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Can Oil-led Growth and Structural Change Go Hand in Hand in Ghana? A Multi-sector Intertemporal General Equilibrium Assessment

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Abstract:

Unlike in Asia, the manufacturing sector has not (yet) become a driver of structural change in Africa. One common explanation is that the natural resource-focus of many African economies leads to Dutch disease effects. To test this argument for the case of newly found oil in Ghana we develop a multi-sector intertemporal general equilibrium model with endogenous savings and investment behavior. Results show that in addition to the well-known short-term Dutch disease effects, long-term structural effects can indeed impede Asian-style economic transformation in Ghana (and other resource rich countries). We also demonstrate how oil wealth may go hand in hand with structural change in the future.

Keywords: transformation, growth, structural change, oil revenue, Dutch disease, Ghana, intertemporal general equilibrium

JEL classification: C68, D58, D90, F43, O11, O41, O55

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1. Introduction

In the literature on economic development, the 'convergence hypothesis' implies that poor countries should be growing at a faster rate than richer countries, given the fulfillment of certain conditions relating to savings behavior, technology and population growth. While this hypothesis has generally held over the past thirty to forty years for those developing countries, whose economies are based on manufacturing, growth rates have often been disappointing in developing countries that are rich in natural resources. The pioneering study by Sachs and Warner (1995) shows that resource rich countries grew on average about one percentage point less during 1970-89. Moreover, the adverse effects of resource abundance on economic growth still hold if country-specific geographical and climate factors are taken into account (Sachs and Warner 2001). These results suggest that resource abundance blocks countries from the kind of beneficial structural change that often accompanies successful development.

The most popular example is perhaps oil-rich Nigeria (Bevan et al. 1999; Sala-i-Martin and Subramanian 2003). Although oil revenues per capita have increased tenfold from 1965 to 2000, income per capita in Nigeria has stagnated.[1] At the other end of the spectrum are countries such as Botswana and Norway, which have shown remarkable growth performances despite their rich endowment with diamonds and oil. Other countries with large extractive sectors that escaped from the so-called 'natural resource curse' are Malaysia, Indonesia and Chile (Frankel 2010; Gelb and Grasmann 2010)

Some observers have offered explanations for the natural resource curse, the most popular being de-industrialization caused by appreciation of the real exchange rate, also called Dutch disease[2]. Dutch disease effects can permanently damage a country's development prospects, for example when they lead to the extinction of export-oriented sectors. Industries that have been pushed out of the market often find it difficult to re-capture market shares even after the resource rents have dried up and the real exchange rate returned to a lower level. This is because foreign competitors are likely becoming more competitive over time by adopting new technologies, which often renders the costs (in terms of human and physical capital) of re-

[1] More recently, economic reforms have put Nigeria back on track towards achieving its full economic potential. Nigerian GDP at purchasing power parity more than doubled from $170.7 billion in 2005 to $374.3 billion in 2010. Correspondingly, the GDP per capita almost doubled from $1200 per person in 2005 to an estimated $2,078 per person in 2011. See EIU (2012).

[2] The phenomenon was first observed in The Netherlands with the export of natural gas found in Slochteren in 1959 and the accompanying relative decline of Dutch manufacturing.

entering the market prohibitively high. A second explanation has been associated with the volatility of world resource prices, which may harm exports and output (El Anshasy and Bradley 2011). Gelb and Grasman (2010) note that even by the standards of volatile commodity prices, oil prices are exceptionally uncertain and oil exporters have typically not succeeded in smoothing these extreme price cycles. Collier and Venables (2011) summarize research on the impact of large terms of trade gains and losses on developing countries and find asymmetric adjustment, where favorable shocks do not have significant effects on growth, while adverse shocks reduce output.

In addition to price-related factors, it has also been argued that resource wealth leads to unsustainable government policies (e.g., Ross 1999) and induces corruption, rent seeking and even armed conflict (van der Ploeg 2011; Gelb 1998; Auty 2001; Collier and Hoeffler 2004). But whether price or non-price factors play the dominant role in the development of resource-based economies is still controversial.

If the appreciation of the real exchange rate is the dominating issue, the government has many policy options ─ both at the macro- and the meso-level ─ to reduce the threat of Dutch disease (Frankel 2010). At the macro level, the government may reduce domestic absorption either through restrictive fiscal and monetary policies or through sterilization of resource revenues; for example by saving part of the revenues abroad in special funds and repatriate them slowly. In a fixed exchange rate system, the government may devalue the local currency to counteract the price-induced real appreciation.[3] However, the impact of these macro policies on structural change depends very much on the structural characteristics of the underlying economy with regard to the employment- and current account-situation. At the meso-level, one option can be to revise trade and tax policies, e.g., by providing temporary export subsidies to manufacturing sectors in order to raise domestic prices and profitability, or to liberalize imports, which would lead to a nominal devaluation (at a flexible exchange rate). Other options are wage subsidies in the manufacturing sector or the hiring of foreign workers in order to lower real producer wages. Finally, the government may invest in core public goods to increase productivity in manufacturing. Analyzing these options requires quantitative modeling of the production possibilities of the economy, the dynamics of natural resource

[3] A policy of "exchange-rate protection", which combines restrictive fiscal and monetary policies with devaluation has been recommended, e.g., by Corden and Warr (1981) to avoid Dutch disease as a result of the oil boom in Indonesia.

earnings, and the investment opportunities at hand, considering both physical investments in productive capacity and financial investments in overseas assets.

While different methodologies have been used to study the resource curse, the literature is dominated by cross-sectional reduced-form growth regressions.[4,5] In addition, a few structural models have been used for explaining how resource abundance in general or resource booms in particular may shift resources away from economic sectors that have positive externalities for growth. Sachs and Warner (1999), for example, develop a dynamic Dutch disease model with increasing returns to scale and show that the possibly positive effect of a natural resource boom on growth critically depends on whether the nontraded sector has positive externalities (through increasing returns to scale) for growth. The manufacturing sector is indeed often characterized by increasing returns, but manufacturing products are also often traded goods. Thus a resource boom may have a negative effect on growth by drawing resources away from the manufacturing sector. Obviously, in the theoretical model the long-run effect of foreign inflows depends on how the relationship between inflows and productivity growth—either through positive externalities as in Sachs and Warner (1999) or through a link to public investment as in Agénor et al. (2008); Breisinger et al. (2010) and é et al. (2011a, b), financed by the inflows[6]—is modeled.

Using a simple growth model, Rajan and Subramanian (2005) show that even under the most optimistic assumptions about the use of aid (optimistic in the sense that all aid is invested, none of it is wasted or consumed, and the Dutch disease effect on domestic price is totally ignored), the impact of aid should be positive but relatively small in magnitude. Moreover, once inflows are partially spent on nontraded goods, through the Dutch disease effect the positive public investment–productivity linkage effect on growth can be canceled out. Agénor

[4] Empirical findings that resource-abundant countries tend to grow more slowly than resource-scarce countries are documented in Sachs and Warner (1995, 2001); Gylfason, Herbertsson, and Zoega (1999); Leite and Weidmann (1999); Auty (2001); Bravo-Ortega and De Gregorio (2005); and Sala-i-Martin and Subramanian (2003). Deaton and Miller (1995) and Raddatz (2007), however, find quite contrary results: Commodity booms significantly raise growth. A few studies that use panel data find that the resource-curse effect disappears once one allows for fixed effects; see, for example, Mazano and Rigobon (2006) and Murshed (2004). Van der Ploeg (2011) and Frankel (2010) provide comprehensive surveys of the resource-curse literature.

[5] To overcome the shortcomings of this methodology, Collier and Goderis (2007) adopt a panel cointegration method to disentangle the short- and long-run effects of commodity prices on growth, and still the authors find strong evidence in support of the resource-curse hypothesis.

[6] Adam and Bevan (2006) consider both increasing returns to scale in the private sector as a result of public infrastructure investment, which is financed by foreign aid inflows and a learning-by-doing externality in the manufacturing sector. In Chemingui and Roe (2008) and AlShehabi (2012) total factor productivities are updated exogenously.

et al. (2008) develop a dynamic macroeconomic model in which foreign aid can raise public investment, which, in turn, either directly results in output growth (through accumulation of public capital) or indirectly improves productivity through human capital accumulation. The model is calibrated to the Ethiopian economy and is used to assess the growth and poverty-reduction effects of changes in the level of nonfood aid. By simulating a permanent increase in nonfood aid that is equivalent to 5 percent of gross domestic product (GDP), the model results in about 1 percentage point of additional growth in the long run. However, this model simulation outcome crucially depends on the fiscal parameters that describe the impact of aid on the tax rate, current government spending, and public investment, as well as on the efficiency assumption of public investment. Within the range of two standard-error confidence intervals, the growth effect of public investment does not necessarily mitigate the Dutch disease effect. With a higher adverse impact of aid on the tax rate and recurrent spending, and a lower positive effect on public investment, the Dutch disease effect would become more persistent, which would lead to an unsustainable external position.

Despite the value of structural models relating empirical results to specific behavioral assumptions and parameters, most models that have been used in the past seem either too aggregate or too simple to explain the long-term effect of Dutch disease on structural transformation. Most importantly, by ignoring intertemporal behavior, previous studies only capture part of the transitional dynamics that occur during the growth and transformation process. This paper fills the gap in the literature by developing a detailed multisector intertemporal general equilibrium model for Ghana. In this model capital accumulation is an endogenous result of the private sector's intertemporal saving/investment decisions. Thus, in addition to capturing the Dutch disease effect on relative prices, the model also takes changes in savings and investment decisions and allocations into account.

Ghana provides a good case study as one of Africa's rising economic stars, which has recently become an oil exporter (Breisinger et. al. 2011). 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 caused by institutional and/or political factors. State and institution building in Ghana has made rapid progress in recent years, and some important governance indicators, including government effectiveness, regulatory quality, and control of corruption, have exceeded the regional averages of Asia, Latin

America, and Africa (Kaufmann et al. 2008). In terms of economic development, Ghana has experienced more than two decades of sound and persistent annual growth of around 5 percent and is among a group of very few African countries with positive per capita GDP growth over a relative long period of time. Despite this success, however, the Ghanaian economy displayed several structural characteristics typical of African countries with symptoms of Dutch disease even in the pre-oil era. Although the share of the agricultural sector in the total economy has declined over time, the sector still contributes about one-third of total GDP, which is above the African average. Also, the country's export structure has not changed much over the last 50 years. Agricultural exports are concentrated in one crop (cocoa), which, together with gold, constitutes more than 60 percent of total exports. Declines in the relative importance of agriculture as a share of GDP have been compensated by the increases in services, urban construction, and utilities. These domestic-oriented activities currently make up more than 40 percent of the economy. The manufacturing sector, which has been the main driver of growth in many Asian countries, has been declining relative to other sectors, from 9.0 percent of GDP in 2000 to 6.9 percent in 2008 (Figure A1 in Appendix). In comparison, the share of manufacturing in GDP in Vietnam, Thailand, and China rose during their rapid economic transition process and was between 15 and 37 percent when these countries had similar per capita income levels to Ghana in 2007 (Breisinger and Diao 2009).

In 2007 oil was discovered off the coast of Ghana, 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 (Osei and Domfe 2008; World Bank and IMF 2009). Measured by 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 annually and constitute 10 percent of GDP over the exploitation period. Although the relative amount of expected oil revenue is smaller than in some other resource-rich countries (e.g., Angola and Nigeria), the expectations that additional oil revenue will help the country further accelerate growth and speed up economic transformation are high in the country. Given the experiences of its West African neighbors and other African countries, the Government of Ghana is well aware of the potential challenge that oil could present to economic development and the still very young democratic political system. However, there is an urgent need to spend the oil revenue to address key bottlenecks in developing industrial capacities, as stated in Ghana's ambitious development plan, which aims at reaching a middle-income country status by 2015.

In the rest of paper we first introduce the multisector intertemporal general equilibrium model in Section 2 and then describe alternative oil-revenue spending options and how these are introduced into the model in section 3. Section 4 presents the short- and medium-run impacts of oil inflows on both growth and economic structure based on the model. In Section 5 we assess whether smart oil management options can mitigate the Dutch disease by examining different oil management scenarios. Section 6 concludes the paper.

2. A Multisector Intertemporal General Equilibrium Model for Ghana

To address the policy questions raised in the introduction of the paper, an analytic tool that is dynamic and incorporates multiple sectors in a general equilibrium framework is required in order to capture changes in the economic structure and the linkages between growth and the structure of the economy in the dynamic process. For this purpose, we develop a multisector intertemporal general equilibrium model for Ghana. With some modifications, this model is an extended neoclassical intertemporal general equilibrium model. Similar models have been developed by Wilcoxen (1988); Goulder and Summers (1989); Go (1994); Mercenier and de Souza (1994); Diao and Somwaru (2000); and Diao, Rattsø, and Stokke (2005) for various developed and developing countries. In the context of the current study, we have made the following structural changes to the model.

We first assume a relatively closed capital market in Ghana, even though the country is an open economy in terms of trade, and commodity imports and exports are endogenously determined in the model. While FDI has come to Ghana recently (stimulated particularly by the discovery of oil), foreign inflows through private-sector borrowing from international financial markets are still limited. Thus, in the model the domestic private sector is not allowed to borrow from abroad and the only foreign inflows are remittances, foreign aid and grants, and the government's foreign borrowing. Such inflows are treated exogenously without an intertemporal decision making problem.[7] The advantage of this assumption is that it allows for an endogenous interest rate measured in the domestic currency and determined by the equilibrium in the domestic capital market. The domestic capital market is modeled through the intertemporal decisions of private savings and investment. While private savings (and investment) is an endogenous variable (as in any Ramsey-type intertemporal model),

[7] This does not mean that foreign inflows are fixed. Growth in such inflows is constant when inflows are treated exogenously. Moreover, to support the existence of a steady-state equilibrium, the growth rate of foreign has to be the same as the long-run economic growth rate.

government savings (plus foreign inflows to finance public investment) are exogenous. In this way, the government's foreign debt is only an accounting term and will not affect the long-run equilibrium.

The second structural change in the model relates to linking public investment with productivity at the sector level. While the fundamentals of the model are consistent with the neoclassical growth theory in which productivity growth is an exogenous variable, additional public investment through increased oil revenue is assumed to have growth effects on some sectors' productivity, and hence the model can be used to quantitatively measure the impact of oil revenue management as either a short-run level effect or a long-run growth rate effect. Specifically, let

$$X_i = A_i \left(\sum_f \alpha_{i,f} \cdot (B_{i,f} v_{i,f})^{-\rho_i} \right)^{-1/\rho_i} \quad (1)$$

represent the production function for sector i, which has constant returns to scale with constant elasticity of substitution (CES) among inputs. In Equation (1), X_i is output of sector i, $v_{i,f}$ is a vector of inputs, A_i is the shift parameter in the production function, and $B_{i,f}$ is the level of factor productivity and is linked with public investment:

$$B_{i,f,t} = (1 + g_f + g_{i,t}^p) \cdot B_{i,f,t-1}, \text{ with } B_{i,f,1} = 1 \quad (2)$$

In Equation (2), g_f is an exogenous part of the factor productivity growth rate that is not linked with increased public investment, and $g_{i,t}^p$ is an endogenous part of the productivity growth rate that is the outcome of increased public investment. Both g_f and $g_{i,t}^p$ are positive for inputs of labor and land and zero for capital in each sector. $g_{i,t}^p$ is determined by the growth in public investment financed through increased oil revenue only, that is:

$$g_{i,t}^p = \varepsilon_i \left(\frac{\Delta K_t^p}{K_t^p} - \frac{\Delta K_t^{p,0}}{K_t^{p,0}} \right) \quad (3)$$

Where K_t^p and $K_t^{p,0}$ are, respectively, the public capital stock formed by the public investment in the situation with oil revenue and without, ΔK_t^p and $\Delta K_t^{p,0}$ are the public investment at time t with and without oil revenue, and ε_i is the elasticity of productivity growth with respect to additional growth in the stock of public capital, and $0 < \varepsilon_i < 1$.

Recognizing the separability of the consumer's intratemporal decision problem from his or her intertemporal choices, the consumer's optimization can be divided into two components. In the first component the representative consumer in the economy maximizes the overall utility defined in Equation (4) by choosing a composite consumption good intertemporally, and in the second component he or she chooses each sector's good intratemporally for a given amount of the composite good defined in Equation (5) and subject to the current budget constraint defined in Equation (6):

$$\text{Max } U_1 = \sum_{t=1}^{T} (1+\mu)^{-t} \frac{Q_t^{1-\sigma}-1}{1-\sigma} + \frac{(1+\mu)^{1-T}}{\mu} \frac{Q_T^{1-\sigma}-1}{1-\sigma} \quad (4)$$

$$Q_t = \prod_i (c_{i,t} - \gamma_i)^{\vartheta_i} \quad (5)$$

$$\text{s.t. } PQ_t \cdot Q_t = Y_t - S_t^h \text{ and } PQ_t \cdot Q_t = \sum_i P_{i,t} \cdot c_{i,t} \quad (6)$$

In Equation (4), U_1 is the value of the intertemporal utility evaluated at time period 1's price of aggregate consumption (the composite good Q_t), μ is the time discount rate for the representative consumer, and σ is the substitution elasticity over time. In equation (5), $c_{i,t}$ is the intratemporal consumption for sector good i, γ_i is the minimum consumption of this good, which is constant over time, and ϑ_i is the intratemporal marginal budget share for consuming good i. In equation (6), PQ_t and $P_{i,t}$ are, respectively, prices for Q_t and $c_{i,t}$ at time t. Y_t is the consumer's income in each time period, and S_t^h is his or her savings at time t, which, as in a typical Ramsey one-sector framework, is an endogenous variable. In the general equilibrium framework, we assume that factor incomes, which are endogenous variables, all go to households, together with the exogenous incomes transferred from the government and abroad through remittances. Specifically:

$$Y_t = \frac{\sum_f W_{f,t} V_{f,t} + trns_{gov,t} + trns_{row,t}}{PoP_t}, \text{ and } V_{f,t} = \sum_i v_{i,f,t} \quad (7)$$

where W_f is returns to factor f, V_f is the total supply of factor f, trnsgov and trnsrow are transfers received by all the households from the government and abroad, and PoP is the country's population. Besides capital that is endogenously accumulated over time, growth in labor and land supply is assumed to be exogenous. Similar as any intertemporal general equilibrium model, a complete labor market is assumed such that the wage rate is an endogenous variable. Along the transitional equilibrium path, the wage rate is not only affected by the change in labor allocation across sectors over time, but also affected by productivity growth. To simplify the model, we assume that the labor growth rate is the same as the population growth rate, while land expansion is assumed to be slower than population growth. This implies that productivity growth for land (used by agricultural production only) must be faster than productivity growth for labor such that the differential transitional growth across sectors can eventually reach the same steady-state growth in the long run.

We skip the detailed discussion about the Euler equation for the consumer problem and the no-arbitrage condition for the investment problem. We also skip the discussion on the factor demand functions and commodity and factor market equilibrium conditions, which are similar to those in a static general equilibrium model (see Appendix B for the mathematical presentation of the model).

The model is calibrated to a 2007 social accounting matrix (SAM) for Ghana, which is based on a 2005 SAM documented in Breisinger, Duncan, and Thurlow (2007). While the SAM provides information on the demand and production structures of much more detailed sectors, for the purposes of this study we aggregate the economy into five sectors: (1) staple agriculture, (2) export agriculture, (3) mining, (4) tradable nonagriculture, and (5) nontradable nonagriculture. Although we include nontraditional agriculture exports in the export agricultural sector, the sector is primarily dominated by cocoa and forestry, the most important traditional agricultural export products in Ghana. Staple agriculture includes both staple crops and livestock to mainly meet domestic food demand. Mining is an export sector and is dominated by gold in Ghana. We distinguish tradables from nontradables in the economic activities other than agriculture and mining because of the expected differential impact of the oil boom on these sectors. The tradable sector is dominated by manufacturing (which is highly import-dependent) and exportable services, while the nontradable sector includes construction, utilities, and private and public services.

We calibrate the model without considering the oil boom and then shock it by introducing oil revenues in three different spending scenarios. To assess whether the model projections fit with the actual performance of the economy in the past, we first conducted a back casting exercise with the model. We find that the growth path for GDP and agricultural GDP matches the actual performance of the economy well between 1995 and 2007 (see Figure A2 in Appendix). After that, we run the model starting in 2007 and extending to 2050 for three core scenarios corresponding to three government spending options to be discussed in the following section. Oil inflows are assumed to start in 2010.

3. Design of oil revenue spending options

The Ghanaian government has a wide range of options for using its oil rents. We focus on three spending options that are most relevant to the current study and discuss their short-, medium- and long-run impacts on growth and structural change. These are (1) to spend all petrodollars in each year as recurrent expenditure (scenario OIL-1); (2) to invest 50 percent of oil revenue in productivity-enhancing public goods and services and allocate the remaining 50 percent to recurrent spending (scenario OIL-2); and (3) to save 50 percent of oil revenue into an oil fund that invests in riskless foreign assets and earns a fixed income from these foreign assets in the future, and then to spend a certain percentage of the accumulated oil fund in the future. Together with 50 percent of current oil revenue, the spending will be equally split between public investment and recurrent expenditures (scenario OIL-3).

The first option can be seen as an example of a painful lesson that many oil-rich developing countries in the past experienced when oil was first found in their territory (see, for example, Harberger [2009] in the cases of Venezuela and Mexico). The second option is designed to evaluate whether a “smart” way of using oil revenues to encourage economic diversification by actively using oil rents to increase the productivity of non-oil exportable sectors and reducing their production costs can overcome the negative Dutch disease effect. The examples of Malaysia, Chile, and Indonesia suggest that diversification outside the dominant resource sector is not impossible. The third option reflects the practice of some oil-rich countries that have long experience in managing their natural resource revenues sustainably by using an allocation formula. The best self-restrained oil management model is Norway’s, which is based on a principle that oil is “national capital under the ground,” and it should remain national capital after it is extracted. With this option, the oil fund, which is invested in riskless or low-risk foreign assets, becomes permanent income-producing capital. The above three options can be formally presented as follows:

$$TY_t^{oil} = a \cdot CY_t^{oil} + (b + r) \cdot LY_{t-1}^{oil} \tag{8}$$

In Equation (7), TY_t^{oil} is total government income created from the oil sector; CY_t^{oil} and LY_t^{oil} represent, respectively, the current oil extraction revenue and the oil fund; and $(b + r)LY_t^{oil}$ is the income earned or drawn from the oil fund. *a* represents the oil revenue allocation rule, *b* is the oil fund drawing rule, and *r* is the rate of return from investing in riskless foreign assets. In the first two options, *a* is 1.0 and *LY* is zero. Thus, *b* becomes irrelevant. In the third case, *a* is chosen to be 0.5, and *r* is around 0.12. We choose *b* to be at the same value as the long-run growth rate, that is, 0.051.

The accumulation of the oil fund is as follows:

$$LY_t^{oil} = (1 - a) \cdot CY_t^{oil} + (1 - b) \cdot LY_{t-1}^{oil}, \text{ and } LY_1^{oil} = (1 - a) \cdot CY_1^{oil} \;. \tag{9}$$

In all three spending scenarios, oil revenue growth is assumed to be rapid in the first five years after oil is found—a common observation in most countries where oil is discovered, and in line with the World Bank's projected extraction path for Ghana (World Bank 2009). After the first five years, oil revenues are assumed to grow steadily at a constant rate. In order to assess the robustness of central findings, we consider two variants in terms of medium- to long-run oil revenue growth for each spending option. In the first variant, labeled "low oil growth scenario" (scenario a), the medium- and long-run oil revenue growth rates are the same and consistent with long-run GDP growth of 5.06 percent. Thus, the ratio of oil revenue to GDP is relatively stable at 10 percent in the long run, as projected by the World Bank (2009). The second variant (b), labeled "high oil growth scenario" (scenario b), assumes a higher medium-run oil revenue growth rate of 7.62 percent, which implies a higher long run rate of oil revenues to GDP of 13 percent. In the following section, we focus on the first spending option, in which all oil revenue is spent by the government on recurrent items, and discuss the short- and medium-run impact of this oil management option.

4. The Dutch Disease of the Oil Boom: Short- and Medium-run Impacts on Growth and Structural Change

In the short run, the expected outcome of a sudden increase in government's recurrent spending of oil revenues is an increase in demand for both domestic and imported goods, higher prices for nontradable goods ─ at constant world market prices for exports and imports ─ and therefore an appreciation of the real exchange rate, which tends to pull resources away from the tradable sector thereby leading to a restructuring of production from tradables towards nontradables. Consistent with this broadly accepted Dutch disease outcome, the results for scenario OIL-1a in Table 1 show that while oil revenues increase total GDP in Ghana in the short run, growth in the tradable sectors, including the export agricultural and tradable nonagricultural sectors, actually declines sharply. Growth in the nontraded nonagriculture sector rises significantly and is almost unaffected in the staple agriculture sector. This structural effect of oil inflows leads also to a decline in non-oil GDP growth compared to the base run without oil.

Table 1. Short-run impact of oil revenue: Annual growth rate of total and sectoral GDP in the first five years under the model's base run and first oil scenarios

		2010	2011	2012	2013	2014	2015
Total GDP with oil	Oil-1a	13.8	12.3	11.1	10.1	9.4	5.2
Total non-oil GDP	Base run	5.8	5.7	5.6	5.5	5.4	5.4
	Oil-1a	5.5	5.3	5.2	5.2	5.1	5.2
Staple agriculture	Base run	4.8	4.8	4.8	4.8	4.8	4.8
	Oil-1a	4.6	4.7	4.7	4.7	4.7	4.8
Export agriculture	Base run	4.4	4.6	4.9	5.1	5.3	5.5
	Oil-1a	-0.3	0.6	1.4	2.0	2.5	6.0
Tradable nonagric.	Base run	5.1	5.1	5.1	5.1	5.1	5.1
	Oil-1a	2.2	2.4	2.6	2.9	3.1	5.3
Nontrad. nonagr.	Base run	5.6	5.5	5.4	5.3	5.3	5.3
	Oil-1a	8.4	7.9	7.5	7.1	6.8	5.2

Source: Simulation results of the multisector intertemporal general equilibrium model for Ghana.

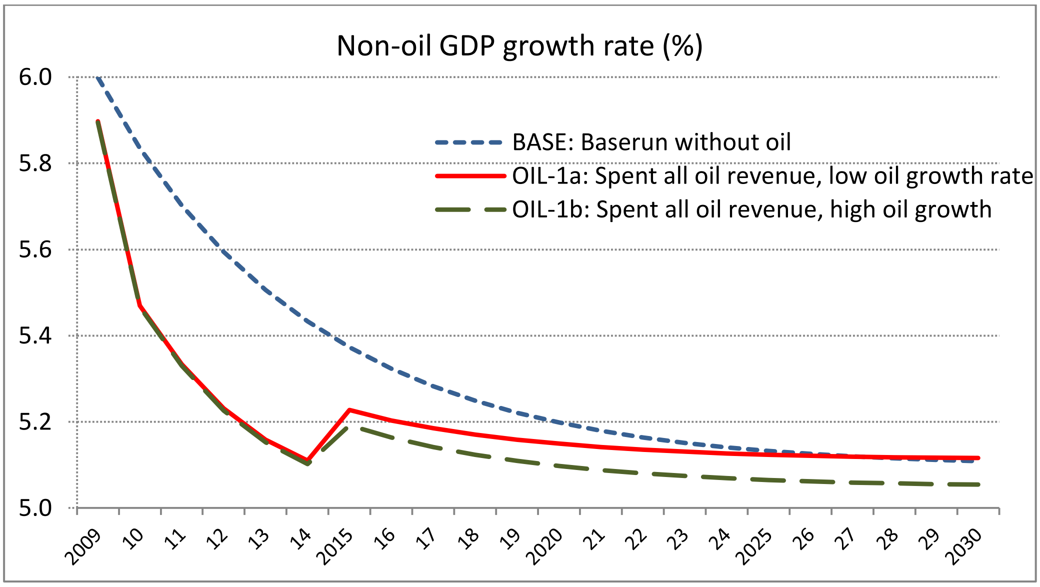
Notes: 1. Total oil revenue is assumed to equal the total value added of the new oil sector (given that extraction of oil is highly capital intensive and uses few intermediate inputs). Statistically, the oil sector's total value added (including the part shared by foreign companies) is counted as part of Ghana's GDP, which explains the sudden increases in the total GDP growth rate in the first few years when oil starts to be extracted—a similar situation is observed in the other countries.

The principal reason is that the demand pull effects from increased government recurrent (and investment) expenditure fall disproportionately on nontraded and tradable nonagricultural sectors. The former produces public goods and services (including construction services) while the latter's output is used as investment goods and intermediate input in the production of these public goods and services. Yet, while demand pull leads to rising prices for the nontradable nonagriculture sector and generally higher wages, domestic prices for all other goods are largely determined on the world market. Thus, these other sectors do not benefit from higher output prices but are negatively affected by increasing production costs. The exemption is staple agriculture. Although not affected directly by oil-financed government expenditures, this sector benefits indirectly from increased spending of higher private income that is generated in nontradable nonagriculture, but is negatively affected by higher wages. Obviously, cost push and demand pull effects almost compensate each other leaving this sector's short-run growth rates nearly unaffected.

The negative effects on non-oil GDP growth diminish in the medium-run after peak oil production is reached in year 2014 (Figure 1) and oil revenues and government spending grow in line with overall GDP, as assumed in the "low oil growth" scenario OIL-1a. Virtually all of the real exchange rate appreciation has been unwound after a 10-year period. Yet, the negative impact of government recurrent spending on non-oil GDP growth persists over the medium- and long-term if higher oil revenues ─ as assumed in the "high oil growth" scenario OIL-1b ─ hamper a gradual depreciation of the real exchange rate.

While the negative impact of oil-revenue spending diminishes in the medium run, the structure of the Ghanaian economy is affected permanently. This can be seen clearly from Table 2, in which the non-oil GDP share of the nontraded nonagricultural sector in years 2030 (2050) rises from 41.1 (41.5) percent in the base run to 46.2 and 48.5 (46.4 and 48.7) percent in the low and high oil growth scenarios, respectively. The higher shares of the nontraded sector's GDP (48.5 and 48.7 percent) correspond to the higher medium-run growth rate of oil revenue inflows in scenario OIL-1b. Moreover, this structural change becomes permanent if oil revenue continues to flow to the country in the long run, i.e. after year 2030.

Figure 1. Medium-run growth effect of oil revenue inflows



Source: Simulation results of the intertemporal CGE model for Ghana.

Note: The low oil growth rate is 5.06 percent and the high oil growth rate is 7.62 percent.

The long-term structural effect of oil revenues poses a huge challenge to Ghana and other natural resource dependent countries and may undermine their industrialization process. The manufacturing sector remains small in many African countries, accounting for 10–15 percent of the economies. Instead of a growing manufacturing sector, the continuous expansion of nontraded industrial (construction) and service sectors, together with rapid urban population growth, seems to lead to urbanization without industrialization. This resource-driven development reflects the difficulty many African countries experience in pursuing sustained and broad-based growth that allows the majority of the population to participate in the growth process.

Can oil revenue be used smartly so that the negative growth effect of higher oil revenues and the structural effect of the real appreciation can be mitigated by better oil revenue management? We design two additional oil scenarios to investigate this possibility. In the next section, we first focus on the role of government investment financed by oil revenues before turning to the role of an oil fund in the remainder of the section.

Table 2. Short-, medium- and long-run structural effect of oil revenue inflows under different oil-revenue spending scenarios (total non-oil GDP = 100)

		Low oil growth rate			High oil growth rate		
	Base-run	Spent all oil revenue	Investing 50% of oil revenue	Oil fund 50% of oil revenue	Spent all oil revenue	Investing 50% of oil revenue	Oil fund 50% of oil revenue
Scenario	BASE	OIL-1a	OIL-2a	OIL-3a	OIL-1b	OIL-2b	OIL-3b
2010							
Staple agriculture	22.7	22.8					
Export agriculture	11.0	10.6					
Tradable nonagriculture	16.2	15.8					
Non-traded nonagriculture	41.6	42.8					
2030							
Staple agriculture	20.9	21.4	21.5	21.5	21.5	21.7	21.6
Export agriculture	12.0	10.5	10.9	11.0	9.6	10.0	10.4
Tradable nonagriculture	15.9	14.6	14.7	14.8	13.8	13.9	14.2
Non-traded nonagriculture	41.1	46.2	46.0	45.7	48.5	48.2	47.3
2050							
Staple agriculture	20.0	20.5	20.6	20.7	20.6	20.9	20.9
Export agriculture	14.2	12.2	12.8	12.9	11.1	11.9	11.9
Tradable nonagriculture	15.8	14.4	14.5	14.5	13.6	13.7	13.7
Non-traded nonagriculture	41.5	46.4	46.0	46.0	48.7	48.1	48.1

Source: Simulation results of the multisector intertemporal general equilibrium model for Ghana.

Note: The low oil growth rate is 5.06 percent and the high oil growth rate is 7.62 percent

5. Can Smart Use of Oil Revenue Foster Structural Change?

The analysis in the previous section shows that the Dutch disease effect of oil revenue inflows on growth and the structure of the Ghanaian economy can become permanent if these inflows last long, are high in relation to domestic absorptive capacities, and are spent on recurrent government expenditures. A smart use of oil revenues, thus, should reconsider this type of spending pattern. We consider two alternative oil revenue allocation options, as introduced in Section 3: investment instead of recurrent spending (scenario OIL-2) and the creation of an oil fund (scenario OIL-3). In case of OIL-2, additional investment financed by oil revenues does not reduce additional demand by the government in the domestic market ─ although the composition of investment demand differs from the composition of recurrent demand ─, and thus, if there are no spillovers from public investment on private sector productivity, the result of this scenario is expected to be similar to that of the OIL-1 scenario. In case of OIL-3, the creation of an oil fund reduces the amount of oil revenue available for recurrent and investment spending, and hence the oil fund is expected to partially mitigate or sterilize the Dutch disease effect. The more oil revenue is allocated to the oil fund, the less oil income is available to the government and the weaker the Dutch disease effect. However, with increased oil revenue and the accumulation of the oil fund over time, revenue from continuous oil inflows and from oil fund withdrawals will eventually increase and be spent by the government. This implies that an oil fund can postpone the Dutch disease effect but may be unable to fully mitigate it over time. Thus, to overcome the negative effect of oil revenue inflows, productivity-enhancing public investments can be an option to accelerate growth. We investigate the outcome for growth and structural change in Ghana of this option using the model.

Linkages between public investment and productivity growth are an empirical issue, and no structural model exists to formally analyze such linkages. As an empirical issue, the magnitude of the productivity enhancement of public investment varies in the literature due to differences in estimation methods, country and sector focus, and datasets used for estimation. Moreover, a country's institutional and policy environment matter in determining the efficiency and effectiveness of public investments. The purpose of the scenarios designed in this paper is not to assess whether public investment can stimulate productivity growth in the private sector and what the magnitude of such an impact may be. Rather, we focus on whether investment can fully mitigate the Dutch disease effect on both growth and structural change.

In the simulations, we assume that oil-funded public investment particularly targets productivity growth in the two agricultural sectors and the tradable nonagricultural sector that are negatively affected by government spending, while productivity in the nontraded nonagricultural sector and the mining sector will not benefit directly. Moreover, we assume that the spillover effect of public investment on productivity kicks in in the 10th year (year 2016), and that the effect is modest from the 10th (year 2016) to the 14th (year 2020) year and then takes full effect after that.[8] Consistent with the previous section, we further consider two different oil revenue growth rates in the medium run.[9]

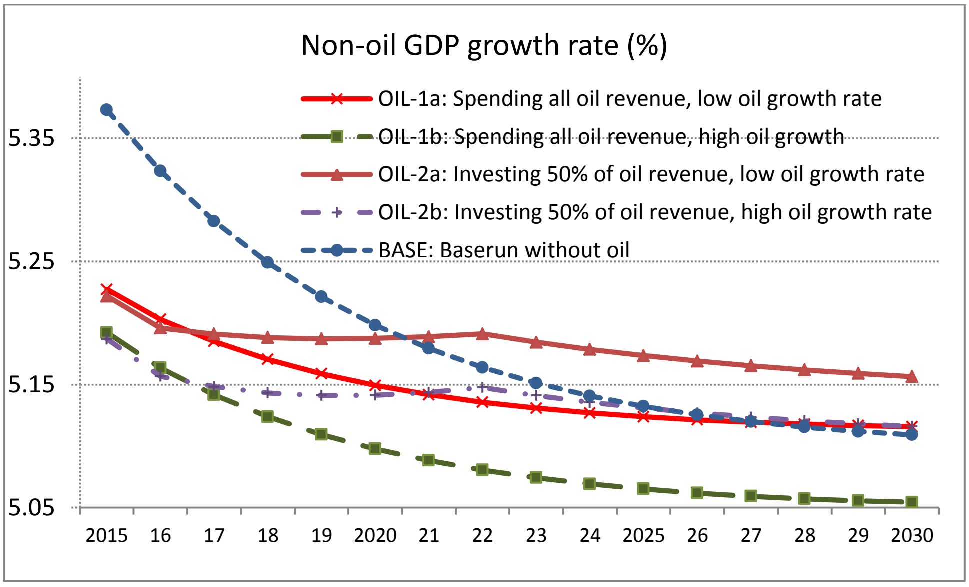
Results show that when government spending increases productivities of one or more sectors, this leads to higher medium-run growth in non-oil GDP. In scenario OIL-2a, annual non-oil GDP growth bounces back to its base-run level in the 15th year (2021) and stays above the base-run growth rate in subsequent years. Under the high oil growth assumption of scenario OIL2-b, non-oil GDP growth returns to its base-run level six years later, in the 21st year (2027), and is only slightly higher than the base-run growth rate after that. Thus, while Ghana's net gain in additional GDP growth as the result of additional productivity growth would be higher with higher oil revenues and higher investment spending than with lower oil revenues (which is captured by a relatively wider gap between the two growth paths corresponding to the two oil scenarios with the high oil growth rate ─ OIL-2b vs. OIL-1b ─ than between the scenarios with the low oil growth rate ─ OIL-2a vs. OIL-1a ─ in Figure 2), productivity growth as the result of increased public investment cannot compensate the loss in non-oil GDP growth that results from real appreciation due to the higher spending of oil revenues in the medium run. The results of the OIL-2 scenario indicate that the positive productivity effect of oil-financed public investment is not always able to mitigate the negative growth effect of the Dutch disease in the medium run. The conclusion depends on the efficiency and effectiveness of Ghana's public investment in stimulating productivity

[8] Specifically, we define the elasticity of productivity growth with respect to additional growth in the stock of public capital ε in equation (3) of Section 2 to be 0.01–0.05 between the 10th and 14th year and 0.06 for all the years after the 14th year. These elasticities imply that for each 1 percent additional growth in public investment, the productivity growth rate of labor and land increases by 0.01–0.05 percentage points in the 10th to the 14th year and by 0.06 percentage points after that.

[9] With the higher oil growth rate and without the creation of an oil fund, investing 50 percent of oil revenue is associated with an annual productivity growth rate of 2.66 percent by the 16th year, rising from 2.5 percent in the base run. The productivity growth rate starts to fall when the oil revenue growth rate converges to its long-run rate after the 25th year. In the long run the productivity growth rate is only slightly higher (2.54 percent) than in the base run (2.50 percent).

growth. Yet, with identical productivity spillovers, it can be said that the more oil revenue flowing in the country each year, the less likely the public investment is to fully mitigate the negative growth effect of Dutch disease.

Figure 2. Growth effect of oil revenue inflows – investing vs. spending



Source: The simulation result of the multisector intertemporal general equilibrium model for Ghana.

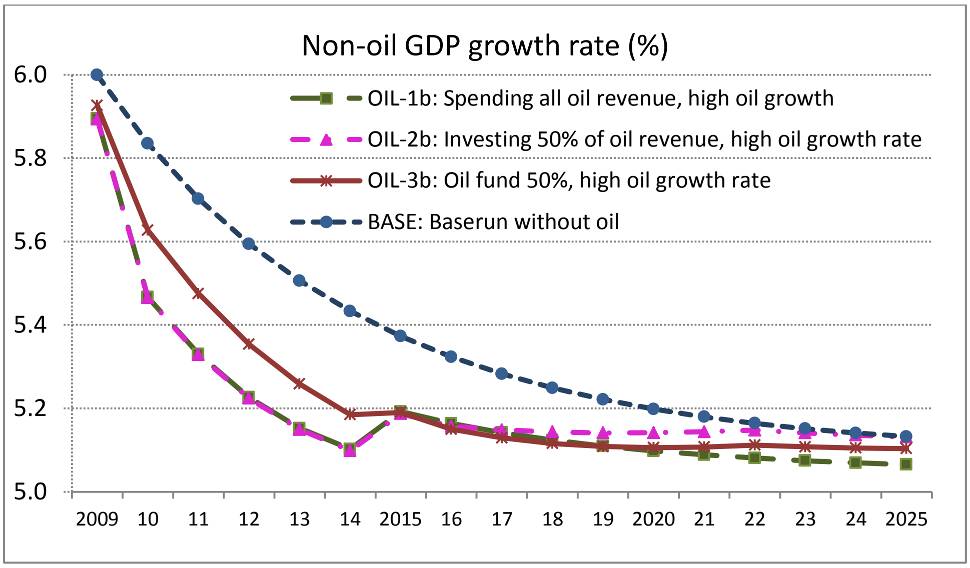
Note: The low oil growth rate is 5.06 percent and the high oil growth rate is 7.62 percent.

Comparing the medium- and long-run result of the investment with the spending-all scenario (see Table 2), GDP shares for staple agriculture, export agriculture and tradable nonagriculture all increase slightly when public investment raises productivity growth in these three sectors. However, the role of public investment in mitigating the economic structural effect is very modest both in the medium run (until 2030) and in the long run (until 2050). The nontraded nonagricultural sector continues to expand from its base-run level, even though the sector is assumed not to benefit directly from increased public investment. Again, with the same investment-to-productivity-growth elasticity, a high oil growth rate (even though higher oil growth also indicates more oil-funded investment) makes public investment less effective in mitigating the structural effect of oil inflows.

In the OIL-3 scenario, it is assumed that the Ghanaian government decides to allocate 50 percent of current oil revenues into an oil fund, and to use the rest equally for investment and recurrent spending to provide public goods. The risk-free return (which equals the interest rate) from the oil fund, together with 5.1 percent of oil fund stock, is spent in the same way as the 50 percent of the current oil inflows.

As the speed of spending oil revenue slows in the short and medium runs in this scenario compared with that in the two previous scenarios, the short-run shock on GDP growth becomes relatively modest but still exists (Figure 3). However, because less oil revenue is allocated to investment each year, given a similar oil growth rate, the growth enhancement effect in the medium run is also more modest with the oil fund than without it. But given that the speed of spending oil fund revenues is assumed to be similar to the growth rate of oil revenues in the long run, the available oil revenue to be spent each year is similar in all three oil scenarios in the long run. Thus, the long-run structural change effect is indifferent under the three alternative oil revenue spending options, while there is a slight improvement in the structural effect in the medium run when an oil fund is created (see the results of OIL-3a and OIL3B for year 2030 in Table 3).

Figure 3. Short- to medium-run effect of alternative oil revenue spending options on GDP growth

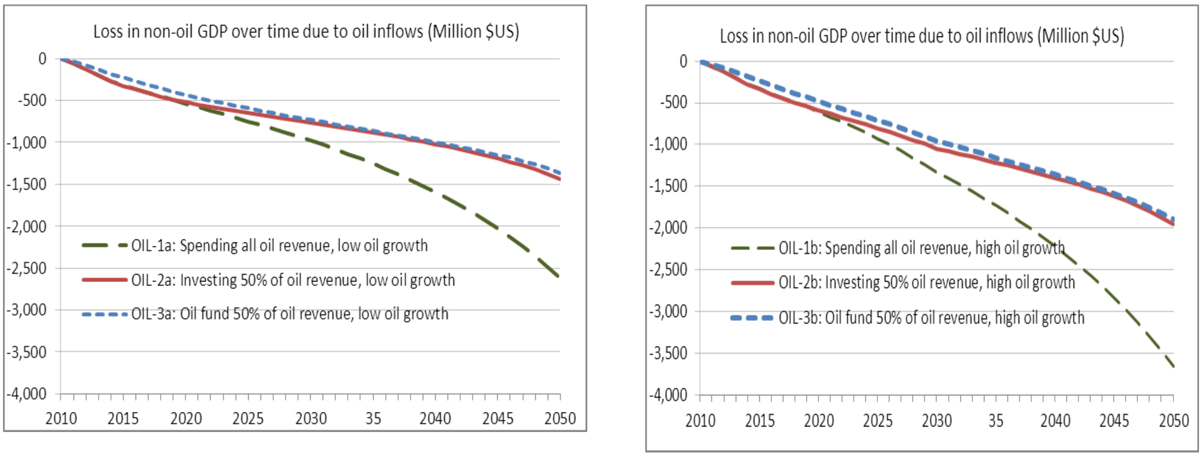


Source: The simulation result of the multisector intertemporal general equilibrium model for Ghana.

Note: The high oil growth rate is 7.62 percent.

Finally, Figure 4 shows the negative effect of oil inflows on the level of Ghana's non-oil GDP over the entire simulation period (2010–2050) under the three oil management scenarios. The left panel of Figure 4 reflects the three scenarios with low oil growth while the right panel of the figure represents the same scenarios with high oil growth. The loss in GDP is significant if there is no measure to mitigate the Dutch disease: GDP will be US$2.62–3.66 billion less compared to the base run by 2050. The mitigating effect of the two alternative oil management options is similar in the long run: The loss in GDP is reduced to US$1.44–1.95 billion in the investment scenario and to US$1.36–1.90 billion in the fund scenario.

Figure 4. Impact of oil inflows on the level of non-oil GDP over time under the three oil management options (difference from base run GDP levels)



Source: Simulation results of the multisector intertemporal general equilibrium model for Ghana.
Note: The low oil growth rate is 5.06 percent and the high oil growth rate is 7.62 percent.

6. Conclusions

Foreign inflows are important sources of income that many African governments use to finance investments. Many countries intend to follow the Asian model and gear foreign inflows toward enhancing export-oriented manufacturing or service sectors to accelerate economic growth and structural transformation. Yet in many African economies the manufacturing sector has grown more slowly than other sectors, and rapid growth in domestic-oriented industries (urban construction and utilities) and services has made these sectors the largest in their economies. Motivated by these stylized facts, we use Ghana and its newly found oil as an example and analyze the dynamic relationship between increased inflows of petrodollars, economic growth, and structural change. The analysis is based on an intertemporal general equilibrium model with five economic sectors and three alternative oil revenue management options.

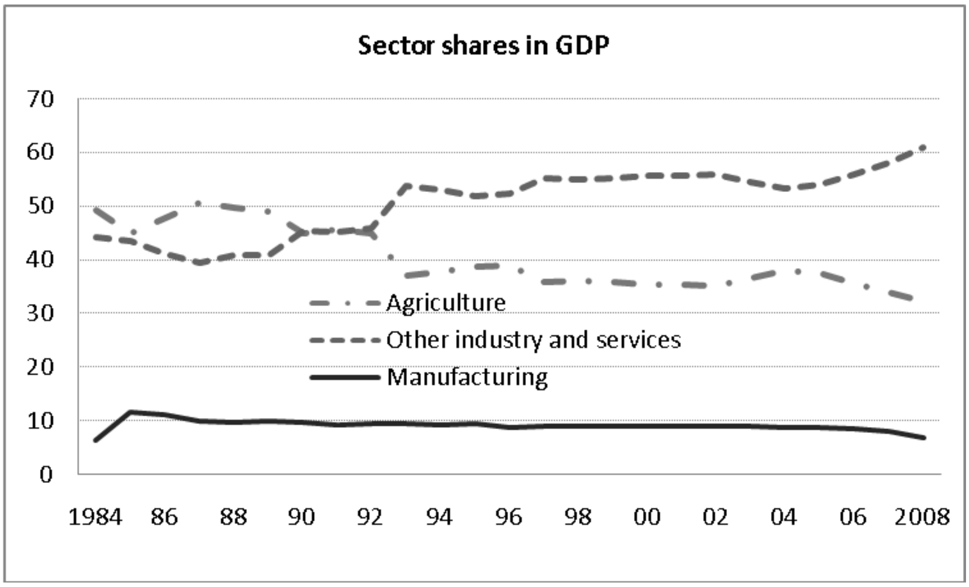
We find that the increased foreign inflows from petrodollars generate a substantial short-run growth shock in non-oil sectors, as predicted by the Dutch disease theory, if the oil revenues are used by the Ghanaian government to finance either recurrent spending or public investment. The growth reduction in the tradable sectors and increase in the nontraded sectors cause the structure of the economy to become more nontradable dominated. When the creation of an oil fund reduces the availability of oil revenues to be spent by the government in the short run, the negative growth effect becomes relatively modest. In the medium run, if oil spending does not enhance productivity growth, the rate of non-oil economic growth slows and the GDP share of the nontraded sector in the economy further increases. Moreover, the impact on the economic structure persists as long as oil revenue continues to flow in the country. Thus, Dutch disease can be a longer term phenomenon and a challenge for growth in the country.

Smart use of oil revenues requires not only sterilization and saving boom revenues in an oil fund but also the financing of productivity-enhancing public investment. While the mitigating role of public investment depends on its effectiveness and efficiency, our paper emphasizes that the growth magnitude of oil inflows matters for the mitigation effect. At the same level of investment-to-productivity-growth efficiency, and if the inflows continue to grow at a relatively high rate, it takes the economy longer to overcome Dutch disease than in a situation in which the inflows grow at a slower pace. Moreover, our paper shows that the structural effects of Dutch disease on economic development are more difficult to correct and in fact can become a persistent phenomenon in Ghana and any other countries that continue to receive foreign inflows in the form of petrodollars or in any other forms.

This longer term structural effect of foreign inflows poses a huge challenge to economic transformation in African countries such as Ghana. The rigidness in their economic structures challenges these countries as they attempt to pursue sustained and broad-based growth in which a majority of the population participates and poverty is reduced. While the importance of institutional and historical factors for understanding the growth challenges faced by African countries has been broadly discussed in the literature, the role played by significant increases in foreign inflows over the past two decades deserve more attention and assessment.

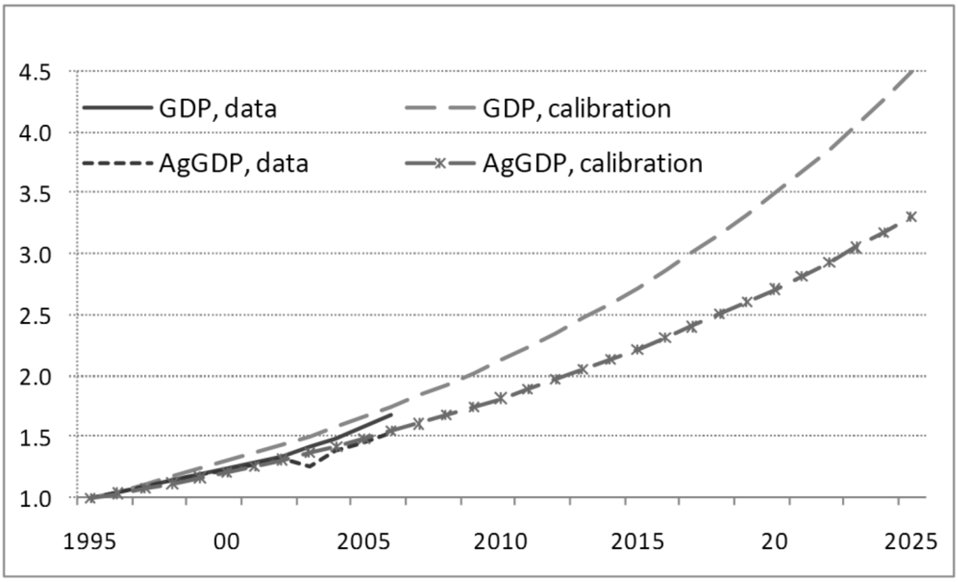
Appendix A: Supplementary Figures

Figure A.1. Sector shares in GDP (Ghana: 1984–2008)



Source: Authors' calculation based on World Bank 2010.
Note: "Other industry" includes construction, urban utilities, and mining.

Figure A.2. Model calibration of GDP and agricultural GDP



Source: Back cast base run of the multisector intertemporal general equilibrium model for Ghana.
Note: Normalized, value in 1995 = 1.

Appendix B: Mathematical presentation of the multisector intertemporal general equilibrium model

A.1. Glossary

A.1.1. Parameters

Λ_i : Shift parameter in Armington import function for good *i*

Γ_i : Shift parameter in Constant Elasticity of Transformation (CET) export function for good *i*

A_i : Shift parameter in value-added production function for good *i*

β_i : Share parameter in Armington import function for domestically produced good *i*

η_i : Share parameter in CET export function for domestically produced good *i*

$\alpha_{i,f}$: Share parameter in value-added production function for good *i* and factor *f*

$io_{i,j}$: Input-output coefficient for good *i* used in sector *j*

θ_i : Marginal budget share for good *i* consumed by consumers

γ_i : Subsistence parameter for good *i* in composite good

ϖ_i : Share parameter for good *i* consumed by government

π_i : Share parameter for good *i* used for investment

a : Allocation rule for current oil revenue

b : Allocation rule for oil fund

ε_i^M : Elasticity of substitution in Armington import function for good *i*

ε_i^E : Elasticity of substitution in CET export function for good *i*

φ_i : Elasticity of substitution in value-added production function for good *i* and $\varphi_i = \frac{1}{1+\rho_i}$

σ : Elasticity of substitution in intertemporal utility function

μ : Time preference in intertemporal utility function

λ : Parameter in capital adjustment function

δ : Capital depreciation rate

g_f : Exogenous growth rate of factor *f*'s productivity

ε_i : Elasticity of increased productivity growth rate with respect to increased public capital stock from its base-run level

A.1.2. Exogenous variables

$V_{f,t}$: Level of labor and land supply

$V_{k,1}$: Initial level of capital supply as $f = k$

PoP_t: Level of population

$trns_t^{gov}$: Transfer from government to households

$trns_t^{row}$: Transfer from rest of world to households

S_t^{gov}: Government savings

S_t^{row}: Exogenous foreign inflows irrelevant to oil revenues

CY_t^{oil}: Exogenous oil revenue inflows

LY_t^{oil}: Stock of oil fund

TY_t^{oil}: Total oil-related revenue spent at time t

$PWE_{i,t}$: World FOB price for good i

$PWM_{i,t}$: World CIF price for good i

$\tau_{i,t}^{M}$: Tariff rate

$\tau_{i,t}^{E}$: Export tax

$\tau_{i,t}^{X}$: Value-added tax

$\tau_{i,t}^{CC}$: Sales tax

EXR_t: Exchange rate

$DEBT_1$: Initial level of foreign debt

K_t^{P}: Stock of public investment with oil revenue spent on public investment

$K_t^{P,0}$: Stock of public investment without oil revenue spent on public investment

ΔK_t^{P}: Flow of public investment with oil revenue spent on public investment

$\Delta K_t^{P,0}$: Flow of public investment without oil revenue spent on public investment

$B_{i,f,t}$: Level of factor productivity in value-added production function for good i and factor f

A.1.3. Endogenous variables

$PX_{i,t}$: Producer price for good *i*

$PVA_{i,t}$: Value-added part producer price for good *i*

$P_{i,t}$: Price for Armington good *i*

$PD_{i,t}$: Price for good *i* produced and consumed domestically

PQ_t: Price for composite good

$W_{f,t}$: Returns or wage rate for factor *f*

P_t^K : Unit value of investment

r_t: Interest rate in domestic capital market

$X_{i,t}$: Output of good *i*

$CC_{i,t}$: Armington good *i*

$E_{i,t}$: Exports of good *i*

$M_{i,t}$: Imports of good *i*

$Z_{i,t}$: Armington good *i*

$D_{i,t}$: Good *i* produced and consumed domestically

$C_{i,t}$: Consumer demand for good *i*

$C_{i,t}^{gov}$: Government demand for good *i*

$C_{i,t}^{J}$: Intermediate demand for good *i* by sector *j*

$C_{i,t}^{INV}$: Investment demand for good *i*

Q_t: Composite good

Y_t: Total household income

Y_t^{gov} : Government income

I_t: Capital investment in quantity

q_t: Tobin's q in capital adjustment function

S_t^H : Household savings

U_1: Intertemporal utility function

$g_{i,t}^P$: Endogenous part of factor productivity growth rate

A.2. Equations

A.2.1. Intratemporal equations

Armington import function and first-order condition for imports

$$P_{i,t} = \frac{1}{\Lambda_i}\left[\beta_i^{\varepsilon_i^M}\left(EXR_t \cdot (1+\tau_{i,t}^M)\cdot PWM_{i,t}\right)^{1-\varepsilon_i^M} + (1-\beta_i)^{\varepsilon_i^M} PD_{i,t}^{1-\varepsilon_i^M}\right]^{\frac{1}{1-\varepsilon_i^M}}$$

$$M_{i,t} = \Lambda_i^{1+\varepsilon_i^M}\left[\beta_i \frac{P_{i,t}}{EXR_t \cdot (1+\tau_{i,t}^M)\cdot PWM_{i,t}}\right]^{\varepsilon_i^M} \cdot CC_{i,t}$$

$$D_{i,t} = \Lambda_i^{1+\varepsilon_i^M}\left[(1-\beta_i)\frac{P_{i,t}}{PD_{i,t}}\right]^{\varepsilon_i^M} \cdot CC_{i,t}$$

CET export function and first-order condition for exports

$$PX_{i,t} = \frac{1}{\Gamma_i}\left[\eta_i^{-\varepsilon_i^E}\left(EXR_t \cdot (1-\tau_{i,t}^E)\cdot PWE_{i,t}\right)^{1+\varepsilon_i^E} + (1-\eta_i)^{-\varepsilon_i^E} PD_{i,t}^{1+\varepsilon_i^E}\right]^{\frac{1}{1+\varepsilon_i^E}}$$

$$E_{i,t} = \Gamma_i^{-(1+\varepsilon_i^E)}\left[\eta_i \frac{PX_{i,t}}{EXR_t \cdot (1-\tau_{i,t}^E)\cdot PWE_{i,t}}\right]^{-\varepsilon_i^E} \cdot X_{i,r}$$

$$D_{i,t} = \Gamma_i^{-(1+\varepsilon_i^E)}\left[(1-\eta_i)\frac{PX_{i,t}}{PD_{i,t}}\right]^{-\varepsilon_i^E} \cdot X_{i,r}$$

Value added, factor demand, and output prices

$$(1-\tau_{i,t}^X)\cdot PVA_{i,t} = \frac{1}{A_i}\left[\prod_{f\in F}\frac{\alpha_{i,f}{}^{\varphi_i}}{\widetilde{B}_{i,f,t}{}^{1-\varphi_i}}\cdot W_{f,t}{}^{1-\varphi_i}\right]^{\frac{1}{1-\varphi_i}}$$

$$PX_{i,t} = PVA_{i,t} + \sum_j io_{j,i}\cdot P_{j,t}$$

$$v_{i,f,t} = (A_i\widetilde{B}_{i,f,t})^{\varphi_i-1}\left[\alpha_{i,f}\frac{(1-\tau_{i,t}^X)\cdot PVA_{i,t}}{W_{i,f,t}}\right]^{\varphi_i}\cdot X_{i,t}$$

Factor market equilibrium

$$V_{f,t} = \sum_i v_{i,f,t}$$

Government income, government demand, and intermediate and investment demand

$$C_{i,t}^{gov} = \varpi_{i,t}\cdot\frac{Y_t^{gov} - trns_t^{gov} - (r_t - g)\cdot DEBT_t - S_t^{gov}}{P_{i,t}}$$

$$C_{i,t}^J = io_{j,i,t}X_{j,t}$$

$$C_{i,t}^{INV} = \pi_{i,t}\cdot\frac{P_t^K I_t}{P_{i,t}}, \text{ for } i \neq \text{nontraded}$$

$$C_{i,t}^{INV} = \pi_{i,t}\cdot\frac{P_t^K I_t}{P_{i,t}} + \lambda\frac{I_t^2}{V_{k,t}}, \text{ for } i = \text{nontraded}$$

Household income and demand

$$C_{i,t} = \gamma_{i,t} + \frac{\theta_i \cdot (PQ_t Q_t - \sum_j P_{j,t}\theta_j)}{P_{i,t}}$$

$$PQ_t Q_t = Y_t - S_t^H$$

$$Y_t = \frac{\sum_f W_{f,t} V_{f,t} + trns_t^{gov} + trns_t^{row}}{PoP_t}$$

Commodity market equilibrium

$$CC_{i,t} = C_{i,t} + C_{i,t}^{gov} + C_{i,t}^{J} + C_{i,t}^{INV}$$

Trade balance

$$\sum_i PWM_{i,t} M_{i,t} = S_t^{row} + trns_t^{row} + \sum_i PWE_{i,t} E_{i,t} + CY_t^{oil}$$

A.2.2. Intertemporal equations

Intertemporal utility function and Euler equation

$$U_1 = \sum_{t=1}^{T} (1+\mu)^{-t} \frac{Q_t^{1-\sigma} - 1}{1-\sigma} + \frac{(1+\mu)^{1-T}}{\mu} \frac{Q_T^{1-\sigma} - 1}{1-\sigma}$$

$$\frac{PQ_{t+1} Q_{t+1}}{PQ_t Q_t} = \frac{1 + r_{t+1}}{1+\mu}$$

Nonarbitrage condition with adjust cost for investment

$$(1 + r_t) q_{t-1} = W_{k,t} + \lambda \cdot P_{i,t} \left(\frac{I_t}{V_{k,t}} \right)^2 + q_t \cdot (1 - \delta), \text{ for } i = \text{nontraded}$$

Tobin's q

$$q_t = P_t^K + \frac{2 \cdot \lambda \cdot P_{i,t} I_t}{V_{k,t}}, \text{ for } i = \text{nontraded}$$

Capital accumulation

$$V_{k,t} = (1 - \delta) \cdot V_{k,t-1} + I_t$$

Debt accumulation

$$DEBT_t = (1 + r_t) \cdot DEBT_{t-1}$$

Oil revenue, oil fund, oil spending, and public investment

$$LY_t^{oil} = (1-a)\cdot CY_t^{oil} + (1-b)\cdot LY_{t-1}^{oil}, \text{ and } LY_1^{oil} = (1-a)\cdot CY_1^{oil}$$

$$TY_t^{oil} = a\cdot CY_t^{oil} + (b+r)\cdot LY_{t-1}^{oil}$$

$$\Delta K_t^{P,0} = \frac{S_t^{gov}}{P_{i,t}}, i = \text{nontraded}$$

$$\Delta K_t^{P} = \frac{S_t^{gov} + 0.5\cdot TY_t^{oil}}{P_{i,t}}, i = \text{nontraded}$$

$$K_t^{P,0} = \Delta K_t^{P,0} + K_{t-1}^{P,0}$$

$$K_t^{P} = \Delta K_t^{P} + K_{t-1}^{P}$$

Factor productivity growth rate

$$g_{i,t}^{p} = \varepsilon_i \left(\frac{\Delta K_t^{p}}{K_t^{p}} - \frac{\Delta K_t^{p,0}}{K_t^{p,0}}\right)$$

$$B_{i,f,t} = (1 + g_f + g_{i,t}^{p})\cdot B_{i,f,t-1}$$

A.2.3. Terminal conditions (steady-state constraints)

$$I_{k,T} = (g+\delta)\cdot V_{k,T}$$

$$(\delta + r_T)\cdot q_T = W_{k,T} + \lambda\cdot P_{i,T}\left(\frac{I_T}{V_{k,T}}\right)^2, \text{ for } i = \text{nontraded}$$

The model is solved using the General Algebraic Modeling System (GAMS).

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