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Managing Future Oil Revenues in Ghana

An Assessment of Alternative Allocation Options

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ABSTRACT

Contemporary policy debates on the macroeconomics of resource booms often concentrate on the short-run Dutch disease effects of public expenditure, ignoring the possible long-term effects of alternative revenue-allocation options and the supply-side impact of royalty-financed public investments. In a simple model applied here, the government decides the level and timing of resource-rent spending. This model also considers productivity spillovers over time, which may exhibit a sector bias toward domestic production or exports. A dynamic computable general equilibrium (DCGE) model is used to simulate the effect of temporary oil revenue inflows to Ghana. The simulations show that beyond the short-run Dutch disease effects, the relationship between windfall profits, growth, and households' welfare is less straightforward than what the simple model of the "resource curse" suggests. The DCGE model results suggest that designing a rule that allocates oil revenues to both productivity-enhancing investments and an oil fund is crucial to achieving shared growth and macroeconomic stability.

Key words: oil fund, public expenditures, growth, Africa, Ghana, CGE analysis

1. INTRODUCTION

Average growth rates of 5 percent and a halving of poverty over the past two decades make Ghana a recent success story and a rising star in African development (Aryeetey and Kanbur 2008; World Bank 2008a). Yet the country remains dependent on relatively few sources of foreign exchange inflows and retains a high level of external debt (IMF 2008). Therefore, the recent discovery of offshore oil is seen by many as an opportunity to overcome persisting structural weaknesses and has raised Ghana's prospects of becoming a frontrunner in African development. However, experiences from other African countries such as Nigeria and Zambia show that properly managing resource windfalls remains a challenge for many developing countries and that misguided allocation strategies can harm the process of economic development instead of accelerating growth (Gelb and Associates 1988; Auty 1990; Rodrik 2003). Cross-country evidence confirms that countries depending heavily on natural resources tend to have less trade and foreign investment, more corruption, less equality, less political liberty, less education, less domestic investment, and less financial depth (Gylfason 2005 and Gylfason 2007).

Given this inherent risk, two extreme positions for managing oil revenue inflows can be distinguished.[1] Proponents of a "conservative" strategy, such as the Bank of Ghana (2007, 2008), argue that government spending of mineral windfalls often leads to excessive Dutch disease effects,[2] where exchange-rate appreciation and competition for domestic resources causes a reduction in the competitiveness of non-oil sectors, and corruption further undermines effective spending (Gylfason, Herbertsson, and Zoega 1999; Eifert, Gelb, and Tallroth 2002; Gelb and Turner 2007). Moreover, notoriously volatile world oil prices and the physical limitations of mineral resources compound the importance of a sound revenue-management strategy. From this perspective, the Norwegian model (essentially the saving of resource inflows in an oil fund) constitutes an important tool to phase in and out of oil-revenue spending and thus to support a balanced budget, a reduction in foreign debts, and the accumulation of savings for future generations (see, for example, Gylfason 2007; Matsen and Torvik 2005).

Advocates of a "big push" strategy argue that developing countries often run fiscal and trade deficits in development periods of rapid economic growth. Revenues from newly found oil resources therefore provide an opportunity to increase government investment to support growth. In fact, public investments that facilitate private-sector-led growth and raise productivity have been identified as an important component for many countries that transitioned rapidly from low- to middle-income status (Syrquin 1988; Collier 2006; Breisinger and Diao 2009).[3] In countries such as Indonesia and Chile, public investments in agriculture and rural development financed by oil and copper revenues have played an important supporting role in growth and structural transformation (Temple 2003). However, cross-country empirical evidence suggests that the impact of resource inflows critically depends on initial conditions, especially on the strength of institutions and human capital (Brunnschweiler 2008; Bulte, Damania, and Deacon 2005; Gelb and Grassman 2008).

Avoiding the resource curse and turning future oil windfalls into an opportunity to accelerate economic transformation in Ghana will therefore require sound fiscal management and a strategy that balances current government spending and savings. In this paper, we focus on the allocation of oil revenues and use a dynamic computable general equilibrium (DCGE) model to assess trade-offs between different spending and saving scenarios. The DCGE model includes different types of public spending and also introduces an oil fund. To calibrate the model's baseline (2009 to 2027), we draw information from the International Monetary Fund's (IMF's) current account, government balance, and interest

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[1] For a comprehensive overview of these and intermediate positions, see van der Ploeg (2006).

[2] There is broad agreement that strong appreciation of the real exchange rate hurt the competitiveness of export sectors. However, Matsen and Torvik (2005) show that some real appreciation might be optimal, given the inflow of resources and the potential to change the growth path of the economy.

[3] The case studies included in Collier and Gunning (1998a, 1998b) center on the savings response of public and private agents when faced with trade shocks.

payments projections. We then use the oil revenue projections of the IMF and the Institute of Social and Statistical Economic Research (ISSER), a local think tank, to assess the trade-offs between macroeconomic stability and productivity-enhancing public investments. As two extreme cases, we consider a scenario in which the government spends all oil revenues it receives annually and a scenario in which the government saves all oil revenues by creating an oil fund and spends only the interest earned from the fund. We also introduce an allocation rule, which allows smoothing of oil-revenue spending, whereby a part of the oil revenue in each period is saved for future government spending, thereby balancing current and future government spending.

The rest of the paper is organized as follows. Section 2 provides an overview of the size of the future oil sector in the Ghanaian economy and discusses related opportunities and challenges in terms of balancing growth acceleration and macroeconomic stability. Section 3 introduces the DCGE model used for this study, and Section 4 presents the allocation of oil revenues and the potential impact of this allocation together with the model simulation results. Section 5 summarizes and concludes.

2. A NEW ERA OF OIL IN GHANA: NEW CHALLENGES FOR GROWTH AND MACRO STABILITY

Oil was discovered off the coast of Ghana in 2007, with total reserves estimated at between 500 million and 1.5 billion barrels and the potential for future government revenues estimated at US$1–1.5 billion annually (Table 1). Even at a modest long-term oil price of US$60 per barrel over the next 20 years, oil revenues will add around 30 percent to government income and will constitute between 6 and 9 percent of gross domestic product (GDP) annually over the period of exploitation. While the relative amount of expected oil revenue is smaller than in other resource-rich countries, the positive shock does provide new opportunities to further accelerate growth and speed up economic transformation. Prospects are further raised by Ghana's sound institutional record.

Table 1. Projection of oil production and revenues

	2010	2015	2020	2025	2030
Barrels per day (in 1,000s)	120	250	250	250	250
Barrels per year (365 days)	43,800	91,250	91,250	91,250	91,250
Oil value (per day, in 1,000s)					
US$60 per barrel	7,200	15,000	15,000	15,000	15,000
US$80 per barrel	9,600	20,000	20,000	20,000	20,000
Oil value (per year, in 1,000s)					
US$60 per barrel	2,628,000	900,000	900,000	900,000	900,000
US$80 per barrel	3,504,000	7,300,000	7,300,000	7,300,000	7,300,000
Government revenue per day (in 1,000 cedis)					
US$60 per barrel	2,750	5,730	5,730	5,730	5,730
US$80 per barrel	3,667	7,640	7,640	7,640	7,640
Government revenue per year (in 1,000 cedis)					
US$60 per barrel	1,003,896	1,343,800	1,343,800	1,343,800	1,343,800
US$80 per barrel	1,338,528	2,788,600	2,788,600	2,788,600	2,788,600

Source: Osei and Domfe (2008)

Compared with other African countries in which oil or other natural resources have been discovered in the past, current conditions in Ghana seem favorable to avoiding the resource curse. First, Ghana has experience in managing resource windfalls. Gold and cocoa have been the most important export commodities throughout the country's entire modern history. After the structural adjustment program implemented in the mid-1980s, the country has finally reached macroeconomic stability, and these favorable macroeconomic conditions, together with other pro-growth and pro-poor strategies, have led to steady growth and rapid poverty reduction over the past 20 years.

Second, politically, Ghana has become a stable democratic state, as demonstrated by peaceful transitions of power in two consecutive free and fair elections, in 2000 and 2008. Third, the governance indicators reported by the World Bank show that Ghana has been steadily improving its governance, and in 2007 the country ranked above the regional averages for Asia, Latin America, and Africa in most important governance indicators, such as government effectiveness, regulatory quality, and control of corruption (World Bank 2008b; Kaufmann, Kraay, and Mastruzzi 2008).

Yet several growth-, equity-, and macrostability-related challenges must still be addressed before Ghana can achieve its development goals. The country aims to become a middle-income country by 2015, and achieving this development goal will require annual growth rates of around 7 percent over the next 10 years (NDPC 2005; Breisinger, Diao, and Thurlow 2009). While this goal seems reasonable given the size of expected oil revenues, this growth requirement is higher than the growth rates that the country has achieved in recent years under favorable international conditions. In addition, the large share of agriculture in GDP (about 40 percent), the high share of agriculture-related processing in manufacturing (about 60 percent), and the high share of the population working in agriculture (about 70 percent) indicate that without Green Revolution–type agricultural growth as a main driver, Ghana may well fail to achieve such rapid growth (Breisinger et al. 2008).

The pattern of current growth reveals certain weaknesses in promoting private investment, generating more employment opportunities, and encouraging economic diversification. The distribution of growth benefits has also started to show warning signs, as income growth in lagging northern regions does not match the fast growth in the coastal regions (Aryeetey and Kanbur 2008).

Lessons from other countries, and from Ghana's own history, show that maintaining macroeconomic stability is crucial for sustainable growth (Bank of Ghana 2007, 2008). Before implementation of the structural adjustment program in the mid-1980s, inefficient public expenditure schemes, overvalued exchange rates, trade protection, and an oversized public sector held Ghana back from transforming its economy (Agyeman Duah, Soyinka, and Kelly 2008). While Ghana also benefited from the Highly Indebted Poor Countries (HIPC) debt relief in 2002 to restore macroeconomic balance (IMF 2008), new debt has started to reaccumulate recently due to rapidly increasing fiscal deficits. The fiscal deficit constituted about 3 percent of GDP in 2005, yet it is expected to reach more than 10 percent in 2009 (IMF 2008). The IMF estimates that public debt will rise to more than 50 percent of GDP in 2009, and other sources' estimations are even higher (EIU 2009). Osei and Domfe (2008) argue that the food and energy crisis is the reason for part of the additional spending. Other sources emphasize the sharp increase in recurrent spending (especially for civil servants' wages) and the stagnation of the share of investment in spending (EIU 2009).

Reducing these high deficits to 5 percent of GDP would require an average annual growth rate of 7.7 percent to stabilize total public debt at 65 percent of GDP. Therefore, oil revenues must help sustain a high spending-to-GDP ratio and will not be available for additional spending.[4] Hence, using these revenues to spur productivity-led growth is critical to achieving growth and sustainable debt levels in the long run. Striking the right balance between growth and macroeconomic stability in the spending of oil revenues will therefore be a key challenge. In the following section we describe a model to address the question of what this balance might look like.

[4] For more details, see Breisinger et al. (2009).

3. MODELING ALTERNATIVE OIL REVENUE ALLOCATION OPTIONS

The ability to capture synergies, trade-offs, and linkages between macroeconomic balances and growth at the sector and household level have made general equilibrium models an important tool to analyze the impacts of resource booms. In this paper, we therefore use a recursive DCGE model for Ghana. While this model does not attempt to make precise predictions about the future development of the Ghanaian economy, it does measure the trade-offs between the alternative options of saving and spending oil revenues.

The DCGE model is constructed consistent with the neoclassical general equilibrium theory. The theoretical background and the analytical framework of CGE models have been well documented in Dervis, de Melo, and Robinson (1982), while the detailed mathematical presentation of a static CGE model is described in Lofgren, Harris, and Robinson (2002). A full description of the DCGE model from which our Ghana model is developed can be found in Thurlow (2004). The equations and parameters are presented in Appendix B.

The Ghana DCGE model is an economywide, multisectoral model that solves simultaneously and endogenously for both quantities and prices of a series of economic variables. On the supply side, the model defines specific production functions for each economic activity. Assumptions that are made before calibrating the model to the data include constant returns to scale technology with constant elasticity of substitution (CES) between primary inputs. This is a necessary assumption for the model to reach a general equilibrium solution. For the substitution between primary and intermediate inputs in the production functions, we assume a Leontief technology.

The demand side of the DCGE model is dominated by a series of consumer demand functions. This demand system is derived from well-defined utility functions. In our model, the consumer demand functions are solved from a Stone-Geary type of utility function in which the income elasticity deviates from 1 (which is a typical assumption in a Cobb-Douglas type of utility function), and hence the marginal budget share of each good consumed differs from its respective average budget share. As in other general equilibrium models, consumers' income that enters the demand system is an endogenous variable in our model. Income generated from the primary factors employed in the production process is the dominating income source for consumers, while the model also considers incomes from abroad (as remittance received) or the government (as direct transfers).

The DCGE model explicitly models the relationship between supply and demand, which determines the equilibrium prices in domestic markets. To capture the linkages between the domestic and international markets, the model assumes price-sensitive substitution (imperfect substitution) between foreign goods and domestic production.[5] While the linkages between demand and supply through changes in income (an endogenous variable) and productivity (often an exogenous variable) are the most important general equilibrium interactions in an economywide model, production linkages also occur across sectors through intermediate demand and competition for primary factors employed in production sectors.

The model has a neoclassical closure in which total domestic investment is determined by the sum of private, public (budget surplus), and foreign savings (current account deficit), net of public savings abroad in the natural resource funds. Public investment is assumed to be a fixed proportion of overall domestic investment, while private investment is constrained by total savings net of public investment, where household savings propensities are exogenous. This rule, broadly consistent with conditions in developing countries where unrationed access to world capital markets is virtually zero and domestic private saving is relatively interest inelastic, means that any shortfall in government savings relative to the cost of government capital formation, net of exogenous foreign savings, directly crowds out private investment (and any excess in government savings directly crowds in private investment).

[5] Appendix Table A.1 provides selected indicators of the export orientation of individual sectors and the import dependence of domestic demand, together with information on sectoral production and employment structure.

The model has a simple recursively dynamic structure. Each solution run tracks the economy over the period 2007 to 2027, in which each period also corresponds to a fiscal year. While public and private capital stocks are fixed within each year, they accumulate over time. Capital accumulation is affected both by savings (particularly for private capital accumulation) and government decisions regarding the allocation of public funds. Investment (and hence capital accumulation) is also affected by the foreign inflow of capital, in which new oil revenues become an important component in the simulations. Distribution of increased capital across sectors is determined by the relative return to sector capital, and such returns are the endogenous variables in a general equilibrium model. Specifically, the accumulation of sectoral capital stock is defined as follows:

$$K_{i,t} = K_{i,t-j}(1-\mu_i) + \Delta K_{i,t-j} \quad (1)$$

where $K_{i,t}$ is the capital stock, μ_i is the rate of depreciation that is sector specific, and t-j measures the gestation lag on investment. In the simulations presented below, the default setting is $j = 1$, although the effects of assuming that public investment augments the stock of infrastructure capital only with a longer lag may also be examined.

The model also considers the effects of public investment on productivity as an externality factor resulting from public investment in infrastructure. Public investment is assumed to generate a Hicks-neutral improvement in total factor productivities. Specifically, the shift parameter in the production function, A_i, changes corresponding to the accumulation of public capital, that is,

$$A_{s,t} = \underline{A}_s \cdot \Pi_g \{(K^g_t/K^g_0)/(Q_{s,t}/Q_{s,0})\}^{\rho_{sg}} \quad (2)$$

where g denotes a set of public capital stocks generally defined over infrastructure, health, and education, K^g and Q_s are the public capital stocks and sectoral output levels under the simulation experiment, and K^g_0 and $Q_{s,0}$ are the correspondingly defined public capital stocks and output levels in the base period. The terms ρ_{sg} determine the extent of the spillovers of public investment to total factor productivities. If $\rho_{sg} = 0$, there is no spillover from public investment in infrastructure, health, and education. The higher ρ_{sg}, the higher the spillover effect.

We calibrate this model to a new 2007 social accounting matrix (SAM) for Ghana, which is based on a 2005 SAM documented in IFPRI 2007. To update this SAM to 2007, we use national accounts provided by Ghana Statistical Services (GSS) for 2007, balance of payments data provided by the Bank of Ghana, and government budget data provided by the Ministry of Finance. The newly developed SAM provides information on the demand and production structure of eight sectors, including two agricultural subsectors (domestic and export), four industrial subsectors (mining, manufacturing, utilities, construction), and two service subsectors (private and public). The SAM and hence the DCGE model consider the existence of three different types of factors—labor, capital, and land—from which rural and urban households derive their income (see Appendix Table A.2).

In addition to the SAM, the main elasticities include the substitution elasticity between primary inputs in the production function, the elasticity between domestically produced and consumed goods and exported or imported goods, and the income elasticity in the demand functions. We use the same CES elasticity of 0.75 in the production function of all individual sectors and for all pairs of production factors, which is drawn from the CGE literature on other African countries. The other parameters or coefficients in the production functions of the model (e.g., the marginal product of each input) can be directly calibrated using the country data of the Ghana SAM (e.g., the share of value-added for each input used in the total value-added of this sector).

For the use of intermediate inputs in the production function, we use a Leontief technology. With this assumption, a set of fixed input-output coefficients can be directly derived using the data of the Ghana SAM. With a Stone-Geary type of utility function applied in the model, the marginal budget share (MBS) is the parameter applied in the demand system, which can be derived from the SAM given that the income elasticity of demand is known. The income elasticity is estimated from a semi-log inverse function suggested by King and Byerlee (1978) and based on the data of Ghana Living Standard Survey (GLSS5 2005/06). The estimated results, together with the average budget share (ABS) for each individual commodity consumed by each individual household group directly calculated using the data of the Ghana SAM, provide a series of MBSs that are applied in the model (see Appendix Table A.3).

For commodities that are sold both domestically and abroad, a constant elasticity of transformation (CET) function is applied, while for commodities that have both domestic and foreign supply, a constant elasticity of substitution (CES) or Armington function is used. To reflect the relative openness of Ghana's economy, we chose high values, of 4.0, for both the CET and Armington elasticity for all traded goods.

4. IMPACTS OF ALTERNATIVE OIL REVENUE ALLOCATION OPTIONS

We use this model to assess the medium- and long-term impacts of four alternative oil revenue allocation options. This section first describes the scenarios in greater detail and then discusses the core results and sensitivity results.

Scenarios

The DCGE model is first applied to a scenario (the base run) in which the sectoral-level growth rate is consistent with the growth trends observed in recent years (between 2001 and 2007). Newly found oil is not considered in this scenario. Along this business-as-usual growth path, Ghana's economy will continue to grow at an annual rate of 5.6 percent until 2027.

Oil extraction will be conducted offshore, and the linkages to the domestic economy are expected to be very weak. Backward linkages will be restricted by the lack of local capacity to provide the highly technology-, capital-, and skill-intensive inputs required for setting up and running oil extraction businesses (Seminar at the Bank of Ghana on June 30, 2009, and personal interview with Ministry of Energy, July 1, 2009). Forward linkages are also likely to be limited, since Ghana does not currently have refining capacities and oil is expected to be exported as crude oil. The most important effect from oil extraction in Ghana will therefore be the royalties and taxes paid by the consortium of oil companies.[6] Accordingly, we model the oil boom as an increase in foreign exchange revenues to the government in the model.

We then develop four policy scenarios in which oil revenue as part of new foreign inflows to the government account is equivalent to 8.5 percent of GDP in 2007 (the base year in the model).[7] This projection of oil revenues is based on Osei and Domge from ISSER (2008), which has been summarized in Table 1 above.

Total oil revenues are then modeled as foreign inflows, which are either exclusively used to finance increased public investment (scenario 1) or are allocated as savings into an interest-earning external oil fund (scenario 2).[8] Interests and revaluation gains (and losses) earned from such savings are used to finance public investments in scenario 2.[9] Scenarios 3 and 4 examine the combination of these two extreme cases, in which only part of the royalties are saved in the oil fund following different allocation rules. Finally, variations of these four basic scenarios investigate the cases in which public investment not only increases the overall capital stock, but in addition raises total factor productivity in export-oriented sectors (scenarios 1a–4a) or domestic sectors (scenarios 1b–4b).

Designs of these scenarios are based on some other countries' practices. In order to guard against the destabilizing impacts of swings in public expenditure, certain fiscal rules have proved useful in anchoring long-term fiscal policy and in ensuring that windfall revenues are saved as a cushion against future adverse shocks. The best-known example of successful fiscal rules is Norway (Larsen 2006), where spending effects are controlled by the government shielding the economy through fiscal discipline and investments abroad. Accumulating oil revenues in an oil fund would allow the fiscal budget to be supported by a moderate but permanent income stream stemming from interest on these assets. Saving at least part of the oil revenues would therefore provide some support to the budget, while at the same time moderating real appreciation and building up assets for buffering future shocks to foreign exchange inflows and/or fiscal revenues. Accordingly, the government of Ghana has proposed the establishment of some form of permanent income fund. However, the details of this plan, in terms of what proportion to

[6] The consortium of oil companies comprises Tullow Oil, Kosmos Energy, and several other small-scale operators.

[7] We adopt the—from the current perspective—more optimistic view that oil prices will average US$80 per barrel over the simulation period. However, assuming a lower oil price will not change the general direction of the results.

[8] We do not consider the case in which royalties are used to finance additional recurrent public expenditure, although a higher public capital stock might provide a case for additional expenditure.

[9] Since we assume that oil revenues are invested abroad, interest revenue also includes revaluation gains and losses.

save and what proportion to spend, do not yet seem to be determined, and the public consultation process has remained limited.

To help in understanding the design of the scenarios, we first provide a simple model to formalize the allocation between government savings and spending, assuming that the government follows a fiscal rule to allocate oil revenues either to the fiscal budget or to an oil fund. In this case, total (additional) government spending in the current period is given by

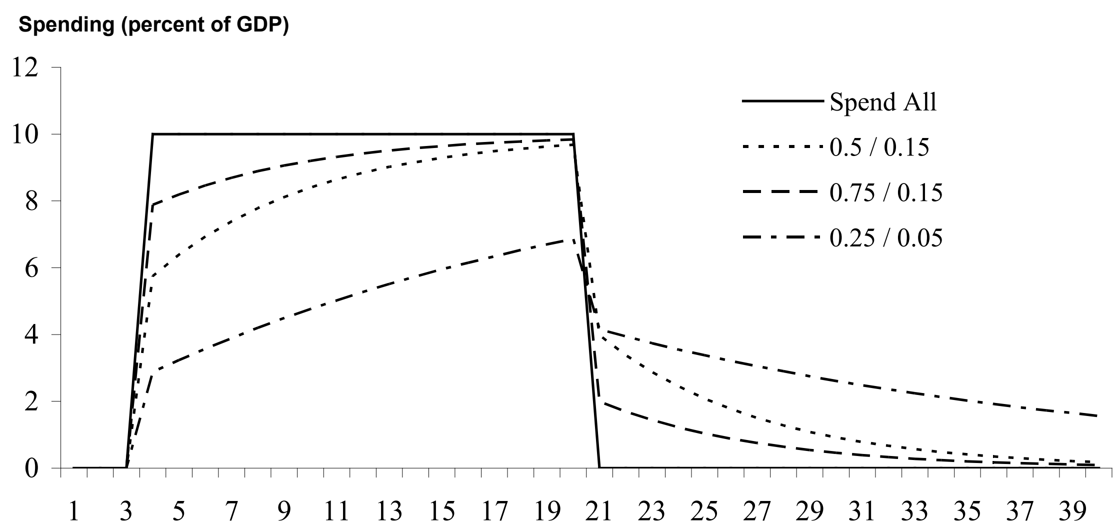
$$\begin{aligned} \text{totgovspen d}_t &= a_1 \cdot \text{oilrev}_t + \text{withdraw}_t \\ &= a_1 \cdot \text{oilrevt} + a2 \cdot \text{oilfund}_{t-1} \end{aligned} \quad (3)$$

With $0 < a_1, a_2 < 1$, the two parameters determine how much of current oil revenues (oilrev) are allocated into the fiscal budget (a_1) and how much are added from accumulated assets (withdraw) out of an oil fund (a_2). The accumulation of assets in the oil fund are, in turn, given by the stock of assets in the previous period that increase due to savings out of current oil revenues and decrease due to withdrawals because of additional government spending:

$$\begin{aligned} \text{oilfund}_t &= \text{oilfund}_{t-1} + (1- a_1)\ \text{oilrev}_t - a_2 \cdot \text{oilfund}_{t-1} \\ &= (1- a_2)\ \text{oilfund}_{t-1} + (1- a_1)\ \text{oilrev}_t. \end{aligned} \quad (4)$$ [10]

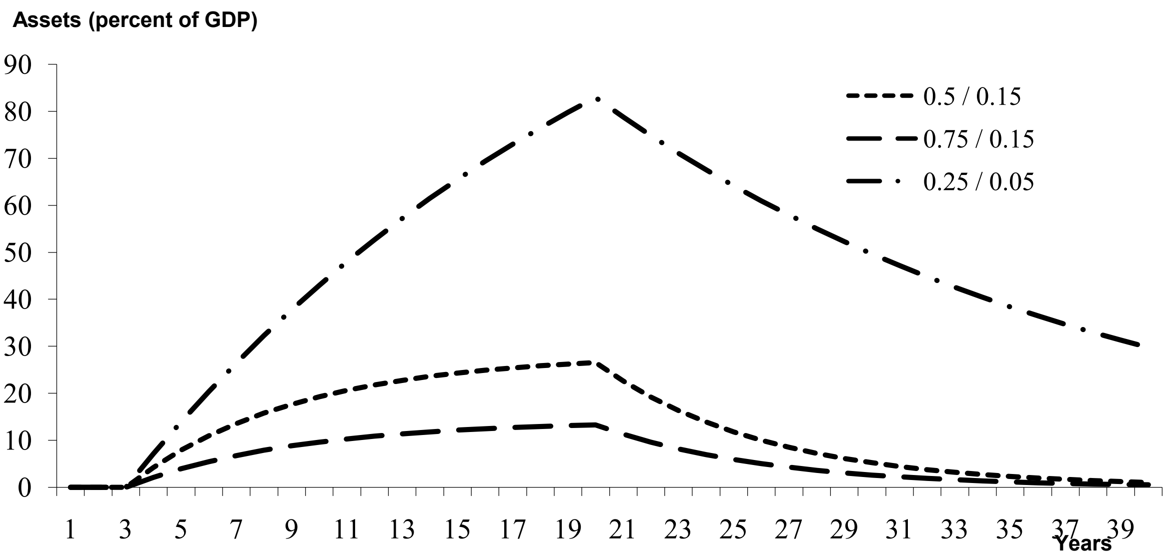
The implications of this simple rule are shown in Figure 1, where we assumed an inflow on oil revenues of 10 each period, starting in period 4 and lasting until period 20. As can be seen, the fiscal rule smoothes the impact of oil revenues on the fiscal budget where the "spending" parameter a_1 determines the (positive) shock at the beginning of oil revenue inflows and the "stretching" parameter a_2 determines the live time of the oil fund. For our model simulations we adopted an intermediate parameter constellation (0.5/0.15) with a spending parameter allocating 50 percent of current oil revenues into the fiscal budget, an amount that is topped up by withdrawals of 15 percent of the oil fund stock in the previous period.

Figure 1. Additional spending and asset accumulation before, during, and after oil inflows (percent of initial GDP)



[10] Equations (3) and (4) imply that the government decides on net savings out of oil revenues in each period. For the formulation of the allocation rule in terms of net savings, see Breisinger et al. (2009). For an application to aid inflows, see Adam et al. (2008).

Figure 1. (Continued)



Source: Authors' calculation for a simulated inflow of oil revenue of 10 units from period 3 to 20. Simulations show parameter combinations of $a_{1/}$ a_2 (see equations 3 and 4 in the text).

In terms of equations (3) and (4), we evaluate the following alternative scenarios:

OIL1: all oil revenues are spent, i.e., $a_1 = 1$, and $a_1 = 0$

OIL2: all oil revenues are saved, i.e., $a_1 = 0$, and $a_2 = 0$

OIL3: a 5 percent budget support, i.e., $a_1 = 0.05 \text{ x } GDP/OIL$, and $a_1 = 0$

OIL4: smoothing oil-revenue spending, in which $a_1 = 0.5$, and $a_2 = 0.15$

In the next step, we design four scenarios to measure the direct and indirect effects of oil revenues that stem from additional public spending or savings, ignoring possible spillover effects of public investments on productivity growth in the economy. Thus, we develop two additional sets of scenarios to evaluate the joint effect of an increase in oil revenues that leads to productivity growth. In scenarios 1a–4a the productivity spillover effects are assumed to occur in the export-oriented sectors, while in scenarios 1b–4b such spillover effects are assumed to occur in the domestic sectors. For example, public investment in telecommunications infrastructure, trade fairs, and so on is likely to affect the production of tradable goods, while the provision and maintenance of rural roads, the funding of agricultural research, or the establishment of local marketplaces increases productivity in the domestic sectors. Given that there is very little empirical consensus on the size of the productivity effects of infrastructure investments in developing economies, we assume a value of 0.5 for the spillover parameter in equation (2), that is, $\rho_{sg} = 0.50$ in both cases.[11] This value is comparably higher than the values estimated by Hulten (1996), who studies the relationship of infrastructure capital and economic growth. This higher value reflects in part the expectation of a higher marginal product of public capital for countries with a severely depleted capital stock and in part the likelihood that the contemporary marginal productivity of public infrastructure expenditure in Ghana may be higher than the historical point estimates suggest.

For each scenario, the average annual changes for selected variables over three periods (2007–2009, 2007–2013, and 2007–2027) are reported. To simplify the presentation, we report only a small number of key aggregate variables in tables: the real exchange rate, total and sectoral exports, real GDP, total and government fixed investment, and real consumption of rural and urban households. At given

[11] This implies that a 10 percent rise in total public capital stock relative to sectoral output induces a 5 percent increase in total factor productivity.

constant income-tax rates and given savings rates, the changes in real consumption reflect changes in real disposable income.

OIL1: A "Spend All" Strategy Fosters Growth, yet Leads to Dutch Disease Effects and Hurts Rural Households

In scenario 1, the primary impact of oil revenues is an increase in public investment, which leads to a higher level of real GDP growth in both the short and medium term compared to the baseline (see Table 2). The real exchange rate appreciates modestly in the short run, which is mainly due to the assumed high adjustment flexibility in foreign trade and domestic factor markets. However, increases in investment demand induce significant changes in the terms of trade and a sizable contraction in exports in favor of higher production of domestic goods.

These Dutch disease effects weaken over time, yet the effect of relative price changes on the cost of capital goods persists. This implies that although these changes moderate over time, the initial decline in export performance does not reverse drastically, and hence initial welfare gains increase only slightly in the long run.

Total household income increases in real terms from the base run, yet the gains are not distributed equally across household groups. While the income levels of urban households increase, rural household incomes fall in the short run and remain largely unchanged in the long run. The main reason for these increasing disparities between rural and urban households is demand-side effects. Additional government investment is primarily spent on capital goods and construction, raising the relative prices for these mainly urban sectors. Moreover, the backward linkages from these urban industrial sectors to the agricultural sectors, from which many rural households earn their income, are weak. In addition, the agricultural export sector is hurt by exchange rate appreciation, which exacerbates the negative effects for rural households. As later results show, these demand-side effects may be largely offset when oil revenues are used for productivity-enhancing investments but may reemerge and increase when relative price effects turn against agriculture.

OIL2: A "save all and Invest Interest Only" Strategy has very Limited Growth Effects

In scenarios 2–4, all or part of the oil revenues are saved in an oil fund (as foreign assets) and only interest earned from the fund is used to finance investments. In scenario 2, a moderate but permanent income stream generated from interest earnings finances additional investment of a modest 1.7 and 1.4 percentage points in the short and long run, respectively. Thus, there is now less cumulative growth in GDP both in the short and long term and a marked reduction in total investment compared to scenario 1. As a consequence, relative price changes are less pronounced in the short run but increase over time with increasing income from interest. Total exports decline in the short run but increase in the long run, compared with the baseline. However, the changes are significantly smaller than in scenario 1.

The short- and long-run effects on household incomes are significantly smaller than in scenario 1. Savings to create the oil fund largely avoid the short-run reduction of rural households' income. In the long run, rural households' income is not affected by the decision to either spend or save oil revenues, indicating the need for more targeted spending to raise rural households' income.

Table 2. Impacts of oil revenue inflows on selected economic variables in the model simulations, without consideration of productivity spillovers from public investments (percentage-point changes compared to base-run growth rates)

Experiment	Period	BASE	OIL1 Spending	OIL2 Saving	OIL3 Budget Support	OIL4 Smoothing
Exchange rate	to T = 2009	0				
	to T = 2013	-0.1	-0.2	0	-0.1	-0.2
	to T = 2027	-0.2	-0.2	-0.1	-0.1	-0.2
Exports	to T = 2009	5.7				
	to T = 2013	5.9	-4.6	-0.7	-1.9	-3.5
	to T = 2027	7.1	1.1	0.3	0.7	1
Agriculture	to T = 2009	7.5				
	to T = 2013	6.6	-5.3	-0.7	-2.5	-3.9
	to T = 2027	3.3	-3.3	-1.7	-2.7	-3.1
Mining	to T = 2009	4.3				
	to T = 2013	5.9	-4.3	-0.9	-1.7	-3.5
	to T = 2027	9.9	2.1	0.9	1.5	1.9
Services	to T = 2009	4.2				
	to T = 2013	3.9	-3	-0.5	-1.4	-2.2
	to T = 2027	2.9	-1.3	-0.7	-1.1	-1.2
Real GDP	to T = 2009	4.6				
	to T = 2013	4.8	0.6	0.1	0.3	0.4
	to T = 2027	5.4	0.7	0.4	0.6	0.7
Investment	to T = 2009	6.1				
	to T = 2013	6.2	9	1.7	4.4	7.1
	to T = 2027	6.8	2.1	1.4	2	2.1
Government investment						
	to T = 2009	6.3				
	to T = 2013	6.4	16.8	17	16.9	16.9
	to T = 2027	7.1	3.4	3.6	3.6	3.5
Real income						
Rural	to T = 2009	3.9				
	to T = 2013	3.9	-0.4	0	-0.2	-0.3
	to T = 2027	4.1	0	0	0	0
Urban	to T = 2009	5.2				
	to T = 2013	5.4	0.8	0.1	0.4	0.6
	to T = 2027	6	0.5	0.3	0.4	0.5
Real wage	to T = 2009	1.9				
	to T = 2013	2.2	1.2	0.1	0.5	0.9
	to T = 2027	2.8	0.8	0.4	0.6	0.7

Source: DCGE model results

OIL3: Supporting the Budget with Oil Revenues Stabilizes the Debt Ratio, yet Only Modestly Accelerates Growth Due to Dutch Disease Effects

While scenarios 1 and 2 represent two extreme cases of oil revenue allocation, scenarios 3 and 4 consider a strategy in which the government decides to save only part of oil revenues in the oil fund. In the case of scenario 3, we assume that, starting with the inflows of oil revenues in 2010, an oil revenue equivalent of 5 percent of GDP is retained to support the public budget. Compared to scenario 2, this allocation rule results in both increasing savings in the oil fund and increasing investment until 2013. As expected, an increase in investment demand results in a worsening of the terms of trade in the short term, with the above-mentioned consequences. After 2013, with stagnant oil revenues but increasing GDP, savings deposited into the oil fund decrease steadily. However, increasing interest revenue from the oil fund still allows for an increase in investment and GDP growth over the whole simulation period. Impacts are comparable to those of scenario 1, yet with less short-run adjustment cost for rural households.

OIL4: In the Long Run, Smoothing Oil-Revenue Spending Balances Growth, Distribution, and Stability Targets

The allocation rule in scenario 4 implies that savings in the oil fund increase with rising oil revenues and decrease with a rise in savings stocks. Thus, given the parameterization indicated above, savings in the oil fund increase between 2010 and 2013 and start decreasing thereafter, until 2027. The long-run macroeconomic, sectoral, and distributional outcomes are comparable to those of scenario 1, in which all oil revenues are immediately invested as they flow in. However, compared to spending oil revenues immediately (scenario 2), saving part of the revenues in an oil fund has the obvious advantage of providing income from interest, even after the oil boom. In addition, the short-run adjustment costs with respect to exports and rural incomes are significantly lower than in the spending scenario.

Robustness Check: Productivity Improvements Due to Investments Accelerate Growth and Can Offset Dutch Disease Effects

In scenarios 1a–4a and 1b–4b, public investments raise the productivity in the economy. The absence of productivity increases in domestic production (in 1a–4a) leads to a stronger appreciation of the real exchange rate compared to scenarios 1–4 (see Table 3). Hence, although the export performance of traditional cash crops and services is significantly stronger because of the productivity bias, mining exports are hit relatively hard, with no productivity effect. When the productivity gain is biased toward production of domestic goods (in 1b–4b), outcomes are markedly different (Table 4). The bias in production (which increases the supply of nontradables and import substitutes) partly offsets the demand effects of the increased foreign exchange inflows so that the initial real exchange rate appreciation is reversed, even in the short run. Yet the effects on exports are symmetrical with those in scenarios 1–4; cash crop exports are hit even harder, while services exports are less affected and mining exports recover less than in earlier experiments. Overall export performance is weaker with a domestic bias than with an export bias. The domestic-biased supply response also leads to a larger improvement in the long-run fiscal balance, reflecting favorable relative price movements as well as the effects of higher growth and investment than in either the case without productivity effects or export-biased forms of productivity growth.

The most striking difference between scenarios 1a–4a and 1b–4b is the effect on households' disposable real income. Compared to the case of no productivity effects, productivity effects induced by public investment lead to higher real income growth for both household groups. However, the income gain is spread somewhat differently across household groups, with rural households benefitting less than urban households when productivity effects are biased toward domestic production. This contrasts sharply with the export-biased supply response, which generates a lower aggregate real income gain in the long run but favors rural households.

Table 3. Impacts of oil revenue inflows on selected economic variables in the model, with consideration of productivity spillovers from public investment in export sectors (percentage-point changes compared to base-run growth rates)

Experiment	Period	BASE	OIL1 Spending	OIL2 Saving	OIL3 Budget Support	OIL4 Smoothing
Exchange rate	to T = 2009	0	0.1			
	to T = 2013	-0.1	-0.5	0	-0.2	-0.3
	to T = 2027	-0.2	-0.1	-0.1	-0.1	-0.1
Exports	to T = 2009	5.7	-0.2			
	to T = 2013	5.9	-1.5	-0.7	-0.7	-1.3
	to T = 2027	7.1	0.9	-0.2	0.4	0.7
Agriculture	to T = 2009	7.5	-1.6			
	to T = 2013	6.6	-1.8	-0.9	-1.2	-1.6
	to T = 2027	3.3	2.9	2.5	2.7	2.8
Mining	to T = 2009	4.3	0.9			
	to T = 2013	5.9	-1.2	-0.5	-0.5	-1.1
	to T = 2027	9.9	-0.1	-1.4	-0.7	-0.2
Services	to T = 2009	4.2	0.7			
	to T = 2013	3.9	-1.9	-0.6	-0.2	-1.3
	to T = 2027	2.9	2.6	0.3	2.4	2.5
Real GDP	to T = 2009	4.6	0			
	to T = 2013	4.8	1.2	0.1	0.6	0.9
	to T = 2027	5.4	0.9	0.3	0.7	0.8
Investment	to T = 2009	6.1	0			
	to T = 2013	6.2	9.1	1.7	4.8	7.2
	to T = 2027	6.8	2.3	1.4	2.1	2.3
Government investment						
	to T = 2009	6.3	0.1			
	to T = 2013	6.4	16.9	17	16.9	16.9
	to T = 2027	7.1	3.5	3.7	3.7	3.6
Real income						
Rural	to T = 2009	3.9	0			
	to T = 2013	3.9	0.4	0	0.2	0.3
	to T = 2027	4.1	0.5	0.1	0.4	0.5
Urban	to T = 2009	5.2	0			
	to T = 2013	5.4	1.3	0.1	0.6	0.9
	to T = 2027	6	0.4	0	0.3	0.4
Real wage	to T = 2009	1.9	0			
	to T = 2013	2.2	1.8	0.1	0.8	1.3
	to T = 2027	2.4	1.4	0.8	1.2	1.4

Source: DCGE model results

Table 4. Impacts of oil revenue inflows on selected economic variables in the model, with consideration of productivity spillovers from public investment in domestic sectors (percentage-point changes compared to base-run growth rates)

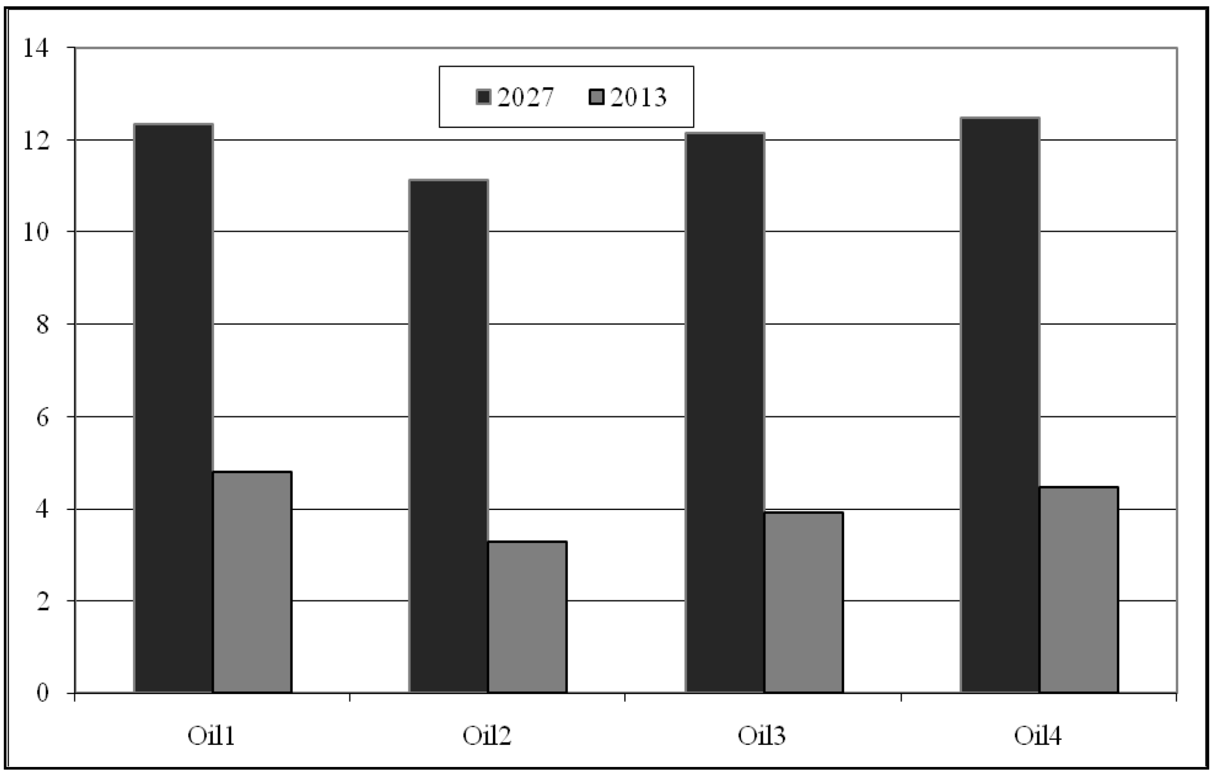
Experiment	Period	BASE	OIL1 Spending	OIL2 Saving	OIL3 Budget Support	OIL4 Smoothing
Exchange rate	to T = 2009	0	0			
	to T = 2013	-0.1	0	0.1	0.1	0.1
	to T = 2027	-0.2	0	0	0	0
Exports	to T = 2009	5.7	-0.1			
	to T = 2013	5.9	-5.1	-0.8	-2.2	-3.9
	to T = 2027	7.1	0.8	0.1	0.4	0.7
Agriculture	to T = 2009	7.5	0.1			
	to T = 2013	6.6	-5.8	-0.8	-2.7	-4.2
	to T = 2027	3.3	-3.5	-1.9	-2.9	-3.4
Mining	to T = 2009	4.3	-0.1			
	to T = 2013	5.9	-5.2	-1.1	-2.1	-4.2
	to T = 2027	9.9	1.7	0.6	1.1	1.6
Services	to T = 2009	4.2	0.1			
	to T = 2013	3.9	-2.7	-0.3	-1.2	-2
	to T = 2027	2.9	-1.2	-0.6	-0.9	-1.1
Real GDP	to T = 2009	4.6	0.1			
	to T = 2013	4.8	0.9	0.1	0.5	0.7
	to T = 2027	5.4	1	0.6	0.8	1
Investment	to T = 2009	6.1	0			
	to T = 2013	6.2	9	1.7	4.7	7.1
	to T = 2027	6.8	1.1	1.5	2.1	2.2
Government investment						
	to T = 2009	6.3	0.1			
	to T = 2013	6.4	17.1	17.1	17.1	17.2
	to T = 2027	7.1	3.7	4	3.9	3.8
Real income						
Rural	to T = 2009	3.9	0			
	to T = 2013	3.9	-0.1	0	0	-0.1
	to T = 2027	4.1	0.3	0.2	0.2	0.3
Urban	to T = 2009	5.2	0.1			
	to T = 2013	5.4	1.1	0.2	0.6	0.8
	to T = 2027	6	0.9	0.5	0.7	0.8
Real wage	to T = 2009	1.9	0.3			
	to T = 2013	2.2	1.7	0.2	0.8	1.2
	to T = 2027	2.8	1.2	0.7	1	1.2

Source: DCGE model results

Comparing Strategies: The Oil Fund will Provide Revenues Long after Oil Resources are Depleted

Figure 2 summarizes the difference in oil-related revenues between a situation with and without an oil fund. We compare the simulation results with the base run and show the deviations in terms of real GDP adjusted for interest income from the oil fund on the basis of an interest rate held constant at 5 percent. This comparison shows that the loss in terms of income between scenario 1 and scenarios 2 or 3 is modest. For scenario 2, GDP plus interest is about 1.5 (1.2) percent lower in 2013 (2027), indicating that the gap closes over time. For scenario 3, in which oil revenues worth about 5 percent of GDP are allocated to each year's fiscal budget, the gap is even smaller and accounts for only 0.2 percent in 2027. For scenario 4, in which oil-revenue spending is smoothed over time according to two parameters for current spending and for drawing out of the oil fund, the GDP figures adjusted for additional interest income are even larger than in scenario 1. Given that the oil fund allows the country to continue to enjoy the income generated from oil even after the end of the oil era, this scenario appears to be the best option for long-run growth and stability.

Figure 2. GDP plus interest on oil fund, deviation from base (percent of GDP)



Source: Authors' calculation from Appendix Table A.4

5. SPENDING VERSUS SAVING OIL REVENUES: CONCLUDING REMARKS

This paper has examined the potential trade-offs between spending and saving oil revenues in terms of growth, income distribution, and stability in Ghana. Consistent with the empirical evidence on the Dutch disease effects characteristic of resource booms, we found that in a scenario in which all oil revenues are spent as they flow in, the growth effect is largest in the short run. However, this short-term advantage declines over time and comes at the cost of significant negative effects for nonmineral export sector performance and rural households. We have therefore considered several other oil revenue allocation options. We show that over the long run the differences between spending- and saving-based allocation options are relatively small, as interest earned from the oil fund can be used to finance investments in the long run. Taking this longer-run perspective, a big push strategy appears even less promising given its relatively modest longer-term growth impacts compared to oil fund options. Smoothing oil revenue allocations into the fiscal budget by saving part of the inflow in an oil fund appears to be the preferred option: results show that it is preferable not only for growth and stability but also for equality, mainly because the negative short-run effects on agriculture are significantly moderated. Yet, in all scenarios, agriculture and rural areas tend to grow less relative to nonagricultural sectors and urban areas, suggesting that more targeted investments are needed to accelerate rural income growth. Results indicate that using oil revenues to increase agricultural productivity and improve rural competitiveness has the potential to offset the Dutch disease effects and make an important contribution to economywide growth.

These positive impacts of an oil-fund-based allocation rule might yet be underestimated. Establishing an oil fund implies the accumulation of assets, which are available to the budget in the post-oil era after 2027. For example, in the extreme case of scenario 2, in which all oil revenues are saved, the size of the oil fund will be equivalent to the level of GDP by 2027 (assuming average oil prices of US$80 per barrel). Income from interest earned from this fund will be about 4.85 percent of GDP (assuming a 5 percent interest rate). Even with the more moderate accumulation in scenarios 3 and 4, incomes generated from the oil fund will still be considerable, amounting to about 2.3 and 0.7 percent of GDP, respectively. Hence, with an oil fund, oil revenues will make a substantial contribution to government revenues in the long run (see Appendix Table A.4).

The creation of an oil fund can also help smooth global commodity price shocks. This function of an oil fund is especially important for countries like Ghana, which have a relatively high exposure to world market price volatility due to their relatively low level of export diversification and high import intensity for capital goods. The recent and ongoing global food, fuel, and financial crisis and the associated extreme volatility in world commodity prices further underline the importance of establishing an oil fund to cope with future shocks. The fact that we did not consider this additional positive effect in this paper suggests that the estimated positive effects of an oil-fund-based allocation rule might be even greater.

Reaping the benefits of an oil-fund-based allocation rule will require improved government capacity in managing macroeconomic policies. Moreover, oil revenues are likely to challenge the country's government in terms of addressing inefficiencies and the corruption often associated with resource rents. Clear and transparent rules will be needed to guide future revenues from interest and the allocation of spending. This paper has provided an example of how such a rule can be designed to further strengthen Ghana's position as a frontrunner in African development.

APPENDIX A

Table A.1. Economic structure in the base year, Ghana, 2007

Sector	VAshr	PRDshr	EMPshr	EXPshr	EXP-OUTshr	IMPshr	IMP-DEMshr
Domestic agriculture	23.5	19.5	15.8			6.6	11.3
Export agriculture	9.9	8.2	8.1	42.2	79.6		
Mining	8.7	7.3	4.3	44.3	96.2		
Manufacturing	10.0	14.7	13.0			76.9	63.1
Industry	4.1	9.1	3.2			16.4	34.8
Construction	10.6	7.8	11.2				
Private services	20.2	25.8	26.4	13.5	8.3		
Public services	13.0	7.5	18.1				
TOTAL-2	100.0	100.0	100.0	100.0	15.7	100.0	27.8
Total agriculture	33.3	27.8	23.8	42.2	23.6	6.6	10.5
Total nonagriculture	66.7	72.2	76.2	57.8	12.7	93.4	32.3
TOTAL	100.0	100.0	100.0	100.0	15.7	100.0	27.8

Source: Appendix Table A.2 and DCGE model results

Notes:

VAshr: Sector share of total value-added

PRDshr: Sector share of total production

EMPshr: Sector share of total labor income

EXPshr: Sector share of total export revenues

EXP-OUTshr: Share of exports in output

IMPshr: Sector share of total imports

IMP-DEMshr: Share of imports in sectoral absorption

Table A.2. 2007 Ghana SAM

	aagrd	aagre	amine	amanu	aindu	acons	aprvs	apubs	cagrd	cagre	cmine	cmanu	cindu	ccons	cprvs	cpubs	lab	cap	land	hrur	hurb	gov	dtax	stax	mtax	etax	s-i	row	total
aagrd									4,773																				4,773
aagre										2,021																			2,021
amine											1,706																		1,706
amanu												3,512																	3,512
aindu													2,235																2,235
acons														1,901															1,901
aprvs															6,879														6,879
apubs																1,859													1,859
cagrd	545			484			114													2,465	1,790							179	5,577
cagre	2	60		324			11																					1,657	2,054
cmine				13		55																						1,638	1,706
cmanu	223	345	331	538	553	412	531	37												2,497	3,072						1,920	673	11,132
cindu	43	12	197	443	937	25	1,458	23												446	665								4,248
ccons					49		42																				1,813		1,904
cprvs	992	348	125	475	184	68	1,945	132	29			317	53		399					658	1,353							964	8,041
cpubs																				33	35	1,791							1,859
lab	1,061	546	273	847	212	751	1,932	1,238																					6,860
cap	170	163	779	387	300	591	847	428																					3,667
land	1,737	544																											2,282
hrur																	1,156	2,095	2,282			564						410	6,508
hurb																	5,704	1,571				872						1,656	9,803
thh																				-535	535								0
gov																							1,252	1,575	775	34		1,303	4,939
dtax																					1,252								1,252
stax												515	708	3	349														1,575
mtax									130			640	5																775
etax										34																			34
s-i																				944	1,101	1,594						93	3,733
row									645			6,149	1,247		415							118							8,574
total	4,773	2,021	1,706	3,512	2,235	1,901	6,879	1,859	5,577	2,054	1,706	11,132	4,248	1,904	8,041	1,859	6,860	3,667	2,282	6,508	9,803	4,939	1,252	1,575	775	34	3,733	8,574	334,218

Notes: *Activities*: domestic agriculture, export agriculture, mining, manufacturing, utilities, construction, private services, public services; *commodities*: domestic agriculture, export agriculture, mining, manufacturing, utilities, construction, private services, public services; *factors*: labor, land, capital; *households*: rural, urban, inter-household transfers (thh); *taxes*: direct taxes, sales taxes, import taxes, export taxes; *S-I*: savings and investment; *ROW*: rest of the world

Table A.3. Expenditure shares and elasticities by household groups

	hrur	hurb
	Average expenditure shares (percent)	
cagrd	0.404	0.259
cmanu	0.409	0.444
cindu	0.073	0.096
cprvs	0.108	0.196
cpubs	0.005	0.005
Total	1.000	1.000
	Income elasticities of demand	
	0.9	0.9

Source: See text

Table A.4. Growth vs. accumulation: Deviation of GDP and oil fund from base run (100 million cedis in constant 2007 prices)

	2010	2011	2012	2013	2014	2021	2027
GDP							
Oil1	1.69	3.30	5.73	7.94	10.31	32.73	63.25
Oil2	0.15	0.34	0.65	1.10	1.69	11.01	30.16
Oil3	1.16	1.93	2.87	3.99	5.30	21.28	49.18
Oil4	1.06	2.18	3.93	5.70	7.71	29.02	59.93
Oil Fund							
Oil1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oil2	6.95	23.53	47.04	74.86	102.75	297.95	465.27
Oil3	2.49	9.96	23.94	41.79	59.23	165.74	228.30
Oil4	2.95	9.56	18.12	27.22	34.99	64.90	73.69
GDP + Interest							
Oil1	1.69	3.30	5.73	7.94	10.31	32.73	63.25
Oil2	0.50	1.52	3.00	4.84	6.83	25.91	53.42
Oil3	1.28	2.43	4.07	6.08	8.26	29.57	60.60
Oil4	1.21	2.66	4.84	7.06	9.46	32.27	63.61

Source: DCGE model results

APPENDIX B

Table B.1. Mathematic presentation of DCGE model: sets, parameters, and variables

Symbol	Explanation	Symbol	Explanation
Sets			
$a \in A$	Activities	$c \in CEN(\subset C)$	Commodities not in *CE*
$a \in ALEO(\subset A)$	Activities with a Leontief function at the top of the technology nest	$c \in CM(\subset C)$	Aggregate imported commodities
$c \in C$	Commodities	$c \in CMN(\subset C)$	Commodities not in *CM*
$c \in CD(\subset C)$	Commodities with domestic sales of domestic output	$c \in CX(\subset C)$	Commodities with domestic production
$c \in CDN(\subset C)$	Commodities not in *CD*	$f \in F$	Factors
$c \in CE(\subset C)$	Exported commodities	$h \in H(\subset INSDNG)$	Households
Equation parameters			
cpi	Consumer price index	$mps01_i$	0-1 parameter with 1 for institutions with potentially flexed direct tax rates
$cwts_c$	Weight of commodity c in the CPI	pwe_c	Export price (foreign currency)
ica_{ca}	Quantity of c as intermediate input per unit of activity a	$shif_{if}$	Share for domestic institution i in income of factor f
$icd_{cc'}$	Quantity of commodity c as trade input per unit of c' produced and sold domestically	$shii_{ii'}$	Share of net income of i' to i (i' ∈ INSDNG'; i ∈ INSDNG)
$ice_{cc'}$	Quantity of commodity c as trade input per exported unit of c'	ta_a	Tax rate for activity a
$icm_{cc'}$	Quantity of commodity c as trade input per imported unit of c'	$tins_i$	Exogenous direct tax rate for domestic institution i
$inta_a$	Quantity of aggregate intermediate input per activity unit	$tins01_i$	0-1 parameter with 1 for institutions with potentially flexed direct tax rates
iva_a	Quantity of aggregate intermediate input per activity unit	tm_c	Import tariff rate
mps_i	Base savings rate for domestic institution i	tq_c	Rate of sales tax

Table B.2. (Continued)

Symbol	Explanation	Symbol	Explanation
Equation parameters, continued			
α_a^a	Efficiency parameter in the CES activity function	δ_{cr}^t	CET function share parameter
α_a^{va}	Efficiency parameter in the CES value-added function	δ_{fa}^{va}	CES value-added function share parameter for factor f in activity a
α_c^{ac}	Shift parameter for domestic commodity aggregation function	γ_{ch}^m	Subsistence consumption of marketed commodity c for household h
α_c^q	Armington function shift parameter	θ_{ac}	Yield of output c per unit of activity a
α_c^t	CET function shift parameter	ρ_a^a	CES production function exponent
β^a	Capital sectoral mobility factor	ρ_a^{va}	CES value-added function exponent
β_{ch}^m	Marginal share of consumption spending on marketed commodity c for household h	ρ_c^{ac}	Domestic commodity aggregation function exponent
δ_a^a	CES activity function share parameter	ρ_c^q	Armington function exponent
δ_{ac}^{ac}	Share parameter for domestic commodity aggregation function	ρ_c^t	CET function exponent
δ_{cr}^q	Armington function share parameter	η_{fat}^a	Sector share of new capital
υ_f	Capital depreciation rate		
Exogenous variables			
$fsav$	Foreign savings (FCU)	qg_c	Government consumption demand for commodity
mps_i	Marginal propensity to save for domestic nongovernment institution (exogenous variable)	$qinv_c$	Base-year quantity of private investment demand
pwm_c	Import price (foreign currency)	$trnsfr_{if}$	Transfer from factor f to institution i
$qdst_c$	Quantity of stock change	$wfdist_{fa}$	Wage distortion factor for factor f in activity a
qfs_f	Quantity supplied of factor		
Endogenous variables			
AWF_{ft}^a	Average capital rental rate in time period t	$QINTA_a$	Quantity of aggregate intermediate input
$IADJ$	Investment adjustment factor	$QINT_{ca}$	Quantity of commodity c as intermediate input to activity a
EG	Government expenditures	$QINV_c$	Quantity of investment demand for commodity
EH_h	Consumption spending for household	QM_{cr}	Quantity of imports of commodity c
EXR	Exchange rate (LCU per unit of FCU)	PA_a	Activity price (unit gross revenue)
$GSAV$	Government savings	PD_c	Demand price for commodity produced and sold domestically
QF_{fa}	Quantity demanded of factor f from activity a	PE_{cr}	Export price (domestic currency)
QH_{ch}	Quantity consumed of commodity c by household h	$PINTA_a$	Aggregate intermediate input price for activity a
QHA_{ach}	Quantity of household home consumption of commodity c from activity a for household h	PK_{ft}	Unit price of capital in time period t

Table B.2. (Continued)

Symbol	Explanation	Symbol	Explanation
Endogenous variables, continued			
PM_{cr}	Import price (domestic currency)	QX_c	Aggregated quantity of domestic output of commodity
PQ_c	Composite commodity price	$QXAC_{ac}$	Quantity of output of commodity c from activity a
PVA_a	Value-added price (factor income per unit of activity)	$TRII_{ii'}$	Transfers from institution i' to i (both in the set INSDNG)
PX_c	Aggregate producer price for commodity	WF_f	Average price of factor
$PXAC_{ac}$	Producer price of commodity c for activity a	YF_f	Income of factor f
QA_a	Quantity (level) of activity	YG	Government revenue
QD_c	Quantity sold domestically of domestic output	YI_i	Income of domestic nongovernment institution
QE_{cr}	Quantity exported of domestic output	YIF_{if}	Income to domestic institution i from factor f
QQ_c	Quantity of goods supplied to domestic market (composite supply)	K^a_{fat}	Quantity of new capital by activity a for time period t
QVA_a	Quantity of (aggregate) value-added		

Table B.3. Mathematical presentation of DCGE model: model equations

Production and price equations

$$QINT_{c\,a} = ica_{c\,a} \cdot QINTA_a \qquad (1)$$

$$PINTA_a = \sum_{c \in C} PQ_c \cdot ica_{ca} \qquad (2)$$

$$QVA_a = \alpha_a^{va} \cdot \left(\sum_{f \in F} \delta_{f\,a}^{va} \cdot \left(\alpha_{f\,a}^{vaf} \cdot QF_{f\,a} \right)^{-\rho_a^{va}} \right)^{-\frac{1}{\rho_a^{va}}} \qquad (3)$$

$$W_f \cdot \overline{WFDIST}_{fa} = PVA_a \cdot QVA_a \cdot \left(\sum_{f \in F'} \delta_{f\,a}^{va} \cdot \left(\alpha_{f\,a}^{vaf} \cdot QF_{f\,a} \right)^{-\rho_a^{va}} \right)^{-1} \cdot \delta_{f\,a}^{va} \cdot (\alpha_{f\,a}^{vaf})^{-\rho_a^{va}} \cdot \left(QF_{f\,a} \right)^{-\rho_a^{va}-1} \qquad (4)$$

$$QVA_a = iva_a \cdot QA_a \qquad (5)$$

$$QINTA_a = inta_a \cdot QA_a \qquad (6)$$

$$PA_a \cdot (1 - ta_a) \cdot QA_a = PVA_a \cdot QVA_a + PINTA_a \cdot QINTA_a \qquad (7)$$

$$QXAC_{a\,c} = \theta_{a\,c} \cdot QA_a \qquad (8)$$

$$PA_a = \sum_{c \in C} PXAC_{ac} \cdot \theta_{ac} \qquad (9)$$

$$QX_c = \alpha_c^{ac} \cdot \left(\sum_{a \in A} \delta_{a\,c}^{ac} \cdot QXAC_{a\,c}^{\;-\rho_c^{ac}} \right)^{-\frac{1}{\rho_c^{ac}-1}} \qquad (10)$$

$$PXAC_{a\,c} = PX_c \cdot QX_c \left(\sum_{a \in A'} \delta_{a\,c}^{ac} \cdot QXAC_{a\,c}^{-\rho_c^{ac}} \right)^{-1} \cdot \delta_{a\,c}^{ac} \cdot QXAC_{a\,c}^{-\rho_c^{ac}-1} \qquad (11)$$

$$PE_{cr} = pwe_{cr} \cdot EXR - \sum_{c' \in CT} PQ_c \cdot ice_{c'c} \qquad (12)$$

$$QX_c = \alpha_c^t \cdot \left(\sum_r \delta_{cr}^t \cdot QE_{cr}^{\rho_c^t} + (1 - \sum_r \delta_{cr}^t) \cdot QD_c^{\rho_c^t} \right)^{\frac{1}{\rho_c^t}} \qquad (13)$$

$$\frac{QE_{cr}}{QD_c} = \left(\frac{PE_{cr}}{PD_c} \cdot \frac{1 - \sum_r \delta_{cr}^t}{\delta_c^t} \right)^{\frac{1}{\rho_c^t - 1}} \qquad (14)$$

$$QX_c = QD_c + \sum_r QE_{cr} \qquad (15)$$

$$PX_c \cdot QX_c = PD_c \cdot QD_c + \sum_r PE_{cr} \cdot QE_{cr} \qquad (16)$$

$$PM_{cr} = pwm_{cr} \cdot (\; 1 + tm_{cr} \;) \cdot EXR + \sum_{c' \in CT} PQ_{c'} \cdot icm_{c'\,c} \qquad (17)$$

$$QQ_c = \alpha_c^q \cdot \left(\sum_r \delta_{cr}^q \cdot QM_{cr}^{-\rho_c^q} + (1 - \sum_r \delta_{cr}^q) \cdot QD_c^{-\rho_c^q} \right)^{-\frac{1}{\rho_c^q}} \qquad (18)$$

Table B.3. (Continued)

$$\frac{QM_{cr}}{QD_c} = \left(\frac{PD_c}{PM_c} \cdot \frac{\delta_c^q}{1 - \sum_r \delta_{cr}^q} \right)^{\frac{1}{1+\rho_c^q}} \tag{19}$$

$$QQ_c = QD_c + \sum_r QM_{cr} \tag{20}$$

$$PQ_c \cdot (1 - tq_c) \cdot QQ_c = PD_c \cdot QD_c + \sum_r PM_{cr} \cdot QM_{cr} \tag{21}$$

$$cpi = \sum_{c \in C} PQ_c \cdot cwts_c \tag{22}$$

Institutional incomes and domestic demand equations

$$YF_f = \sum_{a \in A} WF_f \cdot wfdist_{f\,a} \cdot QF_{f\,a} \tag{23}$$

$$YIF_{i\,f} = shif_{i\,f} \cdot YF_f \tag{24}$$

$$YI_i = \sum_{f \in F} YIF_{i\,f} + \sum_{i' \in INSDNG'} TRII_{i\,i'} + trnsfr_{i\,gov} \cdot cpi + trnsfr_{i\,row} \cdot EXR \tag{25}$$

$$TRII_{i\,i'} = shii_{i\,i'} \cdot (1 - mps_{i'}) \cdot (1 - tins_{i'}) \cdot YI_{i'} \tag{26}$$

$$EH_h = \left(1 - \sum_{i \in INSDNG} shii_{i\,h} \right) \cdot \left(1 - mps_h \right) \cdot (1 - tins_h) \cdot YI_h \tag{27}$$

$$PQ_c \cdot QH_{c\,h} = PQ_c \cdot \gamma_{ch}^m + \beta_{ch}^m \cdot \left(EH_h - \sum_{c' \in C} PQ_{c'} \cdot \gamma_{c'h}^m \right) \tag{28}$$

$$QINV_c = IADJ \cdot qinv_c \tag{29}$$

$$EG = \sum_{c \in C} PQ_c \cdot qg_c + \sum_{i \in INSDNG} trnsfr_{i\,gov} \cdot cpi \tag{30}$$

$$\begin{aligned} YG = &\sum_{i \in INSDNG} tins_i \cdot YI_i + \sum_{c \in CMNR} tm_c \cdot pwm_c \cdot QM_c \cdot EXR + \sum_{c \in C} tq_c \cdot PQ_c \cdot QQ_c \\ &+ \sum_{f \in F} YF_{gov\,f} + trnsfr_{gov\,row} \cdot EXR \end{aligned} \tag{31}$$

System constraints and macroeconomic closures

$$QQ_c = \sum_{a \in A} QINT_{c\,a} + \sum_{h \in H} QH_{c\,h} + qg_c + QINV_c + qdst_c \tag{32}$$

$$\sum_{a \in A} QF_{f\,a} = QFS_f \tag{33}$$

$$YG = EG + GSAV \tag{34}$$

$$\sum_{r\ c \in CMNR} pwm_{cr} \cdot QM_{cr} = \sum_{r\ c \in CENR} pwe_{cr} \cdot QE_{cr} + \sum_{i \in INSD} trnsfr_{i\,row} + fsav \tag{35}$$

$$\sum_{i \in INSDNG} mps_i \cdot \left(1 - \overline{tins_i} \right) \cdot YI_i + GSAV + EXR \cdot fsav = \sum_{c \in C} PQ_c \cdot QINV_c + \sum_{c \in C} PQ_c \cdot qdst_c \tag{36}$$

Table B.3. (Continued)

Factor accumulation and allocation equations (applies to capital only)

$$AWF_{f\,t}^{a} = \sum_{a}\left[\left(\frac{QF_{f\,a\,t}}{\sum_{a'} QF_{f\,a'\,t}}\right)\cdot WF_{f\,t}\cdot wfdist_{f\,a\,t}\right] \tag{37}$$

$$\eta_{f\,a\,t}^{a} = \left(\frac{QF_{f\,a\,t}}{\sum_{a'} QF_{f\,a'\,t}}\right)\cdot\left(\beta^{a}\cdot\left(\frac{WF_{f,t}\cdot wfdist_{f\,a\,t}}{AWF_{f\,t}^{a}}-1\right)+1\right) \tag{38}$$

$$\Delta K_{f\,a\,t}^{a} = \eta_{f\,a\,t}^{a}\cdot\left(\frac{\sum_{c} PQ_{c\,t}\cdot qinv_{c\,t}}{PK_{f\,t}}\right) \tag{39}$$

$$PK_{f\,t} = \sum_{c} PQ_{c\,t}\cdot\frac{qinv_{c\,t}}{\sum_{c'} qinv_{c'\,t}} \tag{40}$$

$$QF_{f\,a\,t+1} = QF_{f\,a\,t}\cdot\left(1+\frac{\Delta K_{f\,a\,t}^{a}}{QF_{f\,a\,t}}-\upsilon_{f}\right) \tag{41}$$

$$QFS_{f\,t+1} = QFS_{f\,t}\cdot\left(1+\frac{\sum_{a} K_{f\,a\,t}}{QFS_{f\,t}}-\upsilon_{f}\right) \tag{42}$$

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