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Optimal Spending and Saving Strategies for Commodity-Rich Countries*

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Abstract

This paper builds a quantitative model to assess the optimal allocation of resources in an economy that is subject to a volatile source of income such as commodity exports, and with imperfect access to international financial markets. In this context the government faces a trade-off between smoothing expenditures and accumulating assets for precautionary motives, as well as saving in risk-free assets and investing in physical capital. The features of the model and the solution method allow for a detailed exploration of the trade-offs involved, particularly those related to volatility and uncertainty. The analysis sheds light about optimal saving and spending in stochastic environments, and best responses to large shocks and to permanent changes in stochastic processes.

Resumen

Este trabajo construye un modelo cuantitativo para evaluar la asignación óptima de recursos en una economía que está sujeta a una fuente de ingresos altamente volátil, como es el caso de exportaciones de commodities, y que tienen un acceso imperfecto a los mercados financieros internacionales. En este contexto el gobierno debe balancear los beneficios de suavizar el consumo y acumular activos con motivos precautorios, además de invertir en activos libres de riesgo o capital físico. Las características del modelo y la manera de resolverlo permiten una exploración detallada de los beneficios de cada una de estas decisiones, particularmente aquellas relacionadas con incertidumbre y volatilidad. El análisis entrega lineamientos sobre el ahorro y consumo óptimo en ambientes estocásticos y las respuestas óptimas a shocks grandes y cambios permanentes in los procesos estocásticos.

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1 Introduction

What are the optimal levels of consumption and saving in an oil-rich economies? How these should react to transitory and permanent shocks to oil prices? The permanent income hypothesis (PIH) gives a precise answer to these questions. However, due to the high volatility of revenues from oil exporting, and in the context of an imperfect access to international financial markets, the optimal strategy requires the building of a buffer stock of assets to be used in times of need. Hence, the trade-off between consumption and savings, and hence the answers to the questions above, become more complex and highly dependent on the extent of oil revenues volatility.

What fraction of savings should be invested in domestic physical capital and how much in external safe assets? The first option may promote economic growth, making the opportunity costs of saving in safe assets rather high. But the return from investing domestically is risky and subject to several frictions and unwanted results such as Dutch disease, capacity constraints and adjustment costs, implying that investing in physical capital is not the optimal use of the resources accumulated for precautionary motives. And since these features are likely affected by the presence of a large oil sector the optimal investment strategy depends as well on revenues volatility.

In this paper we build a quantitative model to assess the optimal allocation of resources in an economy that is subject to a volatile source of income such as commodity exports. The features of the model and the solution method allow for a detailed exploration of the trade-offs involved, particularly those related to volatility and uncertainty. The analysis sheds light about optimal saving and spending in stochastic environments, and best responses to large shocks and to permanent changes in stochastic processes.

We apply the model to The Kingdom of Saudi Arabia (KSA). KSA is the largest oil exporter in the world and hence it is subject to a very large volatility. Oil fiscal revenues, which have been on average 33% of GDP since 1970, fluctuate on average about 14% of GDP annually. In the last years they went from a peak of more than 50% of GDP in 2008 to a level below 14% of GDP in 2016. These high levels of volatility due to large swings in oil prices and the uncertainty concerning their long-run levels complicate the implementation of sound macroeconomic policies. In this paper we explore optimal allocations in a dynamic model that includes a volatile endowment sector to illuminate the discussion about what are the appropriate policies a resource-rich country such as KSA should implement.

Using the model we first explore how the implied path for the main macroeconomic variables compares to actual data in KSA during the last 40 years. We find that the model does a very good job matching the data, particularly the path of net foreign assets. It has a better performance than when using other simple rules for spending oil revenues. In particular we consider a rule where spending varies one-to-one with fiscal revenues, and one in which spending follows the recommendations of a version of the PIH that doesn't take into account neither uncertainty nor financial constraints. We show that the path implied by this last rule is further away from the actual series of foreign assets than the optimal rule that internalizes the effects of high volatility and financial constraints. This implies that precaution against bad shocks have probably played an important role in the economy.

Then we use the model to explore how the economy would react to different paths of oil revenues in the future. We consider scenarios where oil revenues steadily increase or decrease until 2030, but in all of them oil is depleted around 2100. We show that under the optimal rule expenditures are adjusted much more smoothly than what a simple PIH rule would predict. Fiscal deficits are maintained for some years and liquid assets are disaccumulated to allow for this smooth adjustment, and hence expenditures are kept above the levels predicted by a budget balanced rule. Since volatility falls in the long-run as the oil sector shrinks and less risk-free assets are needed as precaution, the optimal rule reallocates resources from these assets to capital as the best way of carrying resources to the future.

2 Related Literature

Although a large literature explores optimal fiscal strategies in commodity-rich countries (see for instance Pieschacon, 2012; Agénor, 2016), few of them assesses quantitatively how uncertainty affects decisions because of precautionary behavior.[1] Cherif and Hasanov (2013) is an exception and it is the closest to this paper. They study quantitatively the allocation problem of an oil-exporting country under uncertainty.[2] They build a model with production of tradable (oil) and nontradable goods, where the first is subject to stochastic shocks. A central planner chooses consumption and saving in a risk-free asset, as well as the time-invariant investment rate in physical capital in the oil sector. Productivity in this sector is low, and investment is risky and irreversible. It is assumed a finite horizon. This restricts borrowing in the last periods, motivating the accumulation of substantial buffer-stock savings in the beginning.

We extend the model by Cherif and Hasanov (2013) in different dimensions. We add a non-oil tradable sector and allow for a time-varying investment rate in both non-tradables and tradables.[3]

[1] This is in large part due to technical difficulties. Most of the literature uses log-linearization around a steady-state to solve the models, and hence focuses on small shocks and don't fully account for nonlinearities. Considering large shocks and nonlinearities is essential to capture the forces behind precautionary savings, and this can only be done solving the models globally, which is what we do in this paper, although it is more complex due to the so-called course of dimensionality problem.

[2] Engel and Valdés (2000) analytically derive optimal fiscal strategies for oil exporting countries with a particular focus on uncertainty and precautionary behavior.

[3] Oil is an endowment in the model. This choice is supported by the close correlation between real oil prices and oil fiscal revenues in KSA. Hansen and Gross (2018) show that an endogenous supply of the commodity may change quantitatively the macroeconomic responses to price shocks. More interestingly in the context of the model in this paper, Van der Ploeg (2010) explores the oil extraction strategy in the context of high uncertainty with respect to future prices. Van der Ploeg (2010) shows analytically in a simple two-period model that uncertainty leads to high exploitation rates together with a large accumulation of safe assets as precaution for large negative shocks.

Then the allocation of resources between physical capital and safe assets is contingent on the state of the economy. Additionally the choice of investing in non-oil sectors allows the planner to reduce the riskiness of physical capital investments.[4] We introduce a financial constraint so the planner doesn't have perfect access to financial markets, and adjustment costs to physical capital. Both factors contributing to the optimality of accumulating safe assets.

Other papers focus specifically on the trade-off between domestic investment and saving in safe assets. Some authors claim that resources should be used to improve internal production capacities through capital investment or other types of spending (e.g. Collier, Van Der Ploeg, Spence, and Venables, 2010), while others propose moderate investment in physical capital due to the frictions already mentioned (Berg, Portillo, Yang, and Zanna, 2013).

3 The Model

The economy is composed by three sectors, the oil sector, the non-tradable sector (superscript N), and the (non-oil) tradable sector (superscript T). Oil is only exported and it is a non-exhaustible stochastic endowment flow. We assume revenues p follow an autoregressive process

$$p_t = \bar{p} + \rho p_{t-1} + \epsilon_t$$

where ρ and $\bar{p}$ are constants and ϵ_t follows a log-normal *iid* process.

Tradables and non-tradables are produced by representative firms using physical capital according to the following functional form for $i = T, N$,

$$Y_t^i = z(K_t^i)^{\alpha^i}$$

where z is a time-invariant productivity process and $\alpha^i \in (0,1)$.[5] We assume only the non-tradable good can be used as capital.[6]

There are adjustment costs to capital. In the absence of stochastic shocks to productivity, adjustment costs make liquid risk-free bonds more attractive to invest the resources that are maintained as a precaution against bad oil revenue shocks. We assume these costs are sector-specific

[4] As noted above Cherif and Hasanov (2013) impose fixed rates of investment in each sector, and allow the central planner to choose this invariant investment rate only in the oil sector. This generates a trade-off between stability and growth, since the higher the investment rate the larger the size of the oil sector and thus the larger the effect of revenues volatility in the economy. Also the correlation between capital returns and revenues is perfect, making even less attractive investing in physical capital. In the present context there is a positive correlation between the return from investing in non-tradables and revenues since the demand for these goods raises after a positive revenue shock, but the correlation is not perfect.

[5] This assumption implies that the economy doesn't grow in the long-run. Since p is stationary this ensures that oil revenues as a fraction of GDP is stationary as well, a feature consistent with the data from KSA. But since each of these variables grows in the data I adjust all of the variables by average GDP growth in the computations.

[6] Alternatively one can think of infrastructure investment being non-tradable and machinery investment being tradable.

and hence even a reallocation of capital between sectors is costly.[7] Defining I^i as total investment in sector $i = T, N$ the law of motion of capital in each sector is given by

$$K_{t+1}^i = K_t^i(1-\delta) + I_t^i - \varsigma(I_t^i)^2$$

where $\varsigma > 0$ is a constant capturing the size of adjustment costs and δ is the depreciation rate of physical capital.

A representative household has per-period utility over tradable and non-tradable consumption $u(c^T, c^N)$. In particular we assume

$$u(c^T, c^N) = \left[\frac{(c^T)^\theta (c^N)^{(1-\theta)}}{1-\sigma}\right]^{1-\sigma}$$

where $\theta \in (0,1)$ captures the preference for tradable goods and σ is the risk aversion coefficient.

Since the aim of the exercise is to find optimal allocations we define the problem of a central planner that needs to allocate investment and consumption of tradables and non-tradables, together with external savings A, to maximize the discounted expected value of the representative agents' utility,

$$\sum_{t=0}^{\infty} \beta^t E\left[u(c_t^T, c_t^N)\right].$$

The central planner faces the following resource constraints for each sector

$$\begin{aligned} Y_t^T + p_t + A_t(1+r) &= c_t^T + A_{t+1} \\ Y_t^N &= c_t^N + \sum_{i=T,N}\left(I_t^i + \varsigma(I_t^i)^2\right) \end{aligned}$$

where A_t is invested abroad in a risk-free asset that pays a return r per period.

Finally the central planner faces a borrowing constraint $A_t \geq \underline{A}$ for any t. This constraint increases the need for precautionary savings since after negative revenue shocks the planner doesn't have the option to borrow abroad to smooth consumption. An alternative way of defining this friction is to assume that r rises with the stock of external debt as a fraction to income. In this case the planner has access to international financial markets in bad times but at a higher cost. Consistent with the constraint used in this paper, net foreign assets in KSA have been positive since at least 1960 according to data from the WDI, which also makes impossible to measure the effect of external debt on the cost of borrowing. When setting the constraint in terms of quantities one can think of some (politically) nonpecuniary cost of having a negative stock of assets.[8]

[7] There are additional frictions that can be included to play the same role. For a rich analysis see Berg, Portillo, Yang, and Zanna (2013).

[8] Cherif and Hasanov (2013) assume alternatively that the planner faces a finite horizon and hence, as time goes by, the amount that he can borrow falls as the present value of revenues falls as well.

Since we explore optimal allocations trough a central planner problem prices are not explicitly defined. However it is useful to define the relative price of non tradable and tradable goods (or the inverse of the real exchange rate) to be able to define aggregate measures of consumption and income, as well as fiscal spending and balance. It is easy to show that in the competitive market equilibrium of the model this price corresponds to

$$q = \frac{u_2(c_t^T, c_t^N)}{u_1(c_t^T, c_t^N)} = \frac{(1-\theta)c_t^T}{\theta c_t^N},$$

which can be recovered from the solution to the central planner problem using the optimal levels of consumption in each good. Now total output in the economy is $Y_t = p_t + Y_t^T + q_t Y_t^N$ and total consumption $C_t = c_t^T + q_t c_t^N$.

3.1 Fiscal Rules

The model presented so far generates optimal paths for aggregate consumption, investment, and savings as functions of revenue shocks. However policymakers have only a small influence on private decisions and hence it is useful to separate the public and private components of these aggregate spending measures. To do this in a simple way we make the following additional assumptions. The government spends directly in non tradable consumption and investment, makes lump-sum transfers to households, T_t, and it is the only agent in the economy with access to international financial markets.[9] Additionally, non-oil production is private and oil revenues are accrued by the government.[10] Under these assumptions we analyze three different fiscal rules using the model outlined above: the optimal rule, which generates the outcome of the model, and two suboptimal rules that generate different outcomes: a budget balanced (BB) rule and a permanent income (PI) rule, where the government spends a fraction of revenues such that the present value of expected future income (from oil and foreign assets returns) stays constant.

Under the tree rules we assume that the private sector spends a fixed fraction of output. Specifically we impose the following exogenous conditions:

$$\begin{aligned} c_{t,p}^N &= \phi_c Y_t^N \\ I_{t,p} &= \phi_I Y_t^N \end{aligned}$$

where the parameters ϕ are positive and lower than one.

[9] Since 1970 the trade balance is KSA has been on average 17% of GDP. Since this hasn't been translated in the external position of the country the model cannot generate such a surplus. To keep the model simple we subtract that fraction from GDP in the comparisons to actual KSA data in the following sections, interpreting it as a fraction of GDP that is owned by foreigners.

[10] Non-oil fiscal revenues in KSA have been on average around 7% of GDP since 1970. Since we don't include these in the model we add this number to fiscal expenditures when we compare them to actual data in the following sections.

3.1.1 Optimal Rule

Since the only friction in the model is about external financing the behavior of the government doesn't affect the solution if it replicates the equilibrium path of external assets. The optimal rule does this. Government expenditures are set in such a way that the fiscal balance is consistent with the optimal path for external assets according to the model. As already mentioned this optimal path is the one that maximizes the utility of the representative agent, obeying mainly to the benefits from smoothing consumption in a context of high volatility and financial restrictions, factors that call for a buffer stock of assets to be used in episodes of very low income shocks and no access to international financial markets.

Under this rule we separate public from private aggregates in a simple way. Because the private sector doesn't have access to international financial markets the value of transfers can be derived from the private sector budget constraint:

$$T_t = c_t^T - Y_t^T + q_t \left(c_{t,p}^N + \sum_{i=T,N} \left(I_{t,p}^i + \varsigma_p (I_t^i)^2 \right) - Y_t^N \right)$$

where the subindex p denotes the private component of the corresponding variable.[11] Under these conditions the fiscal balance is $b_t = A_{t+1} - A_t$, exactly the same as the current account balance since private income and expenditures are balanced by assumption.

This optimal rule is taken as the baseline. We calibrate the model and pursue most of the quantitative exercises under this rule.

3.1.2 Budget Balanced Rule

Under this rule the government equalizes revenues and expenditures. The constrained optimal equilibrium under this rule, i.e. the equilibrium resulting from the optimal reaction of the private sector to the rule, can be obtained by imposing the following additional restriction to the model

$$A_{t+1} = A_t.$$

To see this note that the market clearing condition for the tradable sector implies

$$c_t^T = Y_t^T + p_t + rA_t.$$

Replacing this into the private sector budget constraint

$$T_t = p_t + rA_t - q_t \left(c_{t,g}^N + \sum_{i=T,N} \left(I_{t,g}^i + \varsigma_g (I_t^i)^2 \right) \right)$$

which means $b_t = 0$.

[11] We assume adjustment costs are allocated proportionally to the amount spent by the government and the private sector.

3.1.3 Permanent Income Rule

Finally we consider a rule that constraints the government to spend the perpetuity value of its wealth, i.e. the present value of expected revenues from oil and foreign assets. Under certain conditions this rule is able to smooth consumption perfectly because it implies that only permanent changes in income affect consumption. Purely transitory changes don't affect consumption because otherwise, at the time income comes back to the original level consumption needs to be adjusted, with the consequent utility costs of doing this. Since income shocks are transitory but persistent a fraction of it needs to be saved and a fraction consumed, this last fraction is given by the perpetuity value of wealth. The conditions under which this rule smooths consumption perfectly don't hold in this model. The most important deviation from these conditions is the imperfect access to international financial markets. This feature implies that there are some scenarios where it is not feasible to keep consumption constant after temporary negative shocks. It is at times when the economy is close to the bound on net foreign assets when the two rules differ the most, as we will see below.

Under this rule the constrained optimal allocation can be obtained by imposing the following additional restriction to the model

$$A_{t+1} = A_t + p_t - rP_t.$$

where P_t is the expected present value of future oil revenues

$$P_t = \sum_{s=0}^{\infty} \left(\frac{1}{1+r}\right)^s E_t[p_{t+s}],$$

with the expectation taken with respect to the process for oil revenues already defined.

To see that this constraint is enough, replace it in the market clearing condition for the tradable sector and obtain

$$c_t^T \quad = \quad Y_t^T + r(P_t + A_t).$$

And this into the private sector budget constraint implies

$$T_t \quad = \quad r(P_t + A_t) - q_t \left(c_{t,g}^N + \sum_{i=T,N} \left(I_{t,g}^i + \varsigma_g (I_t^i)^2 \right) \right)$$

meaning that

$$g_t \quad = \quad T_t + q_t \left(c_{t,g}^N + \sum_{i=T,N} \left(I_{t,g}^i + \varsigma_g (I_t^i)^2 \right) \right) = r(P_t + A_t).$$

4 Calibration

Some of the parameters are set to the standard values used in the macro literature. These are $\beta = 0.97$, $\sigma = 2$, $\delta = 0.1$. The rest of the parameters are set to match certain data moments of the KSA economy.

Parameters governing the process for oil are obtained using real Arabian Light oil prices reported by the Saudi Arabian Monetary Authority (SAMA). Although in the model the process corresponds to fiscal revenues, these two variables correlate very closely and have similar characteristics. The benefits of using oil prices is that projections are easier to obtain. Using data from 1970 to 2016 the estimated AR(1) coefficient is $\rho = 0.82$ and the standard deviation of log prices is 0.62.[12] Then we set the value for $\bar{p}$ to obtain a fraction of oil fiscal revenues to GDP of 0.33, which is the average ratio reported by SAMA.

The preference parameter left to be set is θ, the preference for tradable versus non-tradable consumption. We choose its value to match the average ratio of tradable (non-oil) to non-tradable production, which is 0.2 according to data from SAMA for 1970 to 2016.[13] The productivity parameter z is set such that $Y = 1$, as a normalization. In the case of capital-output elasticities, α^T and α^N, we assume that in the long-run wages are equalized across the two sectors. From that condition, and using data since 1990 on employment and production by sector from the WDI, we obtain $1 - \alpha^T/1 - \alpha^N = 0.29$. Then we impose the standard value of 0.4 for the average α in the economy. These two restrictions imply $\alpha^T = 0.79$ and $\alpha^N = 0.25$. The last technology parameter is ς. We choose a value for it such that the volatility of the investment to GDP ratio of 0.04%, the standard deviation observed in KSA.

For financial variables we set $r = 1.5\%$ and $\underline{A} = 0$. Note that the planner has a higher discount rate than the return on investments abroad and hence, without uncertainty, would never find optimal to accumulate a large stock of assets.

Finally to differentiate public and private expenditures we give values to the ϕ parameters using data on government spending and investment from SAMA. We consider total fiscal expenditure reported in the national accounts as non-tradable consumption, and we take public investment directly from fiscal accounts. For each of these measures we compute the average from 1990 as a fraction of non-tradable GDP and derive their private counterpart using average Gross Fixed Capital Formation, which is 21% of GDP. This procedure yields $\phi_c = 10\%$ and $\phi_I = 31\%$.

[12] The correlation between real Arabian Light oil prices and real oil fiscal revenues, reported by SAMA as well, is 0.72. When using fiscal oil revenues we obtain $\rho = 0.8$ and a standard deviation of 56%.

[13] We make the standard assumption that the tradable sector corresponds to agriculture and manufacturing net of oil production, and the non-tradable sector corresponds to services.

5 Results

5.1 The Effects of Revenue Shocks

To understand the main mechanisms of the model in this subsection we show impulse-response functions (IRF) of the main macroeconomic variables, under the optimal rule, to a one standard deviation negative shock in oil revenues. These responses depend on the state of the economy, which is composed by the initial level of tradable and non-tradable capital, oil revenues and foreign assets. It is this last state variable the one that influences the most the responses due to the financial restriction that sets a bound on it. I show two IRF for each variable, the one observed when the economy is close to the bound of assets, i.e. a low level of A, and the one materialized when the stock of assets is large enough so the economy is far from the constraint. In particular we use the minimum and maximum values observed in KSA since 1970, respectively.

Figure 1 shows the dynamics of oil revenues after the shock as well as the response of consumption, foreign assets, and fiscal accounts. The shock to revenues is very persistent (left upper panel) implying that consumption needs to be at least partially adjusted. The planner wants to make this adjustment as small as possible, even lower to the fall in permanent income because he is impatient; the return to safe assets is relatively low compared to his discount rate. Therefore foreign assets fall (center upper panel). But when the stock of initial foreign assets is small the reduction cannot be as large as when this stock is large. This is because the planner doesn't want to get closer to the bound. This is risky because an additional negative shock could force an even larger adjustment in consumption. Because of the smaller adjustment in assets the reduction in consumption is larger when assets are initially low (left upper panel). Under the current calibration the fall in consumption is between 10%, when assets are at the minimum levels observed in KSA, and 5%, when assets are at the maximum observed values.[14] Fiscal expenditures react more severely to the shock than private spending (left lower panel) because they contain public investment, which is the component of demand that adjusts the most. Still the adjustment is smaller than the size of the income shock and the government achieves a deficit, which goes from 4% to 8% of GDP depending on the initial level of foreign assets (right lower panel).

The planner needs to reduce consumption of both tradable and non-tradable goods. Therefore a reallocation of capital to the tradable sector is needed to achieve the equilibrium in the non-tradable sector. This reallocation is generated by a decrease in the relative price of non-tradables, which falls between 2% and 8% depending on the initial level of assets. Tradable investment and production increase as resources are reallocated from the non-tradable sector. These responses are shown in Figure 2.

To see the differences with the sub-optimal fiscal rules we compare the IRF under the optimal

[14] After a positive shock the reaction of consumption is also larger the lower the stock of assets. The difference comes from the fact that when the planner is financially constrained the economy starts from a level of consumption that is below the unconstrained optimal level.

rule with those computed under the BB and PI rules. Results are shown in Figure 3. The largest response of consumption is observed under the BB rule, while the smallest ones is observed under the optimal rule when the stock of initial assets is large (upper right panel). The response of consumption under the PI rule is stronger than the optimal response with high assets. This is because the planner is impatient, and being far from the constraint the risk of hitting the constraint is low, something that only the optimal rule takes into account. For low levels of assets the optimal response is between the PI and BB rule. Foreign assets (upper right panel) reflect these movements. With the BB these don't change, and the largest response in observed by the optimal rule starting from high assets. Fiscal expenditures (lower left panel) follow the same pattern than consumption, and all but the BB rule show a deficit after a negative shock (lower right panel). This is as large as 8% of GDP under the optimal rule, which is behind the large reduction in foreign assets already described.

5.2 Consumption and Saving Allocation in KSA

In this section we analyze the behavior of consumption, saving and other macroeconomic variables in KSA during the last 50 years in light of the model predictions under the optimal rule. To do this we feed the model with the actual series of oil revenues reported by SAMA and compare the predicted path of the main macroeconomic variables with their actual values.[15]

The left upper panel of Figure 4 shows the observed series of oil revenues as a percentage of GDP, which we use to simulate the model. We can divide the period in three. Until the beginning of the eighties we observe very high oil revenues with a peak above 70% of GDP. Then it came the period of low oil prices and the consequent reduction in oil revenues, with an average from 1985 to 2000 of 22% of GDP, below the 46% recorded on average in the previous 15 years. Finally in the last period revenues closely fluctuated around the 1970-2017 average of 33% of GDP, but it ends with three years of very low revenue levels, below 20% of GDP, which represents one standard deviation below the period's average.

The three different periods observed for oil revenues can also be detected in the series of net foreign assets to GDP, depicted in the upper center panel of Figure 4. The blue line is the actual value of this variable and the red line is the path predicted by the model. Overall the two move very closely, meaning that the main mechanisms in the model, i.e. consumption smoothing and precautionary savings, have been probably a key factor behind the actual behavior of the economy.[16] Foreign assets are rapidly accumulated in the first and third periods, and rapidly disaccumulated

[15] In the comparisons we subtract the average trade balance since 1970, which is around 17% of GDP, from the simulated GDP, and add average non-oil fiscal revenues of 7% of GDP to the simulated fiscal expenditures (see footnotes 9 and 10).

[16] Averages (dashed lines), which are not a target in the calibration, are also very close. The fact that this is achieved with standard values of most of the parameters, particularly of the discount rate and the risk-free interest rate, shows that precautionary motives are very influential in the economy.

in the second period. Differences are related to the intensity of these processes. In the first period the model would recommend a faster accumulation, and a slower accumulation in the last period, reflecting the difference between the two periods in terms of average oil revenues. It is interesting to notice that, even though the financial restriction pushes away the planner from the debt limit (zero in this case), the model does a good job, and even underestimate the level of foreign assets, at the end of the second period. This shows that the actual behavior is consistent with the existence of the financial restriction assumed in the model, which, on the other hand, strengthen the precautionary motive in this high volatility context.

The prediction for consumption expenditures, depicted in the right upper panel of Figure 4, behaves similarly as well, particularly from 1980 to 2000. The very high levels of foreign assets are followed by high levels of consumption, which are slowly reduced as oil revenues remain at low levels. Unlike its actual path the planner maintains consumption at relatively high levels for the entire period. Consumption is smoother in the simulations. In the data large swings are observed, which are generated by a reallocation of resources between consumption and investment (see the lower left panel of Figure 4), something not observed in the model simulations where consumption expenditures and investment are positively correlated. Government spending and the fiscal balance follow similar patterns as well, although the model predicts a smoother behavior for their ratios to GDP particularly in the case of government expenditure (center and right lower panels in Figure 4).

To see if the success of the model in matching the data is really due to the incentives to accumulate precautionary savings we compare its predictions for the KSA economy with those obtained under the other two fiscal rules we consider in this paper, the BB and PI rules. In the first case expenditures react one-to-one to revenues while in the second one expenditures react less than one to one, since the effects are proportional to the present value of revenues. In Figure 5 we show this response under the baseline calibration, i.e. a case where oil revenues are stationary and always converge to 33% of GDP in the long-run. To compare the results under different rules we first evaluate how each of them compares to the actual series of foreign assets as a fraction of GDP. This comparison is shown in the upper left panel of Figure 6. Clearly the BB rule (in green), where all the variation comes from changes in GDP, does a bad job matching the data. The PI rule is closer to the data but cannot match it as well as the optimal rule. In the first period it would have accumulated more assets, and in the third period less assets, than both the optimal rule and actual data. The observation that in most of the years the PI rule is further away from the data than the optimal rule reinforces the claim that precautionary savings have been important behind the behavior of the KSA economy. Note that under the PI rule the economy would have hit the bound on assets in the years before 2015. We can see the corresponding adjustment in consumption and government expenditures in the upper right panel and the center lower panel, respectively. This is something that the optimal rule tries to avoid, which explains the relatively lower levels of consumption before

2003. However the time the economy would have stayed financially constrained, and hence the size of the adjustment, would have been relatively small because revenues jumped above their average level and stayed there for at least 5 years. This means that over the period under the analysis the extremely bad state of low assets and revenues, that is behind the accumulation of assets under the optimal rule by the planner, haven't been realized, although today the stock of assets would have been about 30% of GDP lower.

In the rest of Figure 6 we show the comparison with the variables defined in levels to better compare the volatility that accompanies each of the rules. The BB rule generates a lot of volatility, while, with the exception of investment, the PI shows the lowest. In particular the standard deviation of consumption expenditures for the entire sample is 10%, 27% and 4% for the optimal, BB and PI rules, respectively. The fact that PI generates less volatility than the optimal rule is in part because under the PI rule the scenario of a binding constraint would have existed but it would have been very short. Since under the optimal rule the planner reacts before as precaution consumption adjusts significantly when assets get closer to the bound the years before 2000. Moreover, since the planner is impatient, consumption increases more under the optimal rule than under the PI rule in the first period when both the stock of assets and revenues were large. The same pattern is observed with fiscal expenditures, with standard deviations of 17%, 42% and 5% for the optimal, BB and PI rules, respectively.

Finally in Table 1 we present, for the main macroeconomic variables, correlations between the model simulations under each of the three rules and actual data for KSA since 1970. We confirm that the optimal rule fits better the data. With the exception of private consumption, where the correlations under the optimal and PI rules are similar, correlations are always higher for the optimal rule, particularly with respect to the BB rule. When comparing the optimal with the PI rule, the correlations for net foreign assets, investment and fiscal expenditures are significantly higher in the first case.

5.3 Sensitivity Analysis

In this subsection we briefly explore how differences in the value of the main parameters influence the results. First we consider the parameters related to capital investment. We reduce the average participation of capital in the economy α from 40% to 34%. This is equivalent to a reduction in the productivity of investment.[17] The other parameter related to investment is the one capturing adjustment costs, ς, which is reduced by half in this case.

Results are depicted in Figure 7. As expected investment is higher with lower adjustment costs, and lower when capital productivity falls. Resources are reallocated between investment and

[17] Cherif and Hasanov (2013) argue that low productivity is a reason for the accumulation of foreign assets. Calderón, Moral-Benito, and Servén (2015) estimate a long-run elasticity of output with respect to infrastructure capital close to 10%, although that measure is difficult to be mapped into the model.

consumption expenditures, and hence the effects on this last variable are the opposite to those on investment. Although with more profitable capital we could expect a lower accumulation of liquid assets because of the increase in their alternative cost, we observe the opposite. Net foreign assets are larger with lower adjustment costs and lower with lower capital participation. This may be because with more profitable capital the relatively more volatile nontradable sector becomes more important, or because of the increase in total income that a larger stock of capital generates.

Other relevant parameters are those governing the degree of patience of the planner. We explore how a lower interest rate on risk-free assets r, and a higher discount factor β, influence the results. Both factors affect the willingness of the planner to postpone consumption but for reasons not directly related with uncertainty of oil revenues. Figure 8 shows how results change when r is 1% (down from 1.5%) and β is 0.975 (up from 0.97). Now the stock of foreign assets varies much more than with technological parameters. As expected a lower interest rate generates a reduction in assets, and a higher discount factor generates a larger stock. None of these changes improve the fit of the model however. If a change in one of these parameters improves the fit in the first part of the sample, it would worsen the fit in the last part. Note however that the effect on consumption differs between the two periods. For instance a larger accumulation of assets due to a higher β in the first part of the sample leads initially to lower consumption, but thereafter higher wealth leads to higher (and less volatile) consumption.

Overall this sensitivity analysis let us conclude that the fact that the model under the optimal rule mimics closely the path of foreign assets and other macro variables in KSA is not strongly influenced by the values assigned to specific parameters.

5.4 Future Paths

The model can also be used to simulate the future path of the relevant macroeconomic variables under different scenarios for oil revenues. It is important to notice that this is not a forecasting exercise aiming to find the most likely path for macroeconomic aggregates in KSA. It is just an exploration of how these aggregates would react to arbitrary paths for oil revenues according to a model that hasn't been built to replicate the movements, particularly out of sample, in the KSA economy, and that assumes certain welfare concerns that may not be the ones considered by policymakers.

We consider three possible scenarios for oil revenues. The baseline assumes a path for real oil prices in line with the World Bank forecast from 2018 to 2030. This future expected path for prices, together with the historical series from 1990, is shown in the left panel of Figure 9, as deviations from the 2017 real price. The historical series is for the real price of the Arabian Light Oil published by SAMA from 1970 to 2016 (blue line). The growth rate of the series from the World Bank is used to construct the expected path (dashed red line). The baseline scenario assumes that the real price will keep recovering from its relatively low level in 2016 and will increase by around 20% in

2018. From then onward it falls steadily until 2030, when its level would be around 10% higher than in 2017. In this baseline scenario oil revenues are assumed to exactly follow this path from 2018 to 2030. From 2030 onwards it is assumed a steady decrease until reaching a level close to zero in 2100. Therefore we assume that in the long-run oil is depleted. This baseline path is shown in the right panel of Figure 9. We also consider an optimistic and a pessimistic scenario (green and black lines in the right panel of Figure 9, respectively). The optimistic scenario assumes that, after the recovery in 2018, prices continue to rise until 2030, year in which oil revenues reach a level of 30% of GDP, very close to the historical average. The pessimistic scenario assumes that after the recovery in 2018 revenues fall at a higher speed than in the baseline case, reaching only 10% of GDP in 2030. Similarly than in the baseline case it is assumed that in both the optimistic and pessimistic scenarios oil revenues fall steadily after 2030 and converge to zero in 2100.

In all cases the paths just described correspond to expected prices, i.e. the parameter $\bar{p}$, which now takes different values in each year. The planner still faces the same level of uncertainty, although the influence of this on his decisions may vary depending on the size of the oil sector. In the exercises below we assume that the planner realizes in the beginning of 2018 that $\bar{p}$ changes from the calibrated constant value of 0.33 to the respective sequences assumed for each scenario, and show the results for the case where exactly the expected price is realized in each period from 2018 to 2040.

Results under the optimal rule are shown in figure 10. We show each variable as a fraction of the level of GDP in 2017, which on the other hand is very close to potential output according to the data. It is important to notice that these and all the following results need to be interpreted as the counterpart of actual detrended variables. Hence, to obtain the real level of each variable it is necessary to adjust it by the potential growth of the economy, a variable that doesn't play a role in the simulations.[18] For reference Figure 11 shows the same results but defining the variables as a percentage of each year's GDP, together with historical data.

There are two features that influence the macroeconomic response to the new expected oil revenue paths. First expenditures need to be adjusted according to the change in expected income. As the permanent income hypothesis suggests consumption should increase in the optimistic scenario and decrease in the other two scenarios. This pattern can be observed in the upper right panel

[18] It is important to take into account that, since the model is not build for forecasting proposes, it is not able to generate a level of output close to its potential level, as the data suggests was the case for 2017, with such a low level of oil revenues observed in that year. The same happens with all of the flow variables. More flexible models may introduce different types of persistence which may anchor future levels of them to the ones observed in the data, independently of the value of some state variables. That is very complex to introduce in the present model, built to capture precautionary motives, because of dimensionality problems. Therefore we adjust the path simulated by the model. For each flow variable, except the fiscal balance, we take the difference between the simulated value in 2017 under the optimal rule and baseline scenario, and the actual value, and then we add it to all the simulations (for every rule and scenario) of that variable. Hence we keep the differences for the same variable across rules and scenarios unchanged.

of Figure 10. However, unlike under the PI rule, under the baseline and pessimistic scenarios, this effect is counteracted by the impatient planner, who doesn't want to reduce consumption so abruptly. Hence assets are disaccumulated to make the adjustment smoother (upper center panel). The movements in total consumption are also observed for fiscal expenditures (middle center panel) and hence the fiscal balance closes relatively slowly as expenditures remain above revenues from some periods (middle right panel).[19] Since in the three scenarios oil revenues converge to zero in the long-run there is less need for liquid assets for precautionary motives, facilitating the smoother adjustment of consumption. Only in the optimistic scenario assets stop decreasing before 2040, in the years when oil revenues are reaching their highest levels. The second force behind the results is that the planner reallocates resources across the tradable and nontradable sectors depending on oil revenues. High (low) revenues increase (decrease) the demand for nontradables and hence resources are reallocated to (from) that sector (lower center and left panels). Also the planner wants to enlarge the tradable sector as the oil sector shrinks and more tradable income is needed, and hence investment and the size of this sector are inversely related to oil revenues. Behind this there is also the fact that the planner wants to save resources to sustain higher levels of consumption in the future, when income falls as the oil sector shrinks over time. But since this is not due to precautionary motives liquidity is not necessary, and hence capital is preferred over risk-free assets, which eventually converge to zero. A lower demand for investment lowers the relative price of nontradables, and that explains that nontradable GDP is lower in the beginning when oil revenues are high, and larger when oil revenues are low. Total GDP diverges between the three scenarios as oil revenues start to diverge in 2019, with the changes in oil revenues having an almost one-to-one effect in the long-run (lower left panel).

In Figure 12 we pursue the same exercise but solving the model under the BB rule. Again, for reference, we present the results in terms of ratios to GDP with the historical series in Figure 13. Remember that foreign assets and the fiscal balance are fixed under this rule.[20] Consumption and government expenditures are not adjusted as a function of the present value of income now. Instead they follow closely the actual path of oil revenues. The second feature described above, related to capital, is also observed in this case. In particular investment is negatively correlated with oil revenues, nontradables depict a changing pattern, with a negative correlation in the first periods due to price effects, but a positive correlation in the medium-term, and the relative size of the tradable sector grows over time as the oil sector shrinks. Below we compare the results with the optimal rule in the same figures to have a better idea of the quantitative differences, but first we show the same figures for the PI rule. Figure 14 presents the results with the variables defined as

[19] The initial rise in oil revenues generates a transitory surplus in the pessimistic case, where the adjustment in spending is the largest.

[20] The rule starts in 2018 and hence assets decrease according to the actual 2017 fiscal deficit. The 2017 deficit implies that spending in that year was above the level implied by the rule. This explains the fall in expenditures in 2018 despite the increase in oil revenues.

a fraction of GDP in 2017, and Figure 15 shows the variables as ratios to current GDP. We can see now the pure effect of permanent income on expenditures. Consumption and fiscal expenditures are adjusted according to the present value of revenues, which fall more than their current value. Hence the fiscal balance moves quickly to a large surplus of between 5% and 15% of GDP, and foreign assets increase steadily, reaching levels between 250% and 400% of GDP in 2040. Since assets are mechanically accumulated at a high rate the planner doesn't need to increase capital as in the other cases, so investment falls strongly in the first years, and even in the medium-term in the optimistic scenario. The nontradable sector inherits this pattern, and so it does total GDP, albeit less markedly.

To better compare the implications of each rule for the path of the relevant macroeconomic variables we present the previous results grouped in terms of oil scenarios instead of fiscal rules. Figures 16, 17 and 18 show the results, as a percentage of the level of GDP in 2017 and for the three rules, for the baseline, pessimistic, and optimistic scenarios, respectively. In the baseline case in Figure 16, it can be seen right away the much larger responses of consumption and government expenditures, and investment, under the PI rule, leading to a very fast accumulation of assets and large fiscal surpluses. Note that the increase in assets allows the planner to sustain an increasing path for consumption under the PI rule, which eventually leads to higher levels of consumption than under the optimal and the BB rule. The sharp decrease in demand leads to a reallocation of resources from the nontradable to the tradable sector, leading also to a low level of total GDP compared to the other two rules. Consumption under the optimal rule moves closely to the BB rule, but stays above it as the planner wants to make the adjustment in consumption as smooth as possible. This leads to a slower adjustment in the fiscal deficit and a disaccumulation of foreign assets. The planner also uses these resources to sustain a level of investment slightly above the one observed under the BB rule, difference that translates into nontradable and total GDP as well.

Figure 17 shows the results for the pessimistic scenario, where we can see all of the features described for the baseline case but quantitatively more significant. The accumulation of assets is much stronger under the PI rule due to a significantly larger adjustment in expenditures. The fiscal surplus reaches a 15% of GDP and nontradable GDP falls almost 15% of GDP. One difference is that consumption and government expenditures under the optimal rule is much closer than the one observed under the BB rule (it is even lower in the first years for consumption expenditures), and both fall more quickly as revenues decrease over time, converging to the level observed under the PI rule before 2040. The boom in investment is larger under the BB rule. In this case investment increases almost 5% of GDP, and nontradable GDP in around 2%. As it is the case with expenditures, GDP converges to similar levels under the three rules around 2040. Finally Figure 18 shows the results for the optimistic scenario. Although revenues increase, this is only transitory and the present value of oil revenues decreases. Hence consumption and government expenditures under the PI rule decrease as well, generating an even stronger accumulation of assets and the corresponding large fiscal surpluses. Again under the optimal rule the planner takes advantage of the large initial stock of assets to smooth consumption, and hence keep expenditures above the level implied by a BB rule, closing very smoothly the fiscal deficit and disaccumulating around 35% of GDP in foreign assets. Unlike in the PI case the planner sustains higher levels of investment in the medium-term, allocating more resources in physical capital under the optimal and the BB rule to save resources to be spent in the future when the volatile oil sector disappears.

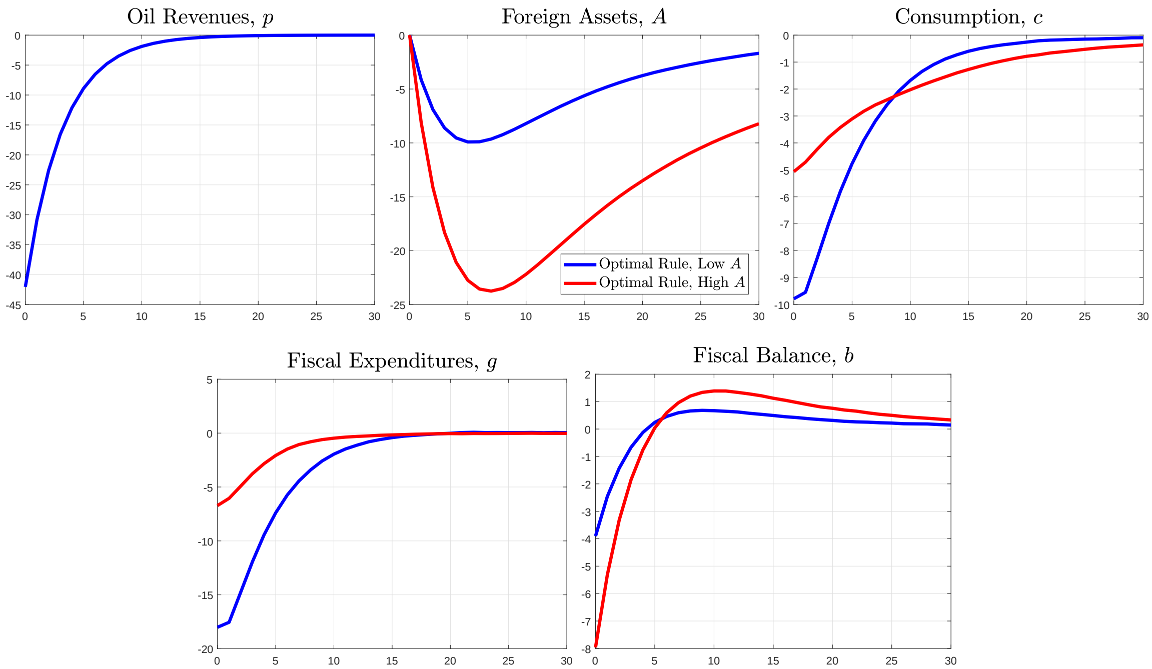
6 Conclusions

This paper builds a model to analyze the optimal allocation of resources in an economy facing a high degree of uncertainty related to revenues from commodity exports. In addition to uncertainty the model includes a financial constraint, features that together generate a high need for precautionary savings. The model is solved in a way that allows for a full characterization of this behavior, and includes two alternatives for investing these resources: physical capital and external risk-free liquid assets. Adjustment costs for investment makes the second option more attractive, although the first one increases domestic output. Therefore the model is useful to characterize the main trade-offs when allocating resources between consumption, savings and investment. Although in a simplified way, different fiscal rules are analyzed in the context of the model. An optimal rule that mimics the optimal path for net foreign assets, a budget balanced rule where the government spends exactly its revenues, keeping fixed the amount of foreign assets, and a rule that mimics what the permanent income hypothesis would recommend in the absence of precautionary motives.

We apply this model to the KSA economy. This is the largest oil exporter of the world and because of this is subject to extreme volatility. Under a parsimonious calibration the model does a very good job matching the data, particularly net foreign assets which is the most important macro variable that relates to precautionary behavior. This validates the existence of a financial constraint and illustrates that the main mechanisms in the model have probably played a role in the performance of the KSA economy. In terms of fiscal rules, the one that mimics the optimal path for assets does a better job than the one following the permanent income advice, and much better than the balanced budget rule.

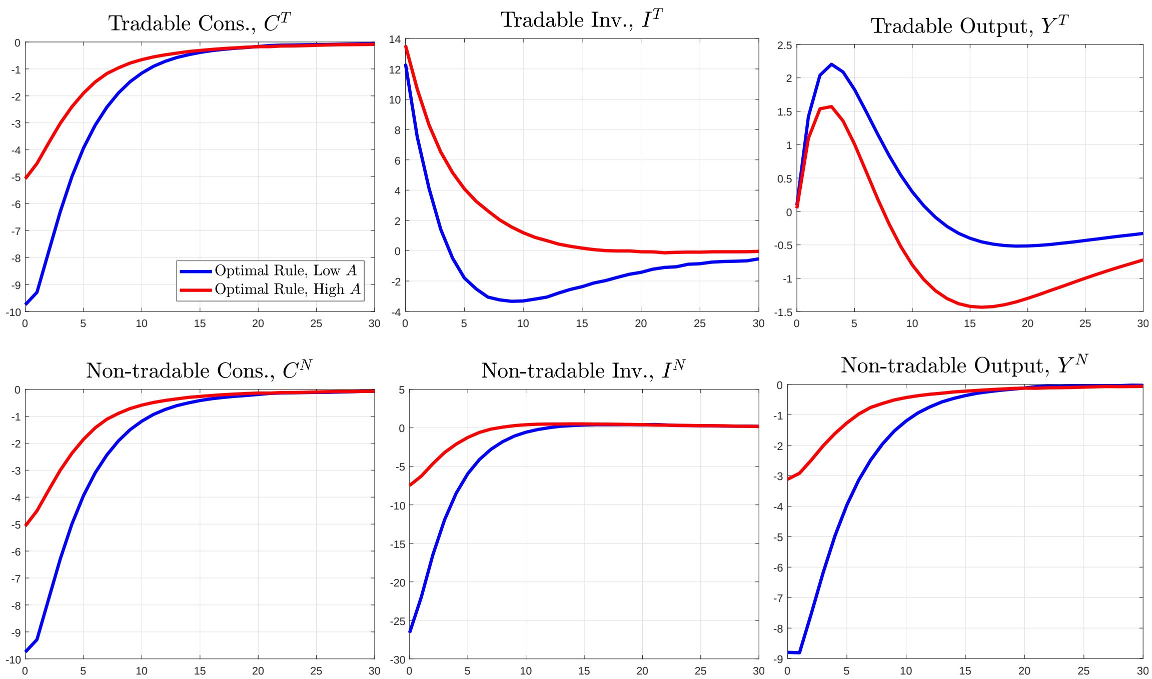
Multiple simulations of the model under different scenarios for oil revenues show that the optimal rule generate smoother expenditure adjustments than a budget balanced and a permanent income rule, and that it better adapts to a reduction in the oil sector reallocating resources from liquid foreign assets to capital and consumption.

7 Figures



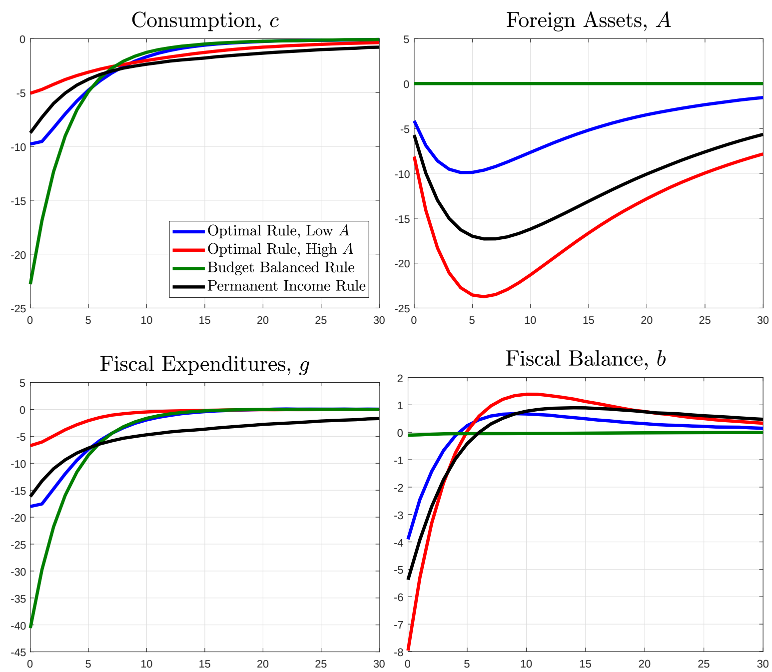
Note: Impulse responses to a negative shock in p of one standard deviation. Deviations from average levels, except for foreign assets which are set at the minimum (blue) and maximum (red) levels observed in KSA during 1970-2017, corresponding to 17% and 110% of GDP, respectively. All variables in logs except foreign assets and fiscal balance which are defined as a fraction of average GDP.

Figure 1: Impulse-Response Functions to an Oil Shock, Main Macroeconomic Aggregates



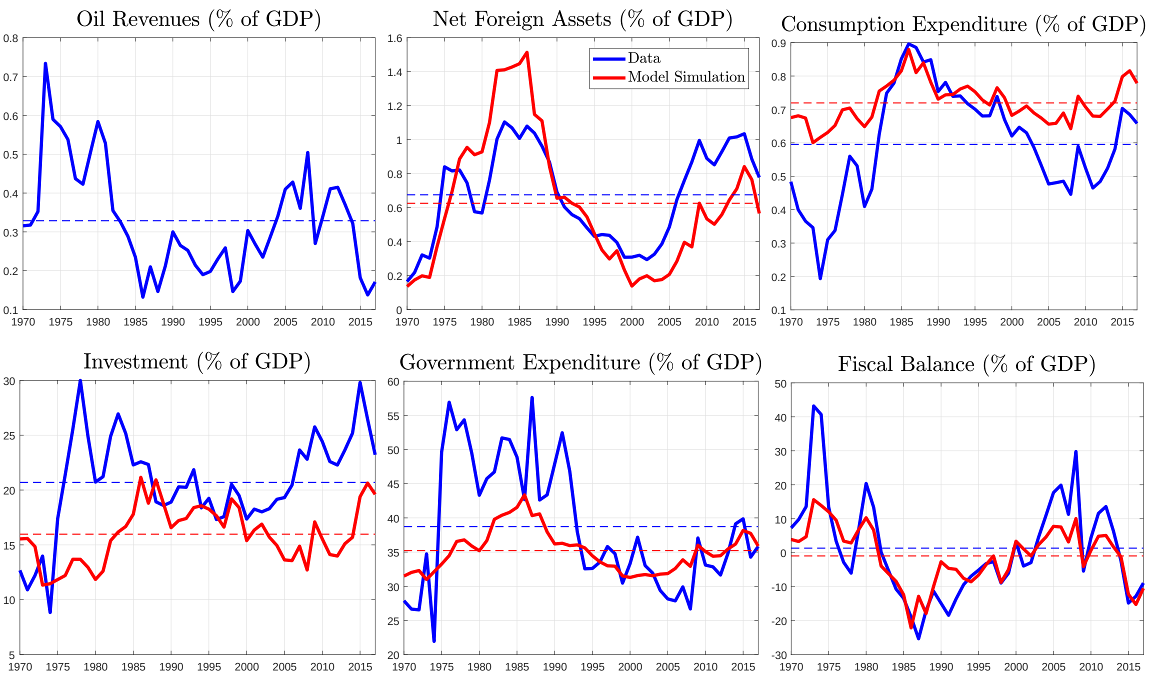
Note: Impulse responses to a negative shock in p of one standard deviation. Deviations from average levels, except for foreign assets which are set at the minimum (blue) and maximum (red) levels observed in KSA during 1970-2017, corresponding to 17% and 110% of GDP, respectively. All variables in logs except foreign assets and fiscal balance which are defined as a fraction of average GDP.

Figure 2: Impulse-Response Functions to an Oil Shock, Tradable and Non-tradable Sectors



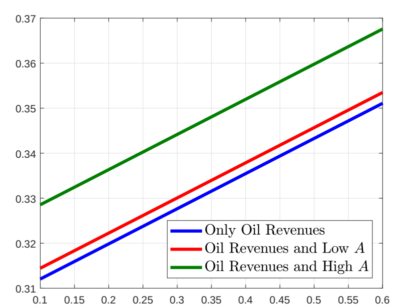
Note: Impulse responses to a negative shock in p of one standard deviation. Deviations from average levels, except for foreign assets under the optimal rule which are set at the minimum (blue) and maximum (red) levels observed in KSA during 1970-2017, corresponding to 17% and 110% of GDP, respectively. All variables in logs except foreign assets and fiscal balance which are defined as a fraction of average GDP.

Figure 3: Impulse-Response Functions to an Oil Shock, Different Fiscal Rules



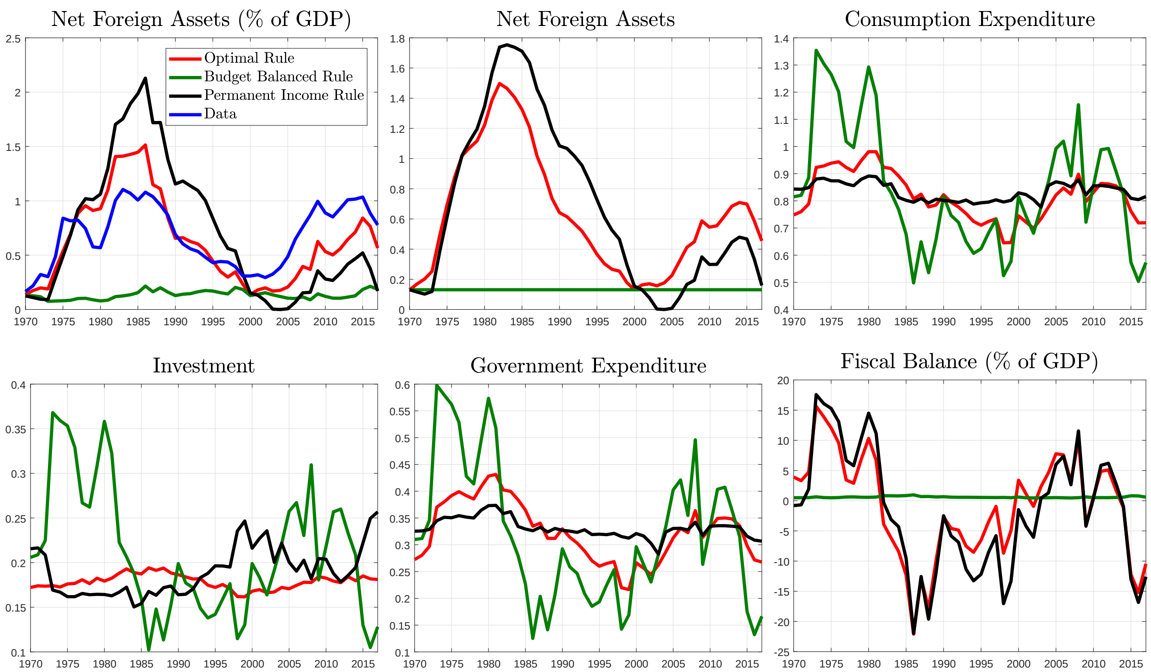
Notes: in blue actual series for KSA and in red the series implied by the model. Dashed lines are the average of each variable. The source for oil revenues from 1970 to 2016 is SAMA, and for 2017 is the Ministry of Finance (Fiscal Balance Program, 2018 update). The sources for the rest of the variables are WDI (net foreign assets 1970-2017), WEO (GDP 2017), Ministry of Finance (balance and fiscal expenditures 2017) and SAMA.

Figure 4: Macroeconomic Aggregates, KSA 1970-2017 vs. Model Simulation under the Optimal Rule.



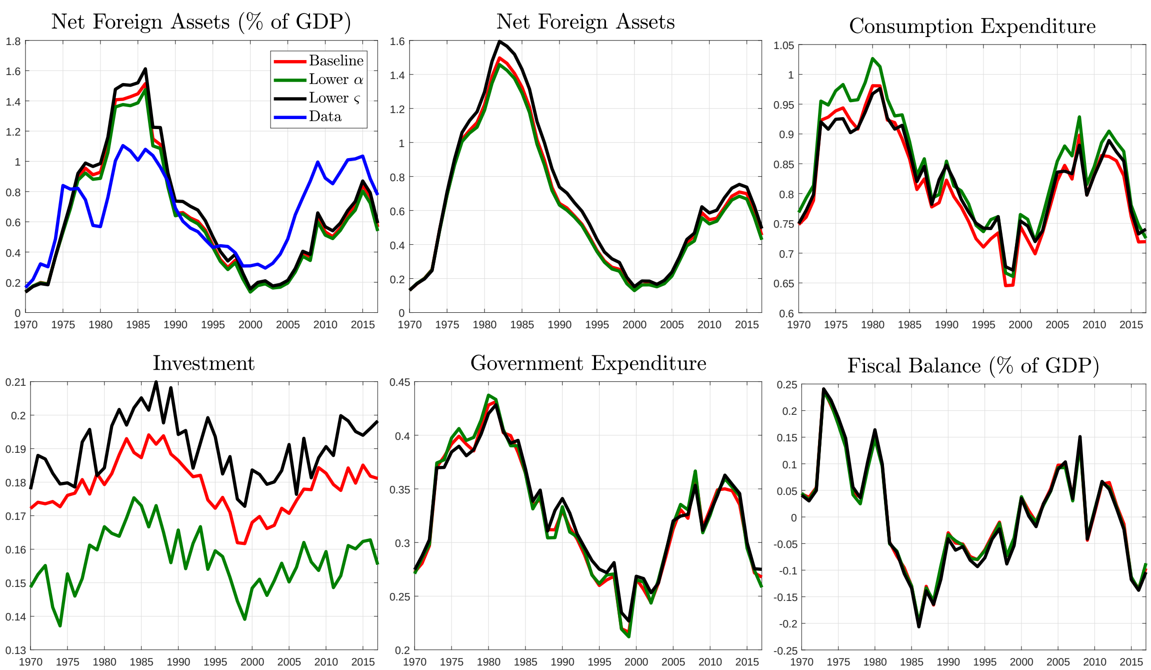
Notes: the figure shows the level of fiscal spending as a % of GDP (in the y-axis) implied by the PI rule, for different levels of oil revenues as % of GDP (in the x-axis), and different levels of net foreign assets. These are zero for the blue line, and the minimum and maximum levels observed in KSA during 1970-2017, corresponding to 17% and 110% of GDP, for the red and green lines, respectively.

Figure 5: Fiscal Spending under the PI Rule



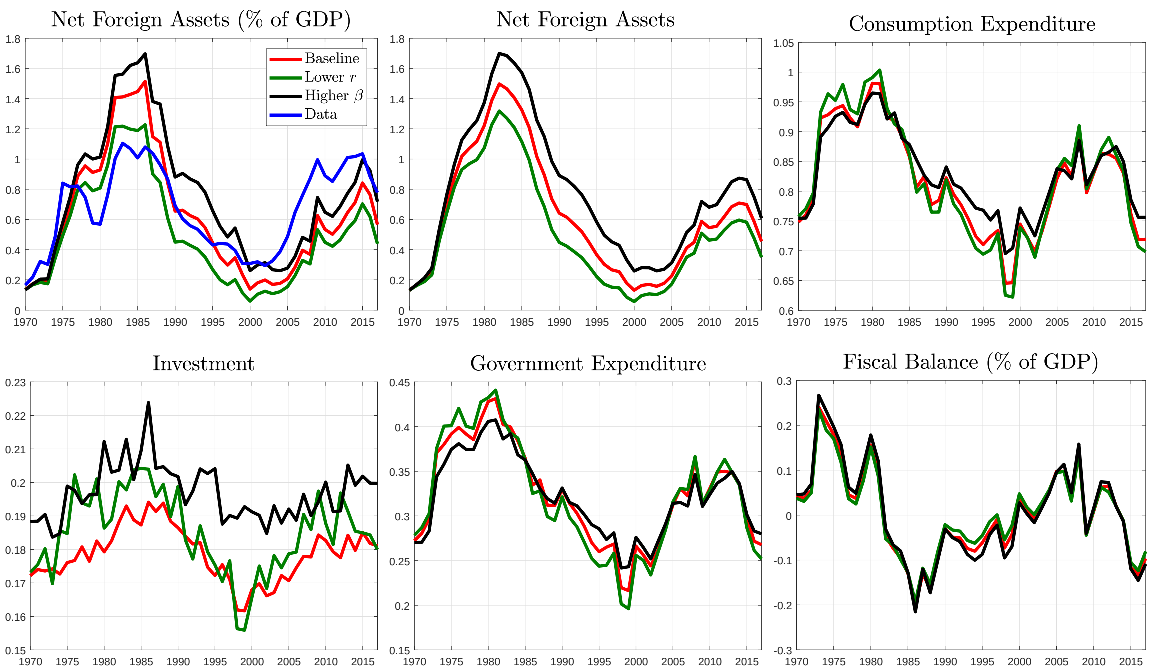
Notes: Series implied by the model under different fiscal rules, except for the blue line which is data from KSA. The sources for this are WDI and WEO (GDP 2017). Except for the upper left panel the series should be interpreted as % of trend GDP.

Figure 6: Macroeconomic Aggregates, KSA 1970-2017 vs. Model Simulation under Different Fiscal Rules.



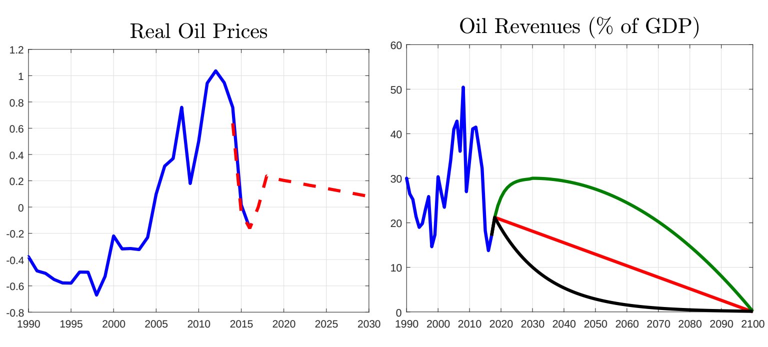
Notes: series implied by the model when reducing α from 0.4 to 0.36, and when reducing adjustment costs ς by half, except for the blue line which is data from KSA. The sources for this are WDI and WEO (GDP 2017). Except for the upper left panel the series should be interpreted as % of trend GDP.

Figure 7: Macroeconomic Aggregates, Model Simulation under the Optimal Rule, Different Productivity and Adjustment Costs.



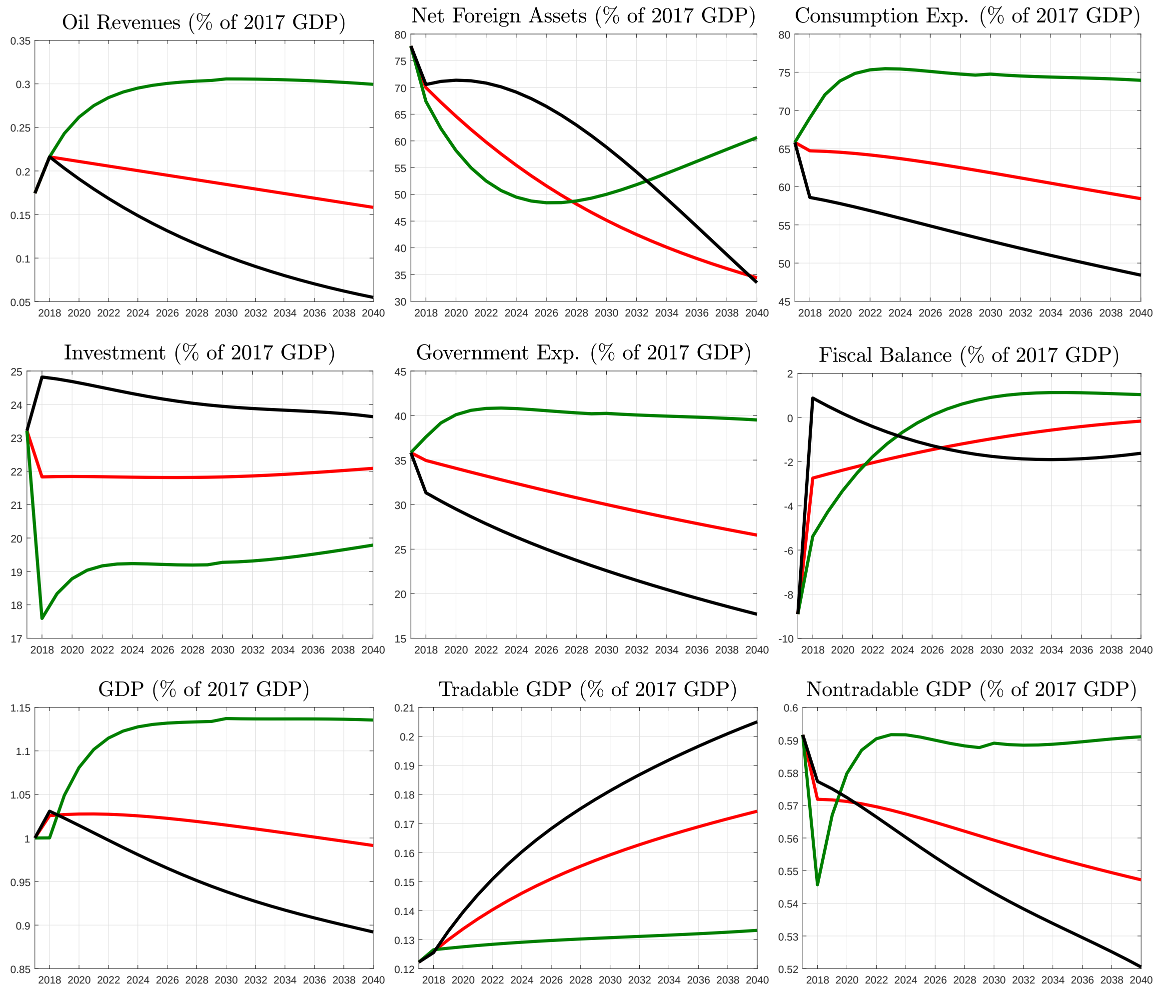
Notes: series implied by the model when reducing r from 1.5% to 1%, and when increasing the discount factor β from 0.97 to 0.975, except for the blue line which is data from KSA. The sources for this are WDI and WEO (GDP 2017). Except for the upper left panel the series should be interpreted as % of trend GDP.

Figure 8: Macroeconomic Aggregates, Model Simulation under the Optimal Rule, Different Interest Rate and Discount Factor.



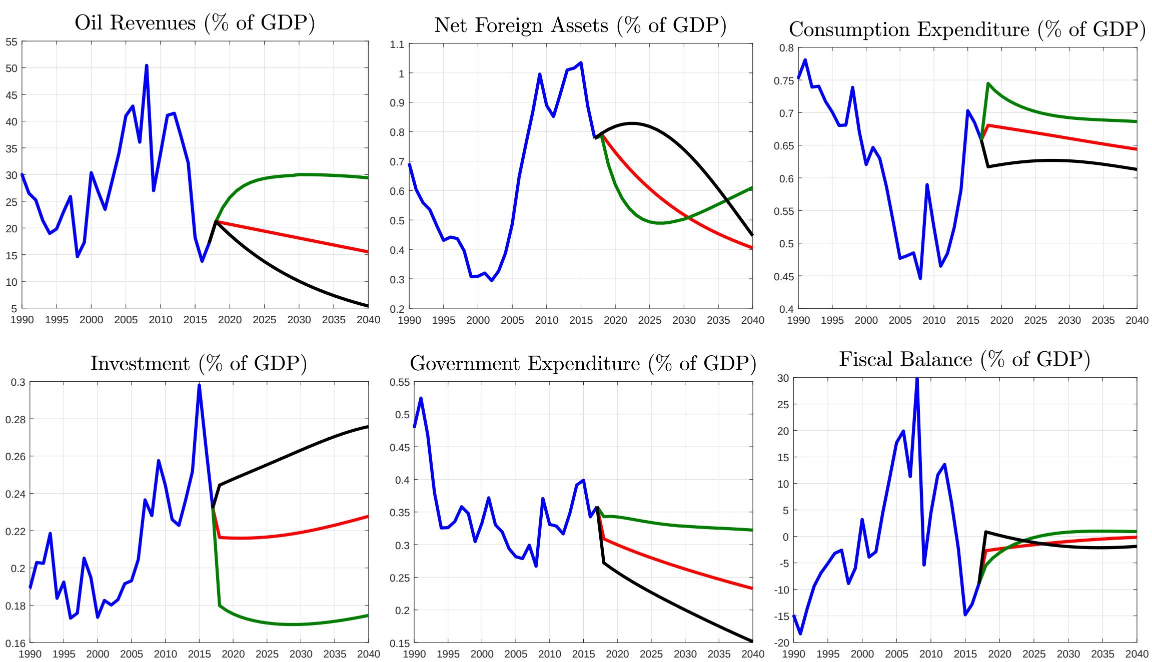
Notes: real oil prices correspond to the price of Arabian Light Oil (blue line) from 1970 to 2016 (SAMA), merged with real oil prices from the World Bank (dashed red line) using growth rates. Oil revenues as % of GDP are actual series for KSA in blue, and in red, green, and black the series assumed by the model under the baseline, optimistic, and pessimistic scenarios for oil revenues, respectively. The source for oil revenues from 1970 to 2016 is SAMA, and for 2017 is the Ministry of Finance (Fiscal Balance Program, 2018 update).

Figure 9: Oil Prices and Revenues, Future Scenarios.



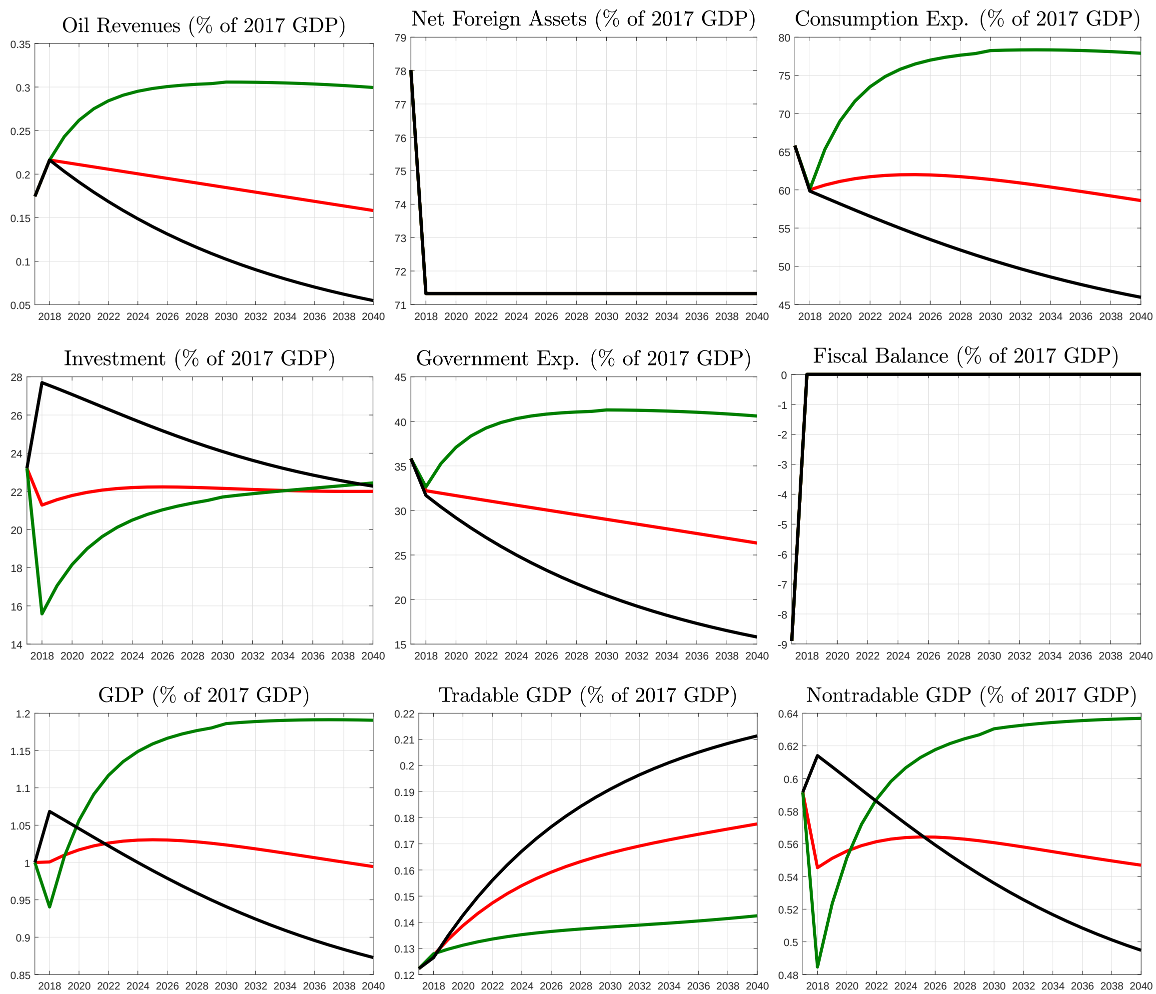
Notes: series implied by the model under the optimal rule and the baseline (red), optimistic (green), and pessimistic (black) scenarios for oil revenues, respectively. All of the variables are defined as ratios of GDP in 2017. They should interpreted as detrended variables (as % of GDP) when compared with actual series.

Figure 10: Macroeconomic Aggregates, Model Simulations under the Optimal Rule, Future Scenarios for Oil Revenues (% of 2017 GDP).



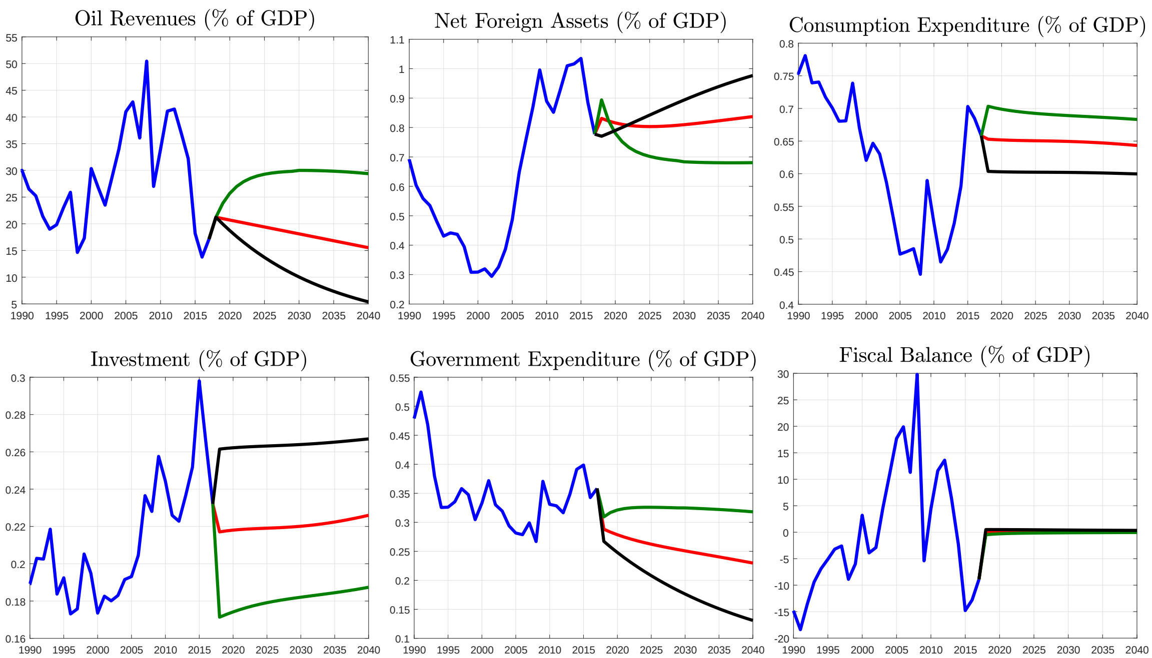
Notes: in blue actual series for KSA and in red, green, and black the series implied by the model under the baseline, optimistic, and pessimistic scenarios for oil revenues, respectively. The source for oil revenues from 1970 to 2016 is SAMA, and for 2017 is the Ministry of Finance (Fiscal Balance Program, 2018 update). The sources for the rest of the variables are WDI (net foreign assets 1970-2017), WEO (GDP 2017), Ministry of Finance (balance and fiscal expenditures 2017) and SAMA.

Figure 11: Macroeconomic Aggregates, KSA 1990-2017 and Model Simulations under the Optimal Rule, Future Scenarios for Oil Revenues (% of GDP).



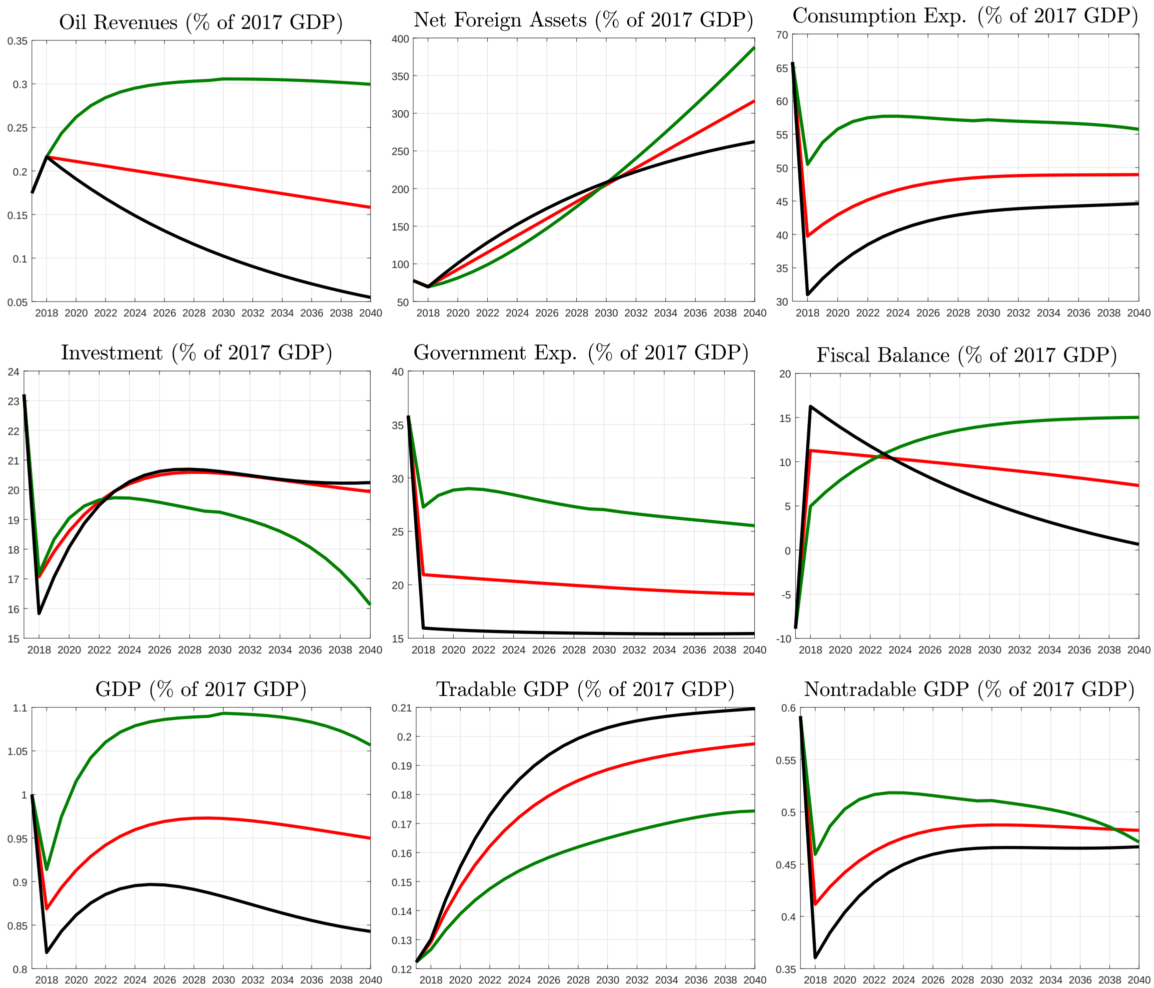
Notes: series implied by the model under the BB rule and the baseline (red), optimistic (green), and pessimistic (black) scenarios for oil revenues, respectively. All of the variables are defined as ratios of GDP in 2017. They should interpreted as detrended variables (as % of 2017 GDP) when compared with actual series.

Figure 12: Macroeconomic Aggregates, Model Simulations under the BB Rule, Future Scenarios for Oil Revenues (% of 2017 GDP).



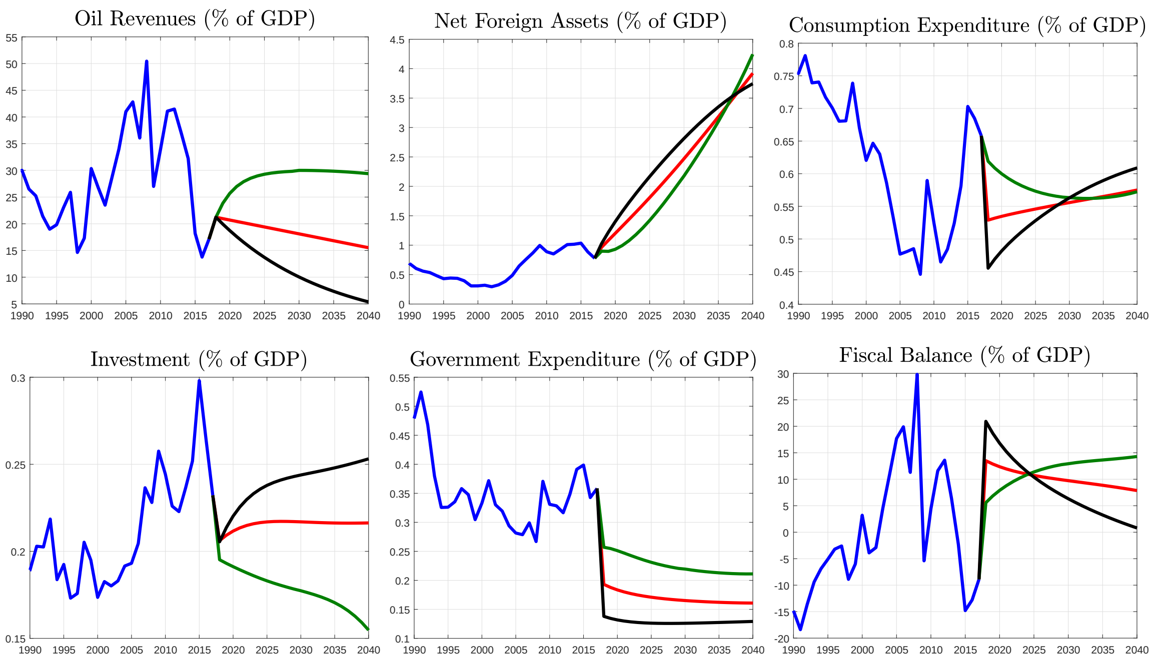
Notes: in blue actual series for KSA and in red, green, and black the series implied by the model under the BB rule and under the baseline, optimistic, and pessimistic scenarios for oil revenues, respectively. The source for oil revenues from 1970 to 2016 is SAMA, and for 2017 is the Ministry of Finance (Fiscal Balance Program, 2018 update). The sources for the rest of the variables are WDI (net foreign assets 1970-2017), WEO (GDP 2017), Ministry of Finance (balance and fiscal expenditures 2017) and SAMA.

Figure 13: Macroeconomic Aggregates, KSA 1990-2017 and Model Simulations under the BB Rule, Future Scenarios for Oil Revenues (% of GDP).



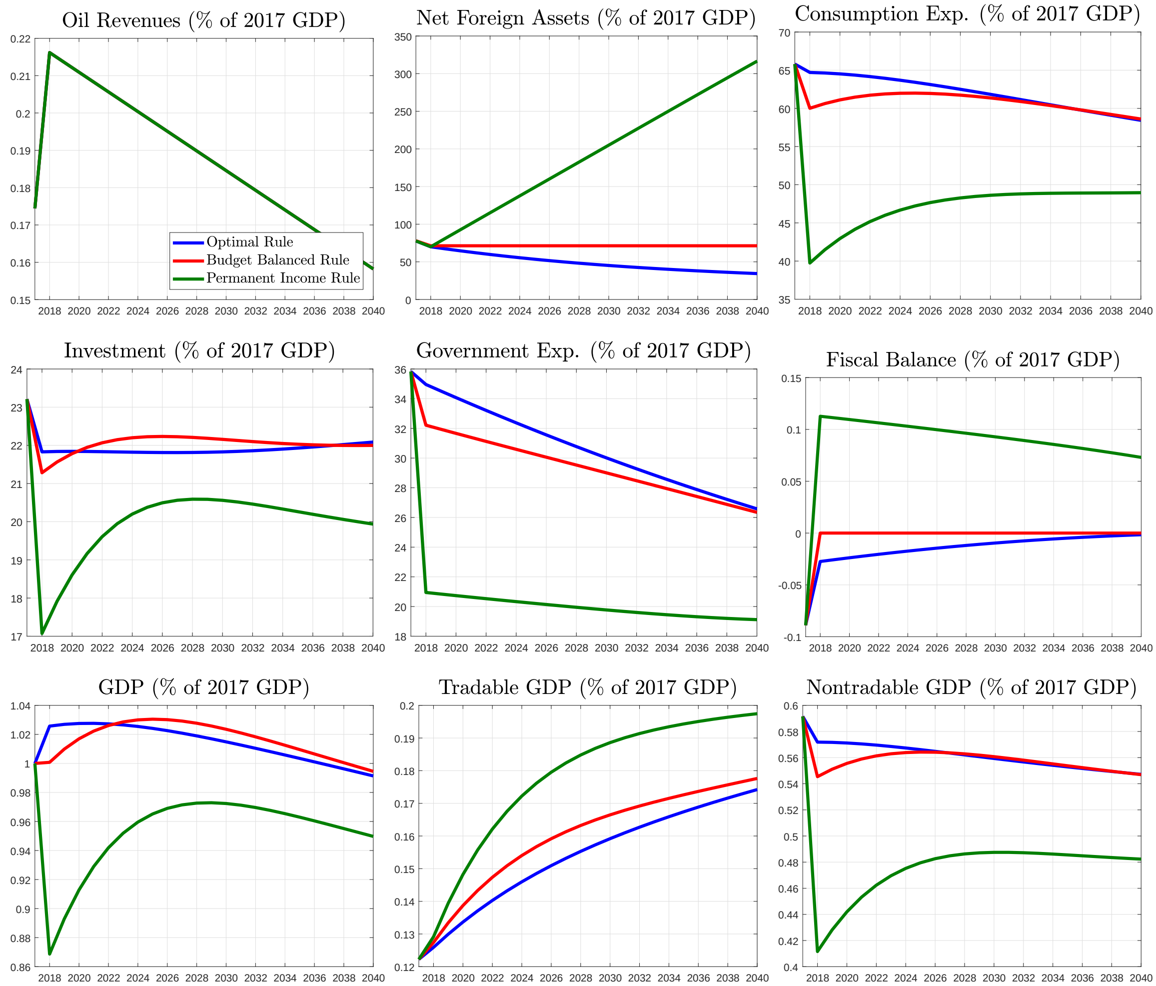
Notes: series implied by the model under the PI rule and the baseline (red), optimistic (green), and pessimistic (black) scenarios for oil revenues, respectively. All of the variables are defined as ratios of GDP in 2017. They should interpreted as detrended variables (as % of 2017 GDP) when compared with actual series.

Figure 14: Macroeconomic Aggregates, Model Simulations under the PI Rule, Future Scenarios for Oil Revenues (% of 2017 GDP).



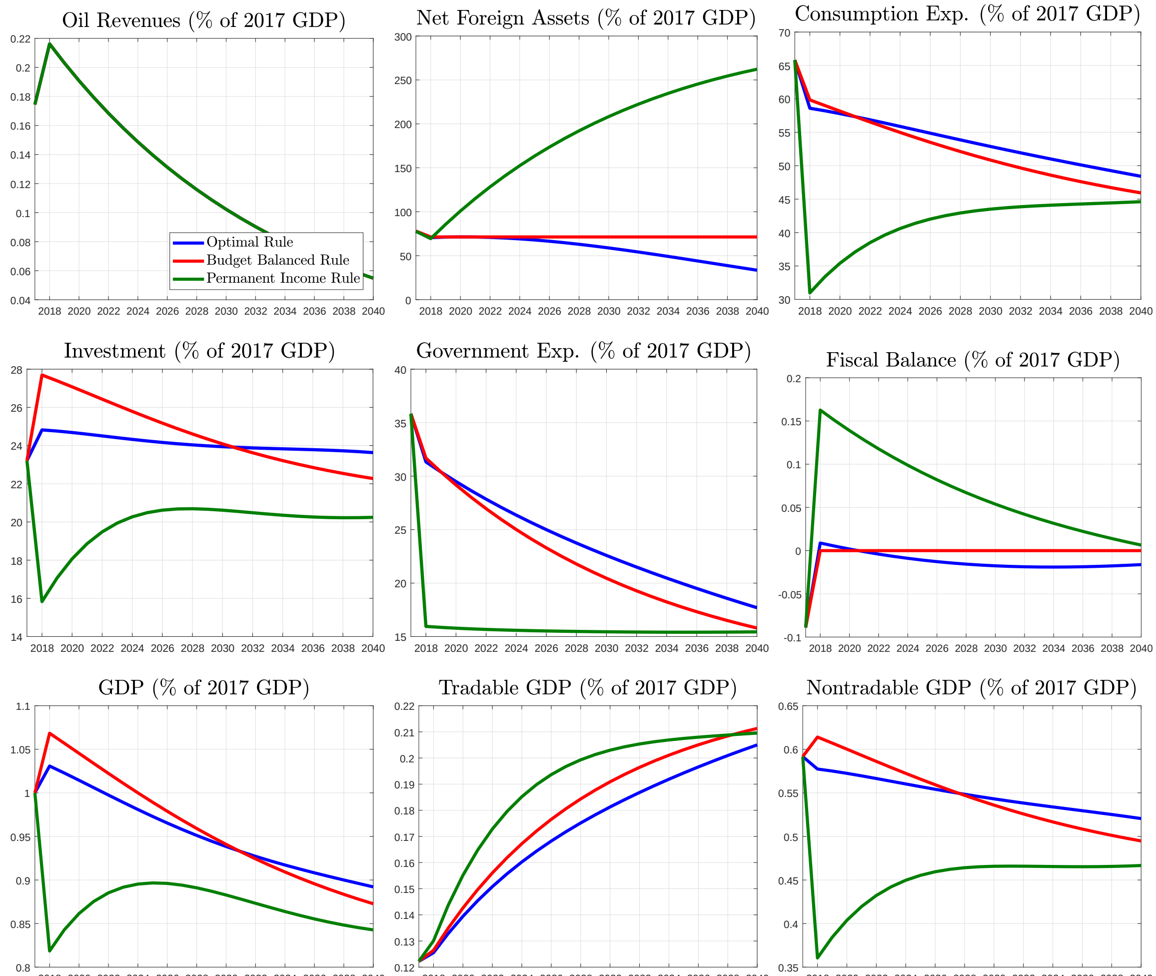
Notes: in blue actual series for KSA and in red, green, and black the series implied by the model under the PI rule and under the baseline, optimistic, and pessimistic scenarios for oil revenues, respectively. The source for oil revenues from 1970 to 2016 is SAMA, and for 2017 is the Ministry of Finance (Fiscal Balance Program, 2018 update). The sources for the rest of the variables are WDI (net foreign assets 1970-2017), WEO (GDP 2017), Ministry of Finance (balance and fiscal expenditures 2017) and SAMA.

Figure 15: Macroeconomic Aggregates, KSA 1990-2017 and Model Simulations under the PI Rule, Future Scenarios for Oil Revenues (% of GDP).



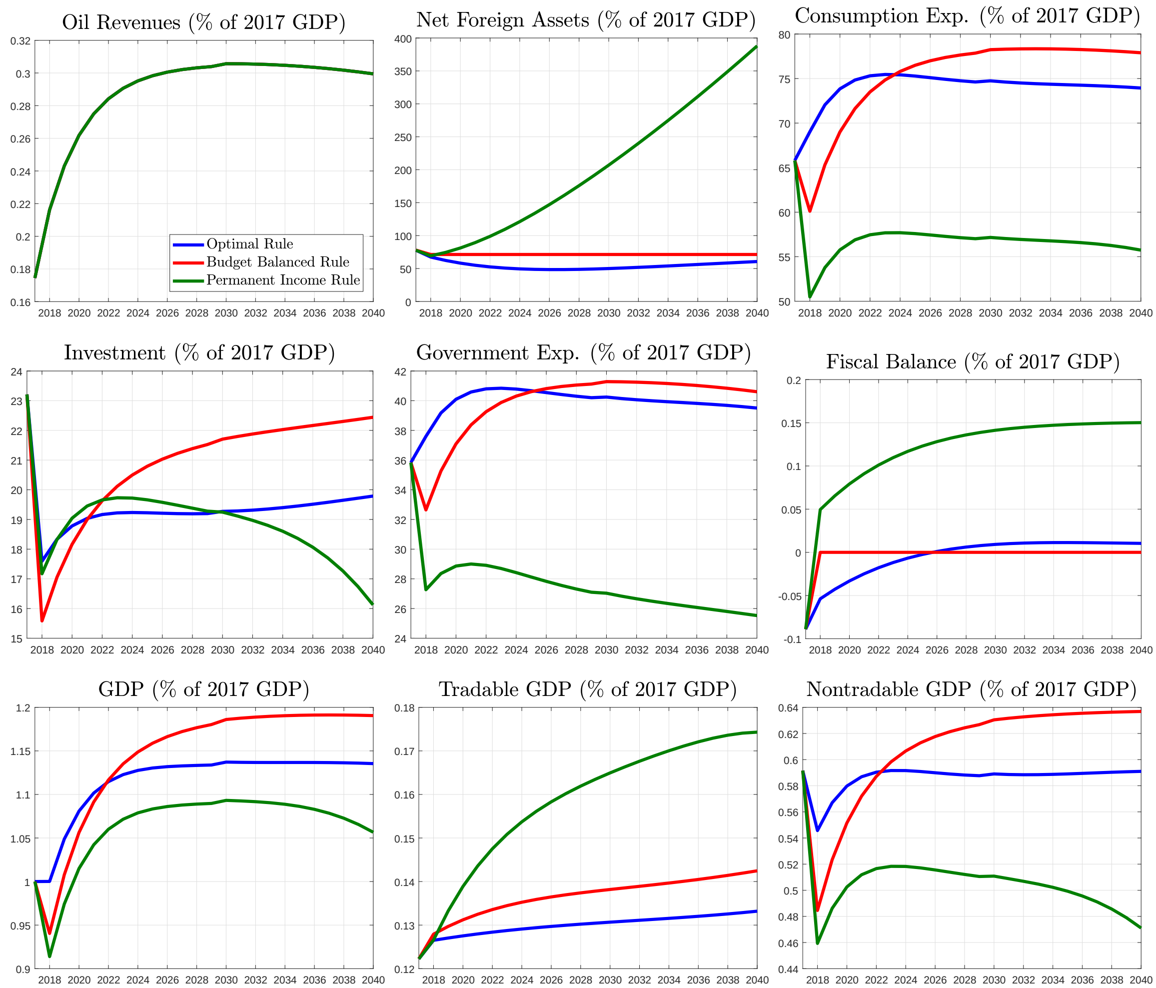
Notes: series implied by the model under the baseline scenario for oil revenues and the optimal (blue), BB (red), and PI (green) rules, respectively. All of the variables are defined as ratios of GDP in 2017. They should interpreted as detrended variables (as % of 2017 GDP) when compared with actual series.

Figure 16: Macroeconomic Aggregates, Model Simulations under different Fiscal Rules, baseline Scenario for Oil Revenues (% of 2017 GDP).



Notes: series implied by the model under the pessimistic scenario for oil revenues and the optimal (blue), BB (red), and PI (green) rules, respectively. All of the variables are defined as ratios of GDP in 2017. They should interpreted as detrended variables (as % of 2017 GDP) when compared with actual series.

Figure 17: Macroeconomic Aggregates, Model Simulations under different Fiscal Rules, Pessimistic Scenario for Oil Revenues (% of 2017 GDP).



Notes: series implied by the model under the optimistic scenario for oil revenues and the optimal (blue), BB (red), and PI (green) rules, respectively. All of the variables are defined as ratios of GDP in 2017. They should interpreted as detrended variables (as % of GDP) when compared with actual series.

Figure 18: Macroeconomic Aggregates, Model Simulations under different Fiscal Rules, Optimistic Scenario for Oil Revenues (% of 2017 GDP).

8 Tables

	Optimal	BB	PI
Net Foreign Assets	0.79	0.08	0.55
Consumption Expenditures	0.90	0.82	0.93
Investment	0.20	-0.14	0.02
Fiscal Expenditures	0.66	0.01	0.39
Fiscal Balance	0.88	-0.50	0.83

Note: the table shows, for each of the variables defined in the first column and each fiscal rule defined in the first line, the correlation between the series simulated by the model and its actual value in KSA between 1970 and 2017. All of the variables are defined as a % of GDP.

Table 1: Correlation of Main Macroeconomic Aggregates between Model and Data

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