clearing fiscal instrument rather than distortionary consumption tax, and there is a variable share of resource revenues saved in the SWF as opposed to its fixed share.

This study finds the optimal level of public capital and its adjustment speed to that new increased steady state. The associated optimal public investment path is front-loaded regardless of absorptive capacity constraints and productivity of public capital. Less productive public capital suggests the lower magnitude of increase for capital and public investment, but should move at a faster adjustment speed to its new steady state level. The gradual non-overshooting increase of public investment causes consumption volatility and is not preferred under a no resource windfall either, since the consumption tax becomes the only source for financing fiscal expenditures within this model. To conclude, resource-rich low-income countries can significantly gain from their commodity blessing by prudent public investment policy.

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A Appendix: calibration

Parameter	Definition
$\beta = 0.909$	discount factor
$\sigma = 2$	inverse of intertemporal elasticity of substitution for consumption
$\psi = 10$	inverse of Frisch elasticity of labor supply
$\varphi = 0.5$	home-bias in private consumption
$\nu = 0.6$	home-bias in government purchases
$\nu_g = 0.5$	home-bias in government purchases above the initial steady state
$\chi = 0.44$	elasticity of substitution between T and N goods
$\rho = 1$	elasticity of substitution between two types of labor
$\alpha^T = 0.65$	labor income share in traded sector
$\alpha^N = 0.45$	labor income share in non-traded sector
$\alpha^G = 0.1$	output elasticity of public capital
$\alpha^o = 0.9$	resource capital income share
$d, \rho_{zT} = 0.1$	learning-by-doing externalities
$\kappa^T, \kappa^N = 25$	investment adjustment cost in T and N sectors
$\delta^T, \delta^N, \delta^g, \delta^o = 0.1$	depreciation rates for K^T, K^N, K^G, and K^o
$\epsilon = 0.7$	public investment efficiency
$\iota^{\text{div}} = 0.4$	share of resource dividends accrued to the government
$\tau^c = 0.18$	consumption tax rate
$\tau^l = 0.08$	labor tax rate
$\tau^o = 0.58$	resource royalty rate
$r^* = 0.027$	real interest rate of SWF
$b = 0.1, 0.2, 0.3$	tightness of absorptive capacity constraints
$\phi = 0.0065$	constant share of resource revenues in external savings
$\rho_{FDI} = 0.8$	persistence of FDI process
$\sigma_{FDI} = 6.26$	standard deviation of FDI shock
$\rho_{swf} = 0.956$	AR(1) coefficient in SWF process
$\frac{C}{GDP} = 57.2\%$	consumption in percent of GDP
$\frac{C^T}{GDP} = 28.6\%$	consumption of traded goods in percent of GDP
$\frac{I}{GDP} = 17\%$	investment in percent of GDP
$\frac{Y^o}{GDP} = 9\%$	resource output in percent of GDP
$\frac{G^C}{GDP} = 13.3\%$	public consumption in percent of GDP
$\frac{G^I}{GDP} = 6.8\%$	public investment in percent of GDP
$\frac{G^T}{GDP} = 8.04\%$	government purchases of traded goods in percent of GDP
$\frac{EX}{GDP} = 21.6\%$	exports in percent of GDP
$\frac{B}{GDP} = 11.6\%$	public debt in percent of GDP
$\frac{SWF^*}{GDP} = 1\%$	SWF in percent of GDP