

Budget Rules and Resource Booms

A Dynamic Stochastic General Equilibrium Analysis

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Abstract

This paper develops a dynamic stochastic general equilibrium model to analyze and derive simple budget rules in the face of volatile public revenue from natural resources in a low-income country like Niger. The simulation results suggest three policy lessons or rules of thumb. When a resource price change is positive and temporary, the best strategy is to save the revenue windfall in a sovereign fund, and use the interest income from the fund to raise citizens' consumption over time. This strategy is preferred to investing in public capital domestically, even when private investment benefits from an enhanced public capital stock. Domestic investment raises the prices of domestic goods, leaving less money for government to transfer to households; public investment is not 100 percent effective in

raising output. In the presence of a negative temporary resource price change, however, the best strategy is to cut public investment. This strategy dominates other methods, such as trimming government transfers to households, which reduces consumption directly, or borrowing, which incurs an interest premium as debt rises. In the presence of persistent (positive and negative) shocks, the best strategy is a mix of public investment and saving abroad in a balanced regime that provides a natural insurance against both types of price shocks. The combination of interest income from the sovereign fund, transfers to households, and output growth brought about by public investment provides the best protective mechanism to smooth consumption over time in response to changing resource prices.

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Budget Rules and Resource Booms: A Dynamic Stochastic General Equilibrium Analysis¹

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1 Introduction

The discovery of oil and gas reserves in Ghana, Kenya, Tanzania, Mozambique and other low-income African countries has revived interest in the management of resource windfalls. On one hand, the experience of Africa's traditional resource exporters has been sobering. Despite hundreds of billions of dollars in oil revenues, countries such as Nigeria, Gabon and Angola continue to suffer from high levels of poverty, low human development and a capital stock that is scarcely adequate for the post-oil era. On the other hand, countries such as Norway and Chile, which used strict fiscal rules to ensure that resource windfalls are saved and not subject to the irresistible temptation to spend, have achieved great progress. Yet, there is an argument that poor countries, being capital-scarce, should be investing their resource windfalls domestically rather than saving them abroad.

In this paper, we attempt to resolve these issues by simulating the impact of resource windfalls and policy responses in a model that captures both the implications of current decisions on future growth and welfare, and the uncertainty that is intrinsic to resource prices. We ask: What rules-of-thumb does dynamic stochastic general equilibrium (DSGE) analysis provide about budgetary spending of uncertain and fluctuating resource windfalls, especially in a low-income and newly resource-rich developing country like Niger? In particular, we analyze in the presence of export price uncertainty the economic implications of budget rules associated with public revenue from natural resources in a developing country. We ask how budget rules should be set in countries that are facing spending pressures for social needs in the context of highly volatile mineral revenue. Several low-income developing countries (like Uganda and Niger) are recently emerging as mineral exporters. With low capacity to hedge or stabilize revenue, budget benchmark spending rules are increasingly being used as simple ways to manage and allocate mineral revenue over time. The experiences of Norway for oil and Chile for copper illustrate the outcomes of well-defined fiscal rules. In that setting, Nigeria adopted in 2004 a fiscal rule for oil revenue, whereby any revenues in excess of the benchmark level for budgetary use are transferred into the "Excess Crude Account (ECA)" for future use. The Democratic Republic of Timor-Leste's natural resource fiscal rule, the Petroleum Fund Law, defines the estimated sustainable income (ESI) as 3 percent of the country's petroleum wealth based on an assumed reference price.

Two features are potentially appealing in their applications to developing countries - a well-defined and conservative budget price or spending rule, which is monitored publicly or by stakeholders, may substitute for weak institutions; and transparent mechanisms may make it easier to plan long term, achieving the necessary savings for future generations and guarding against unsustainable consumption in the present.

Even so, when mineral revenue (or the underlying export price) is volatile, reserves are finite, and spending pressures are high, it is still not easy to set the optimal budget rules. Moreover, in practice, they may not be well chosen.

The most common problem associated with resource windfalls is the paradox of plenty - Dutch Disease that has been examined by several authors, among whom, are Corden and Neary (1982), Gelb (1988), Auty (1993) and Collier and Hoeffler (2004). Even so, Sachs and Warner, (1997) and van der Ploeg (2011) suggest both positive and negative outcomes are possible. Botswana, Chile and Norway are often cited as successful cases.

Several studies in recent years point to pathways by which resources can have positive effects on growth. These include: (i) good governance (Mehlum, Moene, and Torvik, 2006), (ii) openness to international trade (Arezki and van der Ploeg, 2012), (iii) countercyclical fiscal rules in the face of volatile mineral revenue (Frankel 2012 and Schmidt-Hebbel, 2012), and (iv) micro instruments or conditional cash transfers such as Progresa and Bolsa Familia in Mexico and Brazil to help poor people cope with income shocks from commodity price fluctuations (Bourguignon 2012).

Other recent studies have also highlighted the practical policy problems of managing resource revenue in developing countries. Collier et al. (2010), Baunsgaard et al. (2012), Benigno and Fornaro (2014), van der Ploeg and Venables (2011), Arezki et al. (2010), Arezki et al. (2012), and Dixon, Kauzi, and Rimmer (2010) are some examples among several others. Alternative prescriptions include policy rules relating to the permanent income hypothesis (PIH), sovereign wealth funds (SWF), and bird-in-hand (BIH). In addition, Collier et al. (2010) argue for scaling up present consumption and investment in low-income countries where the marginal social value of consumption is high in the near term because the country is poor, and where the social returns to investment are high because capital is scarce.

Most of these analyses have been carried out in a deterministic framework or in a partial equilibrium setting when uncertainty has been accounted for. For example, Go et al. (2013), examine the case of Niger under deterministic revenue flows. In this study, we examine in a dynamic stochastic general equilibrium setting the implications of various budget rules for resource windfalls in a developing country in an uncertain environment. For example, by setting a revenue level for budgetary use, a “budget price” of the natural resource is implied and its difference from the prevailing export price defines a level of savings set aside in a sovereign fund for future use or a withdrawal from the fund for immediate spending. We use, as a case study, the economy of Niger that has recently joined the club of low-income mineral exporter countries.

We develop a simple dynamic stochastic general equilibrium model of the economy of Niger. We build upon recent contributions to the vast and rich literature of DSGE models that have been applied mainly to developed economies and upon the modeling lessons learned from the analysis of the Dutch disease in the static and dynamic CGE literature. More recently, DSGE models have also been applied to policy issues of developing countries, including resource rich countries (see, for examples, Berg et al. 2013, Berg et al. 2012, and Melina et al. 2014). In our study, we extend the well-established 1-2-3 CGE model, a small economy in a dynamic setting, to incorporate uncertainty. The 1-2-3 CGE model, which is a 1 country, 2 producing sectors and 3 goods model, was initially developed in a static framework and has been used to analyze several issues in small open economies by Devarajan, Lewis, and Robinson (1990, 1993) and Devarajan et al. (1997). It has later been extended to incorporate dynamics in a deterministic setting by Devarajan and Go (1998). Our methodology incorporates DSGE analysis to the 1-2-3 model, with the following features: it keeps both the microeconomic foundations of the dynamic analysis and the consistency in the circular flow of incomes and expenditures at every point in time; and it uses a solution strategy that avoids linearization. In addition to introducing uncertainty in the model, we consider productive government spending, whereby public capital affects the productivity of private inputs. We are then able to assess the macroeconomic dynamics of stochastic shocks to resource windfalls in Niger and trace the impulse or time responses of macroeconomic aggregates such as output, consumption, investment, exports, imports, government revenue and balances, real exchange rate, and debt.

The remainder of the paper is organized as follows. We present the model specification in the next section and discuss the data, calibration and solution strategy in the third section. The simulation results are presented in the fourth chapter followed by the conclusions in the last section.

2 The model

2.1 Overview

The model extends the dynamic 1-2-3 (D123) model presented in Devarajan and Go (1998), which considers one country, two sectors, the tradable and non-tradable sectors, and three goods, the domestic good, the export good and the import good. We introduce three new features that make it possible to analyze the impact of uncertainty on the price of natural resources in the economy. First, we split the exports into two goods: traditional exports and natural resource exports. Second, we distinguish two types of capital – private and public. And third, we introduce uncertainty in the model by incorporating the stochastic process of world

price of the natural resource in the decision making of economic agents. Hence, the model becomes a DS1234 model: a dynamic and stochastic model of one country, with two types of capital, three producing sectors, and four goods. The separation of public and private capital permits the government to use the mineral revenue to raise consumption through transfers to households or increase future output through public investment in infrastructure. The three sectors produce the domestic good, which is not exported, the traditional export good and the natural resource export good that are not consumed domestically. The fourth good is represented by the import good, which is not produced domestically.

We consider a small-open economy that consists of four economic agents: the representative firm, the representative household, the government, and the rest of the world (ROW). There are two sectors producing the tradable good and the non-tradable good, and there are four goods, which are the domestic good, the import good, the traditional export good, and the natural resource export good. The domestic good is produced and consumed domestically; the two export goods are produced in the country and are entirely exported; while the import good is consumed in the country but not produced locally. Output is produced using labor and private physical capital. In contrast to the original D123 model, we assume that public capital generates an externality in production and its level affects the productivity of private inputs.

The economy is small in the sense that it takes world prices of the import and export goods as given. Domestic economic agents have access to the world financial market where they can borrow on the international market with a debt-elastic interest rate premium as in Schmitt-Grohé and Uribe (2003). The main justification for introducing the latter assumption of an interest rate premium, which is sensitive to the debt level, is to ensure the independence of the deterministic steady state from initial conditions.

The representative household's portfolio consists of two assets: shares of domestic assets and foreign assets. It values leisure, supplies labor to firms, receives dividends from domestic firms, transfers from the government, and net transfers from the rest of the world. It pays income taxes, consumes goods and saves. The goods produced by the representative firm are used for final demand purposes only. There is no intermediate input in the model; as such, gross output is identical to GDP. Households and firms decisions are endowed with forward-looking behavior: their current decisions are affected by expectations on future period variables or policy parameters.

The government levies taxes on economic activities, on factor incomes and on transactions; it consumes goods, invests in public capital, enacts transfers to households, and

has the option to invest part of its revenue in a sovereign wealth fund that yield an interest rate. The government invests in public infrastructure, whose stock affects the productivity of private inputs. Both firms and households take the government policy variables and the stock of public capital as given. The government does not issue domestic or foreign bonds and it is constrained to follow some fiscal rules that will be discussed later. Since we abstract from government debt to finance its spending, we assume that the private sector (the representative household) is responsible for the foreign debt. We consider various government budget rules in a dynamic setting that would make it possible to answer the specific questions raised in the introduction.

We abstract from the exogenous long-run growth rate of the economy; we make the model stationary by de-trending all quantity variables by expressing them in per efficiency units.

2.2 Households

Consider a small open economy inhabited by a continuum of identical households with unit mass. The representative consumer has preferences over consumption and leisure. In each period, it has one unit of time that can be devoted to work (H_t) and leisure. Its preferences are represented by a time separable utility function U_0 :⁶

$$U_0 = E_0 \sum_{t=0}^{\infty} \left(\frac{1}{1+\rho} \right)^t u(C_t, H_t) \quad (1)$$

where C_t is aggregate consumption, H_t is labor supply, and ρ the time preference parameter. We consider a CRRA (constant relative risk aversion) specification for the period utility function $u(C_t, H_t)$ with the following representation:

$$u(C_t, H_t) = \frac{1}{1-\sigma} C_t^{1-\sigma} + \frac{\mu}{1-\psi} (1-H_t)^{-\psi} \quad (2)$$

where σ is the inverse of the intertemporal elasticity of substitution and ψ is a parameter

⁶ It is possible that liquidity constraints in a poor country like Niger would limit consumption smoothing, making consumption more directly responsive to current income. However, the emergence of resource wealth also presents a significant departure and opportunity to conduct optimal intertemporal decisions through a sovereign wealth fund even in a low-income country. With more income or in high income countries, the permanent income hypothesis is generally supported by studies such as Campbell and Mankiew (1989); Shea (1995) also found that liquidity constrains does not seem to affect consumption behavior in households with no liquid assets relative to those with liquid assets.

linked to the Frisch labor supply elasticity⁷, and μ is the leisure weight in the utility function. The representative household derives income from wages, returns on assets, government transfers TR_t and foreign remittances, FR_t . Its financial assets, F_t , which are remunerated at the debt-elastic interest rate. Households pay taxes on consumption, on labor income, and on dividends received from domestic firms.

The representative household maximizes expected intertemporal utility subject to a sequence of period budget (3) constraints while respecting a transversality condition.

$$F_{t+1} = (1 + r_t)F_t + (1 - \tau_{YL})W_tH_t + TR_t + ER_tFR_t \quad (3)$$

$$-\tau_k Div_t - (1 + \tau_c)PC_t C_t \quad (4)$$

$$\lim E_t \frac{F_{t+1+j}}{\prod_{s=1}^j (1 + r_s)} \leq 0 \quad (5)$$

The parameters τ_{YL} , τ_c , and τ_k are respectively, the labor income tax rate, consumption tax rate, and the tax rate on dividends. W_t , PC_t , ER_t , and Div_t are respectively the wage rate, the price of consumption good, the currency conversion factor (nominal exchange rate) and the dividends received from firms, r_t , is the sum of the value of the domestic firm and the net liabilities of the private sector to foreigners (private foreign debt). The currency conversion factor is in units of domestic currency per unit of foreign currency.

Solving the optimization problem makes it possible to determine the expected optimal paths of consumption and leisure. The first-order conditions of household optimization problem are the consumption Euler equation (6), the period budget constraints (7) and the contemporaneous arbitrage condition between leisure and consumption (8).

$$\frac{1}{C_t} = E_t \left[\frac{1}{C_{t+1}} \frac{(1 + r_{t+1})}{(1 + \rho)} \frac{PC_t}{PC_{t+1}} \right] \quad (6)$$

⁷ In our specification, μ is not exactly equal to the inverse of the Frisch labor supply elasticity.

$$F_{t+1} = (1+r_t)F_t + (1-\tau_{YL})W_tH_t + TRG_t + ER_tFR_t - (1+\tau_c)PC_tC_t - \tau_kDIV_t \quad (7)$$

$$\mu(1+\tau_c)PC_tC_t^\sigma = (1-\tau_{YL})W_t(1-H_t)^\psi \quad (8)$$

The representative household determines the optimal path of consumption spending, which is then allocated within each period between the domestic good and the import good. At the margin, the representative household allocates aggregate consumption between two consecutive periods such that an increase in expected real interest rate in comparison to the rate of time preference penalizes current period's consumption at the benefit of the expected value of next period's consumption. The expected real interest rate depends on the exogenous interest rate and the change in the price of aggregate consumption, which is a composite of the domestic good price and the import good price. Following a terms-of-trade shock, changes in the price of domestic good for example will have an impact on expected real interest rate and induce a change in the path of aggregate consumption. Moreover, a change in the debt-elastic interest rate will induce the same effect. It can be shown that in each period, the level of the aggregate consumption depends on the household's expected total wealth, which is the sum of its expected financial wealth and its expected human wealth. It is important to note that the financial wealth of the representative household is equal to the value of domestic firms less the value of net liabilities by the private sector to foreigners.

In each period, aggregate consumption is allocated between the domestic good and the import good through expenditure minimization. Without loss of generality, we assume that the composition of aggregate consumption is identical to those in other components of the domestic absorption. The latter is the sum of household and government consumption, private and public investment. In other words, we assume that in each period, domestic absorption is a (constant elasticity of substitution) CES aggregate of the domestic good and the import good. At the margin, an increase in the relative price of domestic good will reduce the ratio of the demand for the domestic good to the import good.

2.3 The representative firm

We consider a joint production technology of output which is the composite of the domestic good and the two export goods. The composite good, XTS_t , is produced by means of Cobb-Douglas production function by combining private capital, K_t , and labor, LD_t . The level of public capital generates an externality in production as its level, KG_t , affects the productivity

of both private inputs. As mentioned earlier, firms take the level of public capital as given in their decisions.

$$XTS_t = AV(KG_t)^{\alpha_G} (K_t)^{\alpha_V} (LD_t)^{1-\alpha_V} \quad (9)$$

where AV is total factor productivity parameter and $0 < \alpha_G < 1$ is the output elasticity of public capital.

In each period, the level of capital stock is predetermined by past investment decisions, through the capital accumulation equation, which is characterized by a constant rate of depreciation of capital, δ .

$$K_{t+1} = (1-\delta)K_t + I_t \quad (10)$$

The representative firm funds its investment expenditures out of retained earnings and pays dividends to the representative household. Total investment, J_t , includes installation costs, since private capital accumulation is subject to adjustment costs that are foregone output linked to investment decisions. We consider a quadratic adjustment cost function which is linearly homogeneous in I_t and K_t , hence the following specification for total investment function:

$$J_t = I_t \left(1 + \frac{\beta}{2} \frac{I_t}{K_t} \right) \quad (11)$$

where β is a positive adjustment cost parameter. The installation costs help to capture the fact that the capital stock cannot instantaneously reach its desired level, and hence their presence contributes to reducing the volatility of investment that would otherwise occur in their absence. It follows that labor input and investment decisions are the two decision variables that must be determined by the representative firm in each period in order to determine the aggregate level of output.

The economy is subject to a stochastic shock to the world export price of natural resources. We assume that the world price of natural resource exports follows an autoregressive $AR(1)$ process with a persistence parameter ρ_Z and with identically, independently distributed disturbances ε_t :

$$PWEXR_t = \overline{PWEXR} \cdot \exp(Z_t) \quad (12)$$

$$Z_{t+1} = \rho_Z Z_t + \varepsilon_{t+1}; \quad \varepsilon_{t+1} : NID(0, \sigma_\varepsilon^2) \quad t \geq 0 \quad (13)$$

where \overline{PWEXR} is the steady-state level of the resource export price. These shocks affect the representative firm's decisions, and hence factor prices and domestic good price, with some repercussions on household and government decisions. After determining the expected optimal time profile of its output, the representative firm decides upon its allocation in each of the three markets depending on their relative price.

Intertemporal decisions

The objective of the representative firm is to maximize the expected value of the discounted sum of current and future cash-flows subject to a capital accumulation equation in the presence of adjustment cost, and a transversality condition, in order to determine optimal path of decision variables (labor and investment).

$$\max V_0 = E_0 \sum_{t=0}^{\infty} \prod_{s=0}^{t-1} \left(\frac{1}{1+r_s} \right)^{t-s} Div_t \quad (14)$$

$$s.t. \quad K_{t+1} = (1-\delta)K_t + I_t$$

where Div_t and $PXTS_t$ are respectively the dividends paid to households and the price of the composite output. The first order conditions of the firm's problems are as follows:

$$W_t L D_t = (1-\alpha_V) P X T S_t X T S_t \quad (15)$$

$$(1+n)K_{t+1} = K_t(1-\delta_K) + I_t \quad (16)$$

$$Q_t = \left[1 + \beta \frac{I_t}{K_t} \right] P C_t \quad (17)$$

$$\begin{aligned} Q_t(1+r_t) = & E_t \left((1-\tau_p) P X T S_{t+1} R K_{t+1} \right) + E_t (1-\delta_K) Q_{t+1} \\ & + E_t \left(P C_{t+1} \left(\frac{\beta_{KV}}{2} \right) \left(\frac{I_{t+1}}{K_{t+1}} \right)^2 \right) \end{aligned} \quad (18)$$

$$RK_t = \frac{\alpha_v XTS_t}{K_t} \quad (19)$$

$$DIV_t = (1 - \tau_p) PXTS_t RK_t - PC_t J_t \quad (20)$$

where Q_t , RK_t and τ_p are respectively the shadow price, the marginal productivity of private physical capital and the output tax rate. At the margin, the optimal level of labor will be determined in each period by setting its marginal product to the wage rate (15). Current period investment is determined using the Q-theoretical rule, i.e., the optimal level of investment is determined such as to equalize the marginal cost of investing to the shadow price of capital (17). Expressions (18), (19) and (20) are respectively the motion equation of the shadow price of private capital, the marginal product of private capital and the dividend paid to the households. Once the optimal levels of labor, investment (hence the level of capital), the optimal level of the composite output can be determined.

Intratemporal decisions

We assume that the transformation of the composite good into the domestic good or the export good is costly, in the sense that there exists a concave transformation curve of the composite good into its two components. Namely, we consider a constant elasticity of transformational function (CET) between the composite output XTS_t and sales in the domestic market, XDS_t , traditional exports EXT_t and exports of natural resources, EXR_t . Once the optimal level of the composite output is known, its allocation in the three markets can be determined through revenue maximization subject to the technological constraint. The first-order conditions of this maximization problem are the following:

$$PXTS_t = \left(\begin{aligned} &(\delta_{XT})^{\sigma_X} (PEXT_t)^{+\sigma_X} + (\delta_{XR})^{\sigma_X} (PEXR_t)^{+\sigma_X} \\ &+ (1 - \delta_{XT} - 1 - \delta_{XR})^{\sigma_X} (PD_t)^{+\sigma_X} \end{aligned} \right)^{\frac{1}{1+\sigma_X}} \quad (21)$$

$$EXT_t = (AX)^{(-1-\sigma_X)} XTS_t \left(\frac{PEXT_t}{\delta_{XT} PXTS_t} \right)^{\sigma_X} \quad (22)$$

$$EXR_t = (AX)^{(-1-\sigma_X)} XTS_t \left(\frac{PEXR_t}{\delta_{XR} PXTS_t} \right)^{\sigma_X} \quad (23)$$

$$XSD_t = (AX)^{(1-\sigma_X)} XTS_t \left(\frac{PD_t}{(1-\delta_{XT} - \delta_{XR}) PXTS_t} \right)^{\sigma_X} \quad (24)$$

where $PEXT_t$, $PEXR_t$ and PD_t , are respectively the prices of the traditional export good, the natural resource export good and the domestic good. AX , σ_X , δ_{XT} , and δ_{XR} are, respectively, the shift parameter, the elasticity of substitution, and the weights of traditional exports and resource exports in the CET function. At the margin, an increase in the relative price of any of the component of the composite output induces an increase of its supply at the expense of the other components.

Hence, in our model, changes in the export price of the natural resource will also affect its export supply, which is endogenous (not fixed) and responsive to relative prices in our CET function; the supply of the other two goods are likewise affected by the changes in the relative prices along the process. As the resource export price is volatile, so too is the export volume of the mineral resource, which adds another source of uncertainty in the stochastic dynamics.

2.4 The government

In each period, the government derives revenue, YG_t , from current taxes on output, consumption, dividends, labor income, imports, from transfers received from the ROW and from royalties on the exports of resources (26). The royalties are on an ad valorem basis, and as in (Berg et al. 2013) we assume that for its regular revenue, YG_t , the government does not consider the current value of the royalties, but their steady-state value. Hence, the difference between the current and the steady-state values of the royalties is considered as a windfall, WF_t . We consider four regimes described below for the use of the windfall by the government. It is important to note that in a given year the windfalls could be negative if the current value of the royalties is lower than their steady-state level. With the small-country assumption, the royalties creates a wedge between the world price and the price received by the producer as shown in the following equation:

$$PEXR_t(1+\tau_{EXR}) = ER_t.PWEXR_t \quad (25)$$

where τ_{EXR} is the royalty rate, and $PEXR_t$ is the producer price of the resource export good.

The expressions of government revenue, YG_t and of the windfall WF_t are as follows:

$$\begin{aligned}
YG_t = & \tau_p PXTS_t XTS_t + \tau_c PC_t Ct + \tau_k DIV_t + \tau_l W_t LS_t \\
& + \tau_m PWM_t M_t + \tau_{EXR} \overline{PEXR.EXR} \\
& + ER_t TROWG_t
\end{aligned} \tag{26}$$

$$WF_t = \tau_{EXR} \left(PEXR_t . EXR_t - \overline{PEXR.EXR} \right) \tag{27}$$

Regular government expenditures in each period consist of the current value of its initial steady-state real total expenditures on consumption and investment goods (\bar{G}). Its value changes from year to year because of the changes in prices. We assume that \bar{G} is a Leontief function of government steady-state consumption, \bar{G}^c , and investment in public infrastructures, \bar{G}^i , (28). In addition to the steady-state level of investment in public infrastructure, depending on the fiscal regime considered, the government may use part of the windfall, WF_t^{inv} , to fund additional investment in public infrastructure as described in Equation (29). The evolution of the stock of public capital, which appears in the production function, is described in Equation (30). The parameter $0 < \xi < 1$ captures the inefficiency of public investment.

$$\bar{G} = \min \left[\frac{\bar{G}^c}{a^c}; \frac{\bar{G}^i}{a^i} \right] \tag{28}$$

$$INVG_t = \bar{G}^i + \frac{WF_t^{inv}}{PC_t} \tag{29}$$

$$KG_{t+1} = \xi INVG_t + (1 - \delta_G) KG_t \tag{30}$$

In each period, the government transfers to households, its balance, TR_t , which is the difference between its revenue and its expenditures (31). The right-hand side of Expression in (31) has a third component, WF_t^r , which may differ from zero depending on the fiscal rule used, in which the government may transfer part of the windfalls to households.

$$TR_t = YG_t - PC_t \bar{G} + WF_t^{tr} \quad (31)$$

2.5 Imports, current-account, equilibrium conditions and dynamics

On the demand side, we assume that domestic users consume a composite good made of the domestic good, XDD_t and the import good M_t . We define domestic absorption, XT_t , as the sum of household, government and investment demands as in (32). As discussed earlier, we assume that all components of the domestic absorption have the same preferences over XDD_t and M_t . We assume that domestic absorption is a CES aggregate of XDD and M . A cost-minimization rule makes it possible to determine the optimal allocation of the domestic absorption between its two components. The first-order conditions of this problem give the price of the composite consumption good (33), the demand for domestic good (36) and for the demand for import (34), where δ_M , σ_M and AM are respectively, imports weight, substitution elasticity and shift parameter in the CES aggregate of domestic good and imports. PM_t , PWM_t and τ_M are respectively the price of imports gross of the import taxes in the domestic currency, the world price of imports in foreign currency and the import tariff rate.

$$XT_t = C_t + \bar{G}_t + J_t \quad (32)$$

$$PC_t = \frac{1}{AM} \left((\delta_M)^{\sigma_M} (PM_t)^{-\sigma_M} + (1 - \delta_M)^{\sigma_M} (PD_t)^{-\sigma_M} \right)^{\frac{1}{\sigma_M}} \quad (33)$$

$$M_t = AM^{(\sigma_M - 1)} XT_t \left[\frac{\delta_M PC_t}{PM_t} \right]^{\sigma_M} \quad (34)$$

$$PM_t = ER_t \cdot PWM_t (1 + \tau_M) \quad (35)$$

$$XDD_t = AM^{(\sigma_M - 1)} XT_t \left(\frac{(1 - \delta_M) PC_t}{PD_t} \right)^{\sigma_M} \quad (36)$$

$$FSAV_t = PWM_t M_t - PWEXT_t EXT_t - PWEXR_t EXR_t$$

$$-(FR_t + TROWG_t) + WF_t^{fsav} \quad (37)$$

$$(1+n)BF_{t+1} = (1+r_t)BF_t + FSAV_t \quad (38)$$

$$r_t = r^* + \chi \left(\frac{BF_t - \overline{BF}}{\overline{BF}} \right) - 1, \quad (39)$$

Foreign saving which is the current account deficit (37) is the difference between the trade deficit and the transfers received from the rest of the world by households and the government. A third component, WF_t^{fsav} , related to the use of the windfalls is added to foreign saving. Its value depends on the fiscal rule considered as mentioned in equation 37.

2.6 Fiscal rules

Four different fiscal regimes are considered for the use of the windfall, WF_t :

1. Regime 1 - (All-consuming approach): the resource windfall, is completely transferred to households for consumption. This is technically an all-transferring case as households will save a portion for investment, but the effect is to raise consumption.

2. Regime 2 - (All investing approach): the resource windfall is completely used for public investment in addition to the steady-state public investment

3. Regime 3 - (All savings approach): the resource fund is entirely invested abroad in a sovereign wealth fund, SWF_t ; the interest generated by the fund is entirely transferred to households for consumption. Note that a negative value for the sovereign wealth fund is equivalent to a debt held by the government.

4. Regime 4 - (The balanced approach): A fixed share ϕ of the windfall is invested in the sovereign wealth fund (SWF_t) and the remainder ($1-\phi$) is invested in public infrastructure. The interest generated by the sovereign fund is returned to households.

Regimes 1 and 2, All-consuming and All-investing, are the more aggressive spending strategies to raise consumption or investment, respectively. Collier et al. (2010) argues that the social discount rate is likely high in low income countries like Niger because of the low level of consumption and the scarcity of capital. Hence, spending should be higher in the present. Regime 3 is the conservative spending strategy, similar to the Bird-in-Hand rule in the recent literature (see Go et al. 2013), where the windfall is not valued until it is banked and only the interest income is spent, in this case only for consumption through household transfers. Regime 4 is a compromise between regimes 2 and 3.

Table 1: Values of key variables in the four fiscal regimes

	WF_t^{inv}	WF_t^{tr}	SWF_{t+1}	WF_t^{fsav}
Regime 1- All transferring	0	WF_t	0	0
Regime 2- All investing	WF_t	0	0	0
Regime 3- All wise	0	$r_t SWF_t$	$SWF_t + WF_t$	$WF_t - r_t SWF_t$
Regime 4 - Balanced	$\frac{(1-\phi)WF_t}{PC_t}$	$r_t SWF_t$	$SWF_t + \phi WF_t$	$\phi WF_t - r_t SWF_t$

The values of WF_t^{inv} , WF_t^{tr} , WF_t^{fsav} , and SWF_{t+1} in each of the four rules are presented in table

1. WF_t^{inv} is the value of additional public investment resulting from the use of the windfalls. WF_t^{tr} is the value of transfers to households resulting from the use of the windfalls. SWF_{t+1} is the stock value of the sovereign fund resulting from the use of the windfalls. WF_t^{fsav} is the additional component of foreign saving resulting from the use of the windfalls

The motion equation of foreign debt is presented in (38) and following Schmidt-Grohé and Uribe (2003) the sensitivity of interest rate to the deviation of foreign debt from its steady state value is presented in (39). The domestic interest rate is the risk-free world interest rate plus a premium that increases with the deviation of the debt level from its steady-state value. The currency conversion factor is treated as *numeraire*.

A competitive equilibrium of this economy is represented by allocations of quantity and price variables such that households and firms maximize their respective objective functions, the government satisfies its budget constraint and all markets clear in each period. Equations (40, 41) represent the equilibrium conditions in the domestic good market, the labor market. Equation (42) is an identity which represents the stock version of a saving-investment identity. Household financial wealth is the difference between the value of the firm, WK_t , and foreign

debt, BF_t . As shown in (Hayashi, 1982), the value of the firm is defined as the expected value of product of the shadow price of capital in period t and the capital stock in period $t+1$, (43).

$$XSD_t = XDD_t \quad (40)$$

$$LD_t = H_t \quad (41)$$

$$F_t = WK_t - BF_t \quad (42)$$

$$WK_t = E_t Q_t K_{t+1} \quad (43)$$

2.7 Steady State conditions

In the steady state, all prices and quantity variable expressed per efficiency unit of labor are constant steady state conditions for the shadow price of private capital, household financial wealth, firm value, and foreign debt

$$Q_t(\delta_K + r_t) = PXTS_t RK_t + PC_t \left(\frac{\beta_{KV}}{2} \right) \left(\frac{INV_t}{K_t} \right)^2 \quad (44)$$

$$INV_t = \delta_K K_t \quad (45)$$

$$(n - r^*)F_t = (1 - \tau_{yh})W_t LS_t + TRG_t + ER_t TROW_t \quad (46)$$

$$-PC_t C_t - \tau_k DIV_t$$

$$WK_t = Q_t K_t \quad (47)$$

$$(n - r_t)BF_t = FSAV_t \quad (48)$$

The dynamics of the model is represented by the evolution of state variables whose current values are determined by past conditions, and by jumping variables whose current values are determined by future conditions.

2.8 Data, calibration and solution strategy

As is common in the DSGE literature, we calibrate the model parameters to match the

first moments of various variables of the economy that is assumed to be in a steady state. All quantity variables are presented in per efficiency unit of labor, and the time endowment adjusted for technological progress is normalized to unity. Without loss of generality, the exogenous rate of growth of the economy is ignored; it is set to zero. In the deterministic steady state, all real variables and prices are thus constant. Table 2 presents some key characteristics of the economy in the initial steady state.

In the steady state, the share of resource sector in GDP is only 6.2%, while that of traditional export is 13.8%. Still, according to various outlooks, the resource sector is expected to increase its share in GDP in the future. The calibration approach amounts to using the first-order conditions and the variable means to recover the values of some behavioral parameters to reproduce the deterministic steady state. Still, because of the functional forms used, not all parameters can be recovered. The values of some parameters, like elasticities, must be supplied externally. Following the common practice, by appropriate choice of unit, we set the consumption price, the price of the domestic good, the producer prices of traditional exports and resource exports, and the price of imports gross of taxes to one. Hence, the volume of the variables associated to these prices can be consequently computed using data on the first moments. The various tax rates are computed using the tax revenue and the tax bases. The other prices that are associated with taxes are thus calibrated using the computed tax rates.

The subjective discount factor in the utility function is set to 0.945. This implies a value of 5.8% for the premium-free world interest rate in the steady state, which is well comparable to the values between 4-6% used in many studies. We assume that the representative households devote 30% of their time to work, which leads to a value of 0.3 for labor supply in the steady state. This value is in line with those used in other studies on African countries. There is not much data on capital depreciation and investment function parameters in developing countries. We elect to use the value of 0.1 is for the depreciation rates of private and public capital. This value is higher than the common value of 0.05 found in the literature on developing countries.

Moreover, as in most studies, we set the adjustment cost parameter, β , in Equation 11, which is the sensitivity of investment to Tobin's Q, to 2. There is no consensus on the exact value of the output elasticity of public capital. We follow the value used by Berg, et al (2013) in their study on African countries and set the value of that elasticity to 0.11. Along the same line, the effectiveness parameter of public investment is set to 0.5 as in Berg, et al (2013). That value is close to the high side of the estimates found in the literature for that parameter, which vary between 0.35 and 0.5, as mentioned by Pritchett (2000) for sub-Saharan countries. Khan and Kumar (1997) also found that the rate of return is higher for private capital than public capital

and the implied elasticity of growth to capital is around 0.38 and 0.23, respectively. Moreover, the elasticity of public capital in low income regions like Africa can be higher than average, but it is still lower than that of private capital and the implied elasticity still ranges from 0.2 to 0.5 across different time periods. Using 3SLS system approach, Agénor (2013) recently estimated the direct elasticity of output with respect to public infrastructure to be around 0.1; however, accounting for indirect transmission channels will raise the general equilibrium value to only 0.25. Given these studies, 0.5 is on the optimistic side of the effectiveness of public investment.

There is no precise figure for the value of the intertemporal elasticity of substitution of consumption. Referring to the econometric estimate for Niger provided in Ogaki et al. (1996), we use 0.36 for of the intertemporal elasticity of substitution. We calibrate the parameter ψ in the utility function using the value of 0.25 for the Frisch labor elasticity. As noted earlier, ψ is not the inverse of Frisch labor elasticity in our functional form. We calibrate the value of ψ to 9.33. Using the first order condition arbitrage between consumption and leisure, we calibrate the value of leisure weight in the utility function, μ to 0.103. From the value of private investment demand in final demand (gross of adjustment cost), we use the steady state relationship to derive the value of investment INV_t that effectively increases private capital stock. We then use the steady state relation between investment and private capital to find the value of the stock of private capital K_t . We use a similar method, i.e., the steady state relationship to calibrate public capital stock from the level of public investment in final demand.

Using the calibrated values of private investment and capital stock, we then find the value of the shadow price of capital, which makes it possible to compute the value of the firm. We make use of Equation (18) and we calibrate the value of marginal product of capital, which we then multiply by the value of the volume of capital stock to compute the return to capital. We subtract the return to capital from GDP to find the return to labor, which we use to calibrate the wage rate given the above-defined value of labor supply. Given the level of foreign saving, we compute the level of private foreign debt that is compatible with the steady state condition, which we use in combination with the value of the firm to calibrate household financial wealth. The dividend received by households is computed using Expression (20). Domestic sales are computed as the difference between the value of output and the total values exports.

As in Devarajan and Go (1998), we set the elasticity of substitution in the Armington and CET functions to, respectively, 0.5 and 0.6, which are consistent with the estimates for many low-income countries in Devarajan et al. (1999). The weight of imports in domestic absorption is calibrated to 0.202. There are no precise figures on the sensitivity of interest rate to the

deviation of foreign debt to its steady state level; we set it to 0.0045 to generate reasonable changes to the interest rate following shocks to resource prices. Schmidt-Grohe and Uribe (2003) use a smaller value (0.000742) so that their model generates the observed volatility in the current-account-to-GDP ratio following term-of-trade shocks. The list of the model parameters and their values are provided in Table 3.

Finally, we set the persistence parameter of the shock to resource export price to 0.88 and its standard deviation to 0.13. Recall here that the resource export encompasses mainly the oil and uranium exports in Niger. We could not find in the literature any estimates on the parameters of the stochastic processes of the combined exports of oil and uranium. We believe to the values chosen for these parameters are realistic, since the individual estimates of the persistent parameters found in the literature vary significantly.

Due to its complexity, there is no analytical solution to this model. We resort to numerical solution.

In reality, the model is a system of nonlinear equations containing difference equations. We use the deterministic extended path method of Fair and Taylor (1983) as suggested in Gagnon (1990). We make use of the static and dynamic first-order conditions discussed earlier, and solve the model as a two-boundary-value problem. Referring to Adjemian and Juillard (2010) the main strategy of the extended path method is to use a solver designed for perfect foresight model to solve stochastic forward-looking models, by treating, in each period, contemporaneous innovations as surprise shocks and setting their expected value to zero in all future periods. With that respect, the method neglects the Jensen inequality and introduces therefore some inaccuracies, which are however less dramatic than those introduced through linearization that neglect the deterministic non-linearities present in the model.

In a comparison of numerical methods for solving standard business cycle models, Heer and Maußner (2008) find that the extended path approach is an accurate method. In another interesting comparison of methods to solve stochastic forward-looking models, Love (2010) finds that the relative performance of deterministic extended path is superior to that of log-linearization methods often found in the literature. Its other advantage is that it can handle large models very well in comparison to other methods.

3 Simulations

We examine four spending regimes corresponding to the four fiscal rules described in the model above. In order to look at the implications of the stochastic behavior of the resource

price, each of the four regimes is not associated with a specific forecast or deterministic path of the price of the resource export. Instead, we analyze and emphasize the impact of a temporary shock to that price.

The stochastic revenue windfalls in the simulations emanate from two sources of uncertainty – the export price path and the export volume of the mineral resource. Export volume in our approach is endogenous and also volatile, described in the CET supply function above. As such, export revenue and its components do not adhere to any official projections. Simulations are therefore presented as illustrations for the purpose of deriving some general policy implications of Dutch disease issues in a dynamic and stochastic context. Furthermore, the presence of a windfall revenue in any period implies a positive deviation of the mineral export price from its steady-state (or long-run growth) path. In particular, we assume a one-standard-deviation innovation to the world price of resource in the first period. Because of its autoregressive property, the shock will persist over time, but the resource price will eventually return to its steady state level in the long run as shown in Figure 1. In what follows, we first discuss in detail the transmission mechanisms of a positive price shock in the All-consuming regime. Using this as reference point, we then compare and contrast the results in the other regimes. In order to understand the budget rules in the stochastic case, we also briefly look at the effects of a negative temporary price shock, concentrating mainly on the behavior of consumption and investment.

3.1 Impulse responses

3.1.1 All-consuming regime

Since all variables eventually return to their initial steady state levels, we therefore emphasize the transitional dynamics of the impact of the price shock.

In the results shown by different graphs of Figure 1, it is evident that the transitory increase in the resource price will lead to a favorable transitory increase in the resource exports, with the impulse responses of both variables mirroring one another closely. Although the resource price changes only in the first period and gradually returns to its initial steady state, there are economy-wide repercussions that will lead to different transitional dynamics in some variables.

The government receives a windfall that comes from the rise in the export price and also from the export volume as we shall see. In this All-consuming regime, the windfall is transferred to households via endogenous government transfers according to the closure rules. However, it is interesting to note that transfers to households do not increase by the same

amount (in percent deviation) of the windfalls, which are partially offset by Dutch-disease effects of the resource price increase. Indeed, even though the volumes of government consumption and investment are kept to their initial steady state levels, their values will increase because of the rise in consumption price induced by the appreciation of the real exchange rate. As a result, part of the additional revenue is used to offset the nominal increase in government expenditures. We look at the behavior of the real exchange rate further below.

The increase in household income from the government transfers will induce an immediate transitory upswing in household consumption and savings. Government spending on public investment is kept at the level needed to replace obsolete public capital so that public capital stock does not increase. Private investment will then rise from the higher savings and the volume of gross output will respond positively. This is amplified by further rounds of interacting effects.

Higher consumer demand and investment demand imply increasing domestic absorption, which translates into increases in domestic sales in terms of the demand for domestic good and the demand for imports. The increase in the demand for domestic good puts a pressure on its price, which is the Dutch disease phenomenon. As a consequence of the increase in the price of the domestic good, the consumption price, which is a composite of the price of the domestic good and the price of imports, rises and only slowly moves back towards its original level. This explains the increase in government expenditures alluded to above.

Gross output will increase not just because of the higher investment, but it also reacts to increases in labor. As labor demand initially rises with output, the wage rate will increase. This in turn induces households to increase their labor supply, which increases production further. The increase in both the producer price and volume of gross output are beneficial to dividends paid to households. Both changes in labor income and in dividend income foster household wealth, which will additionally boost household consumption.

All told and in contrast to the short-term burst of resource export price, the supply of the domestic goods increases in most periods before returning to its long-run level. Similar patterns are noted consumption, domestic absorption, domestic sales, and the wage rate.

It is worth noticing that the appreciation of the real exchange rate eventually hurts the resource sector itself, whose exports fall below their steady state level before going back to it in the long run. The main reason for this is the price of the domestic good, which falls at a slower pace in comparison to the price of resource exports. Hence, producers find it profitable to immediately start reducing the production of the resource good in favor of the domestic good.

In an environment characterized by a rise in the costs of capital and labor and no change in the price of traditional exports, resources move out of the latter sector, shrinking it in early periods, but gradually returns to its steady state value after the exhaustion of the initial shock to the resource price and the eventual decline of the price of domestic good.

Despite the small share of resource exports in total exports and the fall in traditional exports, total exports increase as a result of the offsetting movements in the two types of exports. This persists for the first ten periods and then falls below their steady state level, before returning to that level in the long run.

The combined profiles of imports and total exports have a positive impact on current account balance in the initial periods; it becomes negative later and eventually returns to its steady state level. The initial positive impact on current account makes it possible to increase foreign debt in the first few periods, which ultimately decreases before returning to its long term level. In the meantime, the rise in indebtedness vis-à-vis the rest of the world increases slightly the interest premium, which eventually disappears in the long run.

In a nutshell, we observe the traditional dynamics of an increase in the world price of resource exports on the economy, where the traditional export sector shrinks at the benefit of the resource sector and the non-tradable sector. In the end, the exhaustion of the temporary shock and its effects on the shifting relative prices will eventually return the economy to its steady state.

3.1.2 Comparison with other regimes

In general, similar transmission mechanisms are at play in the three other regimes that make use of the revenue windfalls differently from the first regime. Graphs in Figure 2 offer a comparison of the shock on selected variables in all four regimes.

All-investing regime

In the All-investing regime, the resource windfalls are used to increase government expenditures in public investment. As expected, the profile of the change in public investment follows that of the resource price. The stock of public capital increases and has a positive impact on the productivity of private inputs, which induces firms to increase more their demand for labor and investment in comparison to the situation in All-consuming regime.

Even if all variables return to their steady state levels, the impact on private investment in All-investing regime is higher than the one in All-consuming regime for many periods. The

higher impact on private capital stock and on labor is beneficial to gross output, which expands more with a stronger impact on the resource exports.

Similarly, the higher impact on gross output is also beneficial to the sales in the other two markets. Domestic supply increases more and traditional exports fall less in comparison to All-consuming regime.

The same pattern generally applies to consumption whose pathway is higher in this regime in comparison to the previous regime. This result occurs despite the additional transfers received by households from the windfalls in the All-consuming regime. In contrast, transfers to households fall in the All-investing regime because of the increase in government expenditures induced by the increase in consumption price, which reduces the amount available for transfers. The rise in government revenue stemming from the rise of economic activities is not sufficient to compensate for the increase in government expenditures. This decrease of transfers explains the fall during the first periods of household consumption in the All-investing regime before its rise, thanks to the ensuing output and income effects of public investment.

Besides, the beneficial impact of a rising public investment can also be seen on imports, which increase more than in the All-consuming regime. This result is largely due to the growth in all components of domestic absorption, which is stronger in this regime.

The impact on current account balance is almost similar to the one observed earlier as shown in Figure 2.

All-savings regime

In this regime, the windfalls are invested abroad in a sovereign wealth fund that generates interests. Interest incomes accrue to the government but are ultimately given to the households through transfers. The sovereign fund is remunerated at the same interest rate paid on private debt. This regime is thus similar to the All-consuming regime but the profile and timing of transfers to the households will be different, consequently its impact on the other variables.

While transfers in the early periods are significantly lower in the All-savings regime in comparison to the All-consuming regime, the situation reverses after the tenth period as shown in Figure 2. In the medium and long runs, transfers to households in the All-wise regime are higher than the ones in All-consuming regime, where resource windfalls are entirely consumed instead of being invested in a sovereign fund. The main reason stems from the interests

generated by the sovereign fund, which increases over time despite the later decline in the windfalls. As transfers to households rise, households are able to consume relatively more over time in comparison to the first regime.

The impact on investment in this regime is almost identical to the one in the all-consuming regime. It is interesting to note that the transfer of resources from the sovereign fund to the economy reaches a critical point in the future that it becomes harmful to the export sector. This is because the additional resources spent by households will eventually lead to more appreciation of the real exchange rate, affecting the traditional exports more negatively in comparison to the All-consuming regime. The path of imports, on the other hand, is relatively higher in this case.

The balanced regime

This regime is a combination of All-investing and All-savings regimes, in the sense that half of the windfalls are invested in a sovereign fund and the other half in public infrastructure. In the absence of better information about the effectiveness of public investment in any country, this is a prudent Bayesian approach until additional information is available to change the prior estimate. To some extent, it combines the medium- and long-run benefits stemming from increasing public investment, and the short-term benefits for consumers arising from augmented transfers to households due to the windfalls.

Although the transitional dynamics and patterns are similar across regimes, the results suggest that the impact on consumption in the balanced regime is generally higher than the ones observed in the All-consuming and All-investing regimes, and lower than the one in the All-savings regime. The superiority of the All-savings regime to the balanced regime stems from two factors – investing raises prices, leaving less money for government to transfer to households; any amount of immediate investment in public infrastructure is also not 100 percent effective in raising output (Pritchett 2000) and does not generate a return sufficiently high as the one generated by the sovereign fund.⁸

In contrast, the Dutch-Disease-like effect generated by the returns to the investment in the sovereign fund is less pronounced in this regime since only half the windfalls are invested overseas. As a consequence, traditional exports are less hurt in comparison to the All-savings regime. Moreover, traditional exports will benefit from the increased investment in infrastructure in this regime.

⁸ We did sensitivity tests on the effectiveness of public investment. Raising its value did not alter the directions of the results or their conclusions.

3.1.3 Impact of a Negative Temporary Price Shock

What if the resource price declines, which is entirely possible? We briefly examine the impact of a negative temporary price shock of the mineral resource. To be clear about the adjustment in this negative scenario, the All-consuming case now means reducing government transfers to households, thus cutting consumption directly. In the All-investing case, this means cutting public investment in infrastructure, which affects future output and income negatively. In the All-savings case, this implies borrowing, paying interest income throughout. And the Balanced approach distributes the adjustment to cuts in public investment and increases in borrowing.

Figure 3 presents the impulse responses of consumption and investment under the 4 fiscal regimes due a negative temporary negative price shock of the resource sector. The results are mirror images of consumption and investment in Figure 2, due to reverse pattern of effects and the depreciation of the exchange rate. As expected, consumption in each of the four regimes declines throughout the periods. With no windfall to bank into a sovereign fund and no interest income to draw, the consumption path of the All-savings rule is now generally lower than the others; its investment path also has the highest initial decline. Consumption path of the Balanced regime is somewhat in the middle, lower than All-Investing and All-Consuming. The All-Investing has the greatest peak decline in consumption however. The investment paths generally decline in all the regimes.

To compare across regimes more carefully, we look at welfare in each case, which requires discounting the responses of consumption.

3.1.4 Welfare comparison and lessons

Figure 4a presents the welfare impact of a positive temporary shock to the resource price in all regimes. The measure of welfare is the percentage increase in consumption from the steady state level, which generates the same utility as after the shock. A positive number therefore connotes welfare improvement.

Welfare gains in all regimes from the resource revenue in a positive shock. Even so, putting aside the resource windfalls in a resource fund generates the highest welfare gain. This result is at first sight surprising given the consumption profiles presented in Figure 2 show the highest pick in consumption is in the All-investing regime. Two points explain this relative welfare ranking. First, despite the highest peak in consumption in the All-investing regime, it also has the most negative impact on consumption in the early periods largely because of the

initial Dutch disease effects on prices. Second, the peak actually occurs in later periods; because of the discount factor in the computation of utility, the welfare measure in the All-investing regime is lower than the three others since the benefits of future higher consumption are less important than near-term consumption for welfare. The highest welfare impact in the All-savings regime can easily be understood in light of the explanation given earlier on the comparison of the impact of the shock across regimes.

However, exactly the opposite pattern occurs in the case of a temporary negative shock (Figure 4b). The all-savings regime (i.e. borrowing in a negative shock) now has the lowest welfare, followed by the All-consuming regime (i.e. reducing consumption), the Balanced case, and the All-Investing case (i.e. cutting infrastructure) in that order. The pattern reminds us that the Dutch disease effects are just one possible side of the movements of resource price, that price contraction and its opposite effects are just as likely.

With some simplification, the following are therefore the policy rules of thumb. When there is a temporary increase in the natural resource price, the best strategy suggested by the DSGE analysis in this paper is to bank the revenue windfall entirely in a sovereign fund and to draw on the interest income to smooth consumption through government transfers to households. When there is a temporary price decline however, the best strategy is to cut public investment in order to protect consumption as much as possible. This is due to two reasons: investment raises the prices of domestic goods, leaving less money for government to transfer to households; and public investment is nowhere near 100 percent effective in raising output (see discussion of the output elasticity of public capital). Thus, reducing investment is better than cutting transfers to households, which reduces consumption directly, or dissaving from the sovereign fund or borrowing, which incurs an interest premium when debt rises.⁹ In the deterministic case (such as Go et al. 2013), a conservative Bird-in-Hand budget rule is recommended in order to avoid the long-term negative effects of Dutch disease when the resource export price shock is a positive and permanent and when the capacity in a poor country is low so that there is the possibility of boom-bust cycle from wasteful spending. The DSGE analysis in this paper extends prudent budgetary rules to the context when the price shocks are temporary and can be positive or negative.

3.2 Impact of price volatility

⁹ Noting that several countries in West Africa have cut public investment in the wake of a negative shock, Dessus and Varoudakis (2013) caution against this strategy, even if it is inter-temporally optimal. They argue that the stop and go costs and the asymmetric response of investment to shocks (higher during bad times) could be a reason for the relatively low levels of infrastructure in the WAEMU countries. Consideration of stop and go costs, beyond the standard adjustment costs of investment which is already in the model, beyond the scope of the paper.

What if the price shocks occur in all periods and are volatile? We consider unpredictable shocks to the resource export prices in all periods. These innovations to the prices are drawn randomly in each period in the presence of the AR (1) process. The model is run 100 times and we compute the unconditional second moment of selected variables of interest. The data in Table 4 suggest that the volatility of most quantity variables is the highest in the All-investing regime. The reason for this is that in addition to the volatility of the resource price, the economy is subject to the volatility of public capital stock in the All-investing regime. Indeed, because the resource windfalls are used to fund public investment that has an impact on output in that regime, the productivity of private factors and GDP are more volatile in comparison to the other regimes. This phenomenon is also partially observed in the balanced approach in which half of the resource windfalls are used to fund public investment. The All-consuming and All-savings regimes offer the lowest volatilities of quantity variables because the public capital stock is fixed in those regimes. As illustrations, the two panels in Figure 5 show the consumption and investment in the first draw of productivity shocks under All-consuming case. In conformity with results found in most DSGE models, investment is more volatile than consumption.

Among the alternative uses of the windfall revenue, using the resource windfalls to fund public investment would bring greater volatility to the economy when the resource price itself is also volatile and changing. Still, as far welfare is concerned, data in Figure 6 suggest that the average welfare gains of the shock under the four regimes are not significantly different from one another. Even so, the welfare gain in the Balanced regime is the largest, while the All-consuming regime offers the lowest welfare improvement. This result seems surprising in the sense that it does not follow the relative ranking of volatility of the four regimes. Everything equal, welfare should normally be lower the higher the volatility.

Clearly, welfare does not depend on volatility alone, but also on the level of consumption and its reactions to the price shocks that occur in all periods, which encompass both random increases and decreases. The lessons from the temporary price shocks therefore offer the clue: during price increases, one should bank the windfall revenue; during price declines, one should cut public investment. When the direction of the price changes are stochastic and uncertain, the best strategy is to combine both strategies, that is, a balanced regime that provides a natural insurance against both types of price shocks which are occurring persistently and randomly over time. The combination of interest income from the sovereign fund, transfers to households, and output growth brought about by public investment presents the best protective mechanism to smooth consumption over time in response to changing resources. It accentuates not just present consumption but also future consumption. It follows that the balanced regime is the preferred case in the face of volatility in the resource price and

the economy. This is a significant third lesson from the DSGE analysis.

4 Conclusions

In this paper, we have analyzed the economic implications of various budget rules to manage public revenue from natural resources in a developing country. We developed a 1-2-3-4 (for one country, two types of capital, three sectors, and four goods) model by introducing uncertainty in the dynamic 1-2-3 model. We captured the externality of public capital on firms' technology. After defining as resource windfalls the difference between current and the steady state levels of royalties on resource exports, we considered four regimes for the use of the windfalls: All-consuming, All-investing, All-wise and Balanced regimes. We then analyzed the economic implications of the volatility of the resource export price in the case of a temporary shock and in the case of persistent but uncertain shocks in all periods.

Our simulation results suggest three policy lessons or rules of thumb. When a resource price change is positive and temporary, one should bank the revenue windfall in a sovereign fund during the temporary price increase. Drawing interest income from the sovereign fund to raise consumption over time through government transfers to households will provide the largest welfare gains. This is because in the All-investing case, public investment is only partially effective (50 percent) in raising output, as shown in prior empirical estimates. In the presence of a negative temporary resource price change however, the best strategy is to cut public investment rather than trim government transfers to households, which reduces consumption directly, or draw down the sovereign fund or borrow, which incurs an interest premium as debt rises. In the presence of shocks that occur in all periods, the best strategy is to combine both, that is, a balanced regime that provides a natural insurance against both types of price shocks, positive and negative, which are occurring over time. Combining interest income from the sovereign fund, transfers to households, and output growth brought about by public investment presents the best protective mechanism to smooth consumption over time in response to changing resource prices.

We have three suggestions for future research. In the face of uncertainty and volatility of price shocks, a balanced approach seems ideal as a simple budget rule to follow. The optimal distribution between All-savings and All-investment will likely be different from the 50-50 split simulated here under different values of parameters such as the elasticity of output to public capital, trade elasticities, the interest rate premium for rising foreign debt, etc. Hence, determining the optimal rule for a range or combination of these parameters is one avenue for analysis. A second area of research is to model the stop and go costs of public investment, so

that the high price of stopping and restarting public investment is taken into account. Finally, a third research suggestion is to widen the budgetary rule to include government consumption, which is kept constant in real terms in the present paper. To do this properly, the links between two key components of current government expenditures – social spending on education and health – and human capital will need to be defined and explored. The effectiveness of public service delivery in education and health is often hard to model by itself, let alone in a dynamic stochastic framework.

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**Table 2: Ratio of selected macroeconomic variables to GDP in Niger
(Average 1995-2010)**

Selected macroeconomic variables	Ratio to GDP at market prices
GDP (market prices)	100.0%
Private consumption	81.3%
Private investment	13.0%
Public investment	8.1%
Public consumption	9.1%
Traditional exports	13.8%
Resources exports	6.2%
Imports	31.5%
Taxes on consumption	3.2%
Taxes on resources	1.2%
Taxes imports	4.8%
Income taxes	2.0%
Gov transf to households	2.3%

statistics

Table 3: Values of external and calibrated parameters

Description	Value
Sensitivity of interest rate to debt	0.0045
World real interest rate	0.058
Output elasticity of public capital	0.11
Depreciation rate of public capital	0.1
Depreciation rate of physical capital	0.1
Weight of imports in the Armington function	0.202
Efficiency of government investment in public capital accumulation	0.5
Leisure weight in the utility function	0.103
Persistence parameter	0.88
Standard deviation of shocks	0.13
Substitution elasticity in the Armington function	0.5
Substitution elasticity in the CET function	0.6
Intertemporal elasticity of substitution for consumption	0.36
Frisch labour elasticity	0.25

Table 4: Standard deviation of selected variables

(average of 100 simulations based on different draws of the resource price shocks)

	All- consuming	All-investing	All-wise	Balanced approach
GDP at market prices	0.84	1.27	0.84	1.04
Consumption	0.71	0.99	0.78	0.85
Private investment (inc. Adjustment cost)	3.42	4.11	3.40	3.73
Traditional exports	1.32	1.11	1.31	1.16
Resource exports	14.54	14.85	14.66	14.76
Imports	1.33	1.66	1.35	1.44
Domestic absorption	0.69	1.03	0.70	0.83
Domestic sales	0.50	0.79	0.51	0.61
Output	0.74	1.16	0.74	0.94
Private investment (w/o Adjustment cost)	3.20	3.85	3.17	3.49
Private capital stock	1.72	2.04	1.67	1.85
Labor supply	0.47	0.56	0.47	0.52
Foreign savings	2.59	2.51	2.11	2.30
Foreign debt	19.80	19.49	16.56	17.86
Consumption price	1.51	1.48	1.53	1.45
Price of domestic good	2.29	2.23	2.31	2.19
Price of resource export	27.28	27.28	27.28	27.28
Wage rate	7.66	7.78	6.68	6.98
Government revenue	1.00	1.13	0.99	1.03

Figure 1: Impulse responses of selected variables following a positive one-standard deviation shock to the price of resource exports: All Consumption Regime

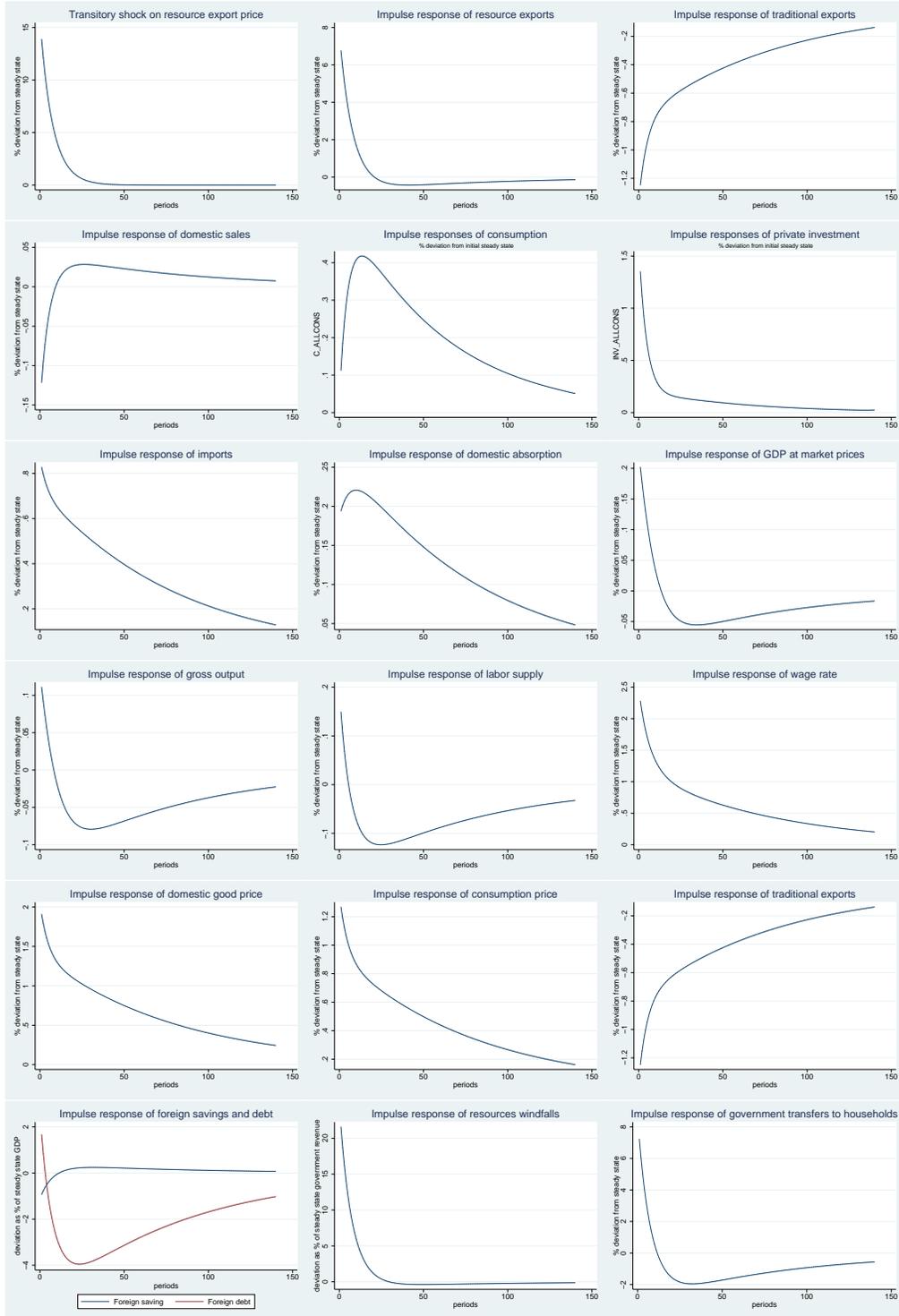


Figure 2: Impulse responses of selected variables following a positive one-standard deviation shock to the price of resource exports: Comparison across regimes

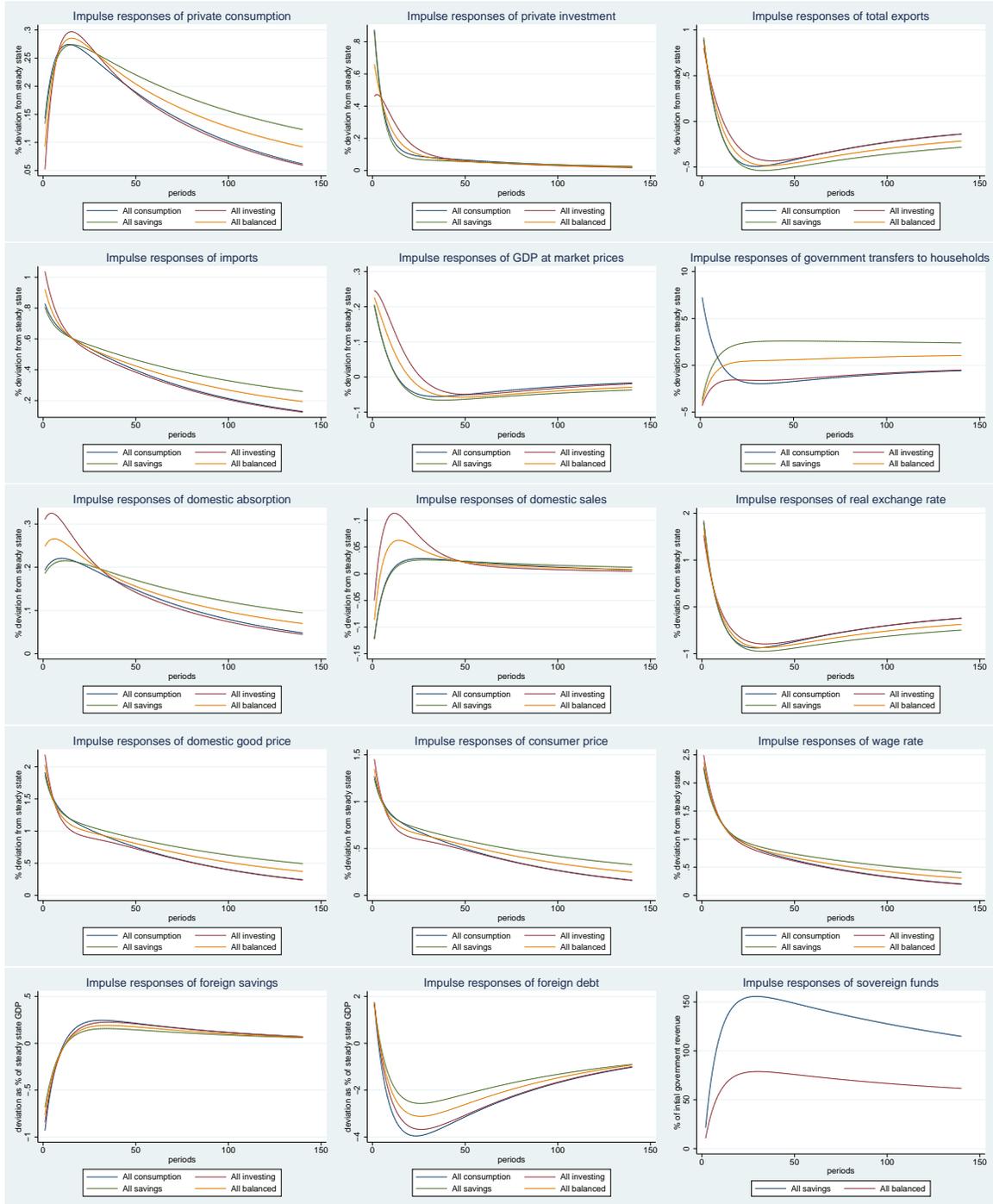


Figure 3: Impulse responses of selected variables following a negative one-standard deviation shock to the price of resource exports: All Consumption Regime

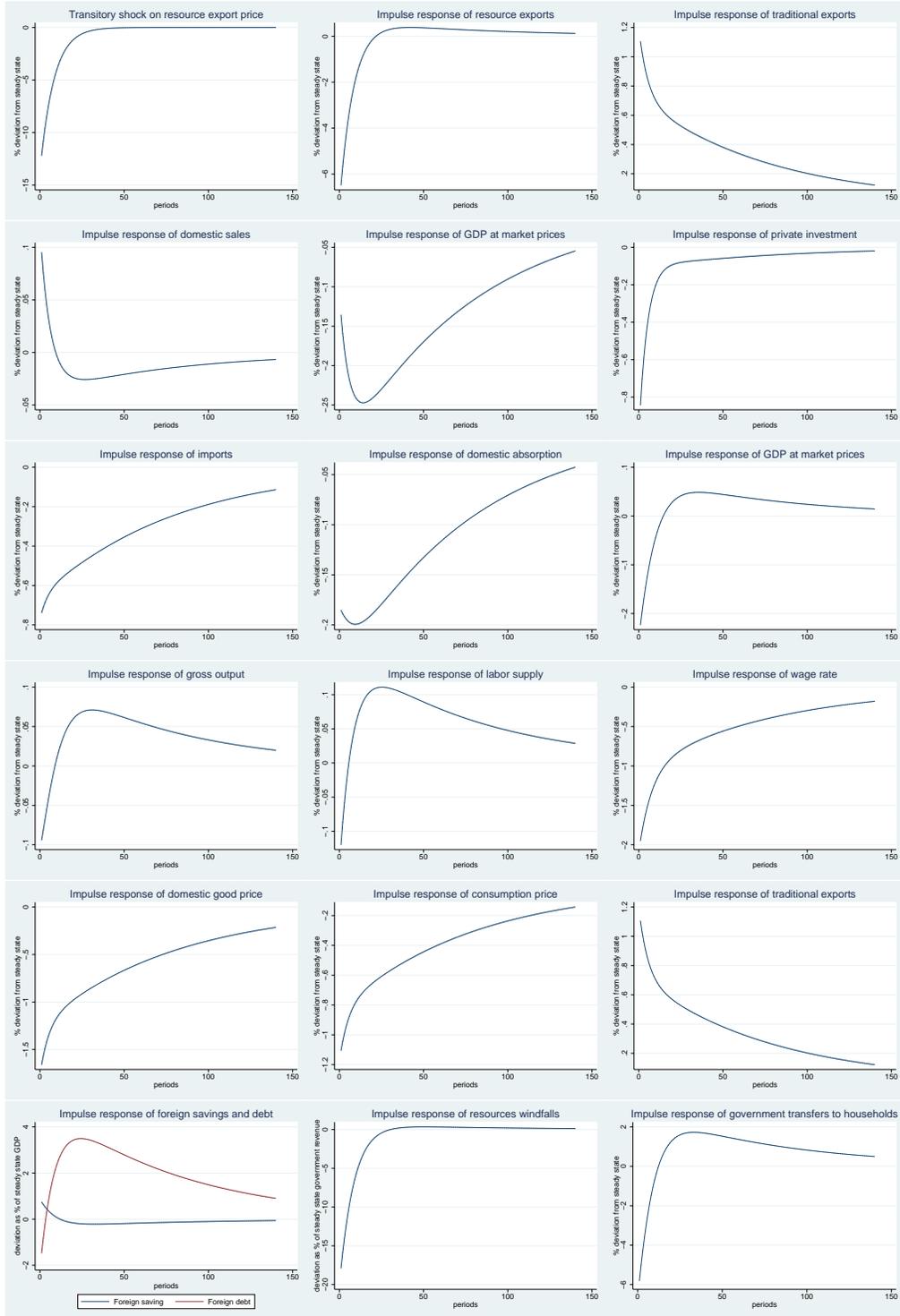
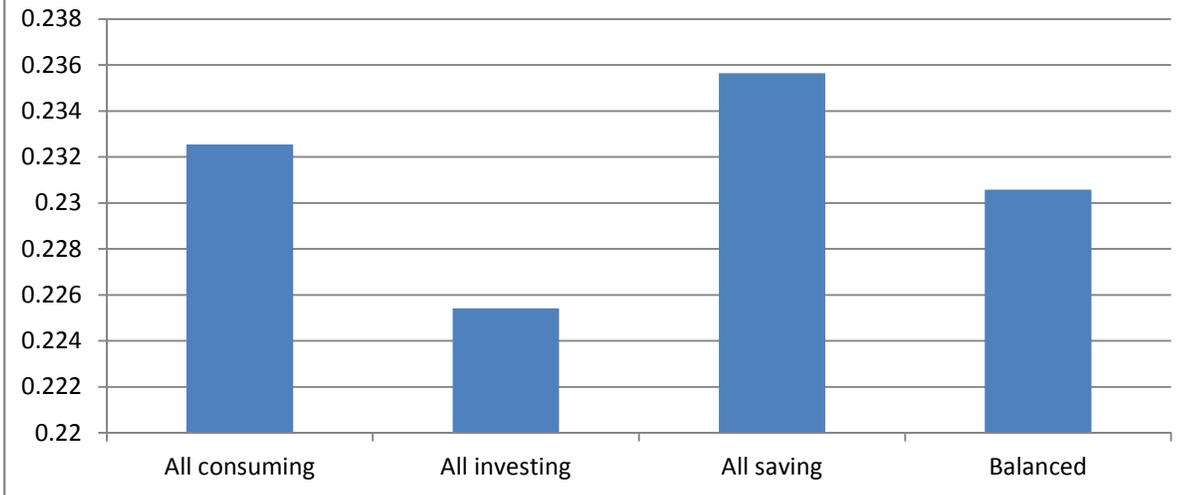
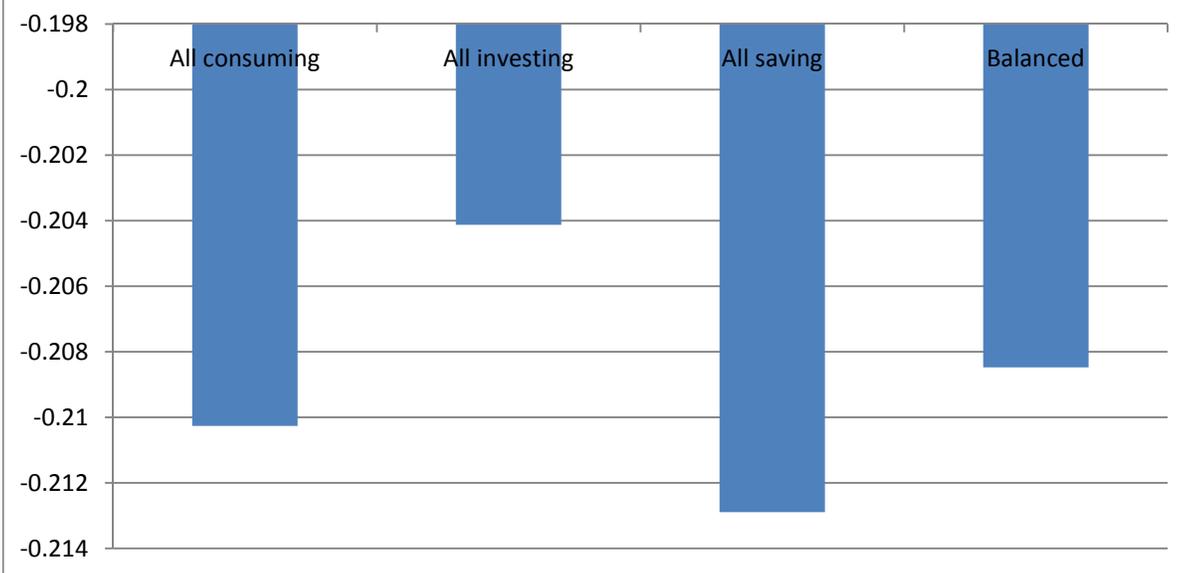


Figure 4a: Welfare impact of a temporary positive one-standard deviation of the resource price



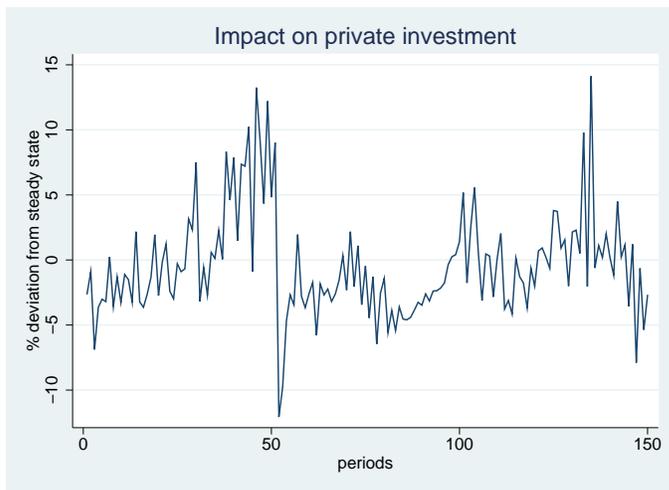
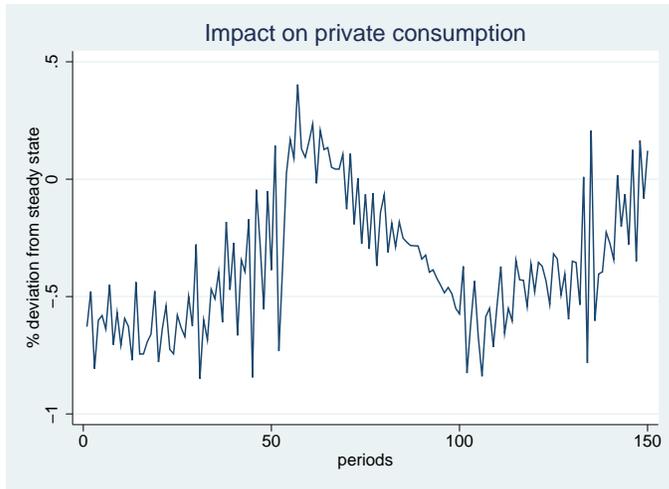
The welfare measure is the percentage increase in the deterministic steady state consumption that gives the same level of utility brought about by the shock to resource price

Figure 4b: Welfare impact of a temporary negative one-standard deviation of the resource price

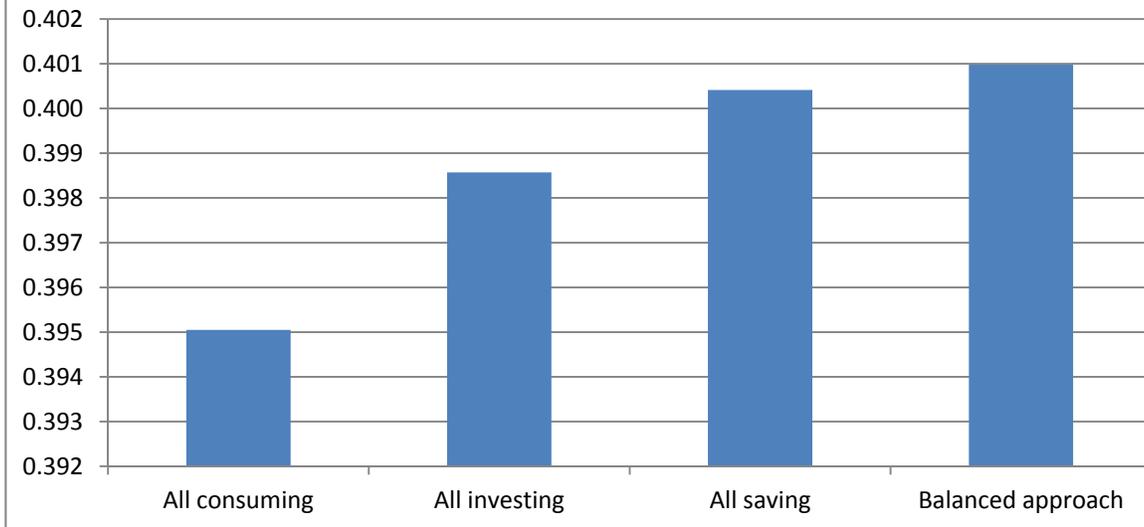


The welfare measure is the percentage increase in the deterministic steady state consumption that gives the same level of utility brought about by the shock to resource price

Figure 5: Stochastic simulation of the shock of the price of resource exports (one of 100 stochastic draws): Impact on consumption and investment



**Figure 6: Welfare impact of persistent shocks to resource price
(average of 100 simulations based on various draws of the resource price shocks)**



The welfare measure is the percentage increase in the deterministic steady state consumption that gives the same level of utility brought about by the shock to resource price