Analyzing the Effects of Saudi Arabia's Economic Reforms Using a Dynamic Stochastic General Equilibrium Model

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Key Points

The economy of Saudi Arabia is heavily dependent on oil. About 44% of its gross domestic product (GDP) and 75% of its exports are oil dependent. Oil exports are also by far the largest source of government income. In 2018, they accounted for 68% of government revenues.

The country is the 10th-largest consumer of total primary energy, according to 2016 data. Among the drivers underlying its high domestic consumption are administrated low fuel prices, which reportedly cost the Saudi government an estimated \$61 billion in 2015.

In 2016 the Saudi government announced Saudi Vision 2030, an ambitious plan to build “a vibrant society, a thriving economy and an ambitious nation.” Vision 2030 comprises a newly introduced value added tax (VAT), alongside fuel price reform and a target to reduce the use of hydrocarbons in the power generation fuel mix.

We use a dynamic stochastic general equilibrium model (K-DSGE) calibrated to the Saudi economy to analyze the macroeconomic impacts of the key economic policy reforms of Vision 2030.

The impact of these policy reforms depends upon how revenues generated from taxes or oil exports are fed back into the economy. This could be either through lump-sum transfer payments to Saudi households, or through government spending that benefits Saudi households.

Results for all key macroeconomic variables of the model economy are presented. In addition, we report the welfare gains and the dynamic adjustment of oil exports and GDP under the two recycling scenarios for each policy.

We find that the energy price reforms deliver significant welfare gains, over 20% of current consumption, while the introduction of VAT entails a more modest welfare gain (roughly between 3% and 4% of current consumption).

The deployment of renewables does not increase welfare because it is assumed to be financed by a reduction in either government consumption or transfers to households. However, the welfare effect might be positive with a different financing scheme, e.g., private initiatives.

The three policies produce an increase in oil exports, albeit in differing magnitudes. The energy price reform can increase oil exports by more than 20% and increase real GDP by over 5%, while the effect on non-oil GDP is mixed. With VAT, both real GDP and non-oil GDP decrease by less than 1%, with a small increase in oil exports of between 0.5% and 1.4%. For the deployment of renewables, the oil export gain is about 2% with an increase of below 1% in both real GDP and non-oil GDP in the long run.

Summary

Saudi Arabia is the world's second-largest holder of proved oil reserves and the second-largest producer of petroleum liquids. The country is the largest exporter of crude oil, with a share of 16% of total crude oil exports in 2017.

Saudi Arabia's economy is heavily oil dependent. About 44% of its gross domestic product (GDP) and 75% of its exports depend on oil. Oil exports are also by far the largest source of government income. In 2018, they accounted for 68% of government revenues. The country is the 10th-largest consumer of total primary energy, according to 2016 data. Among the drivers underlying its high domestic consumption are administrated low fuel prices, which reportedly cost the Saudi government an estimated \$61 billion in 2015.

There is no personal income tax in Saudi Arabia. However, nonresidents conducting business in the Kingdom are taxed as corporations at a rate of 20%.

On April 25, 2016, the Saudi government announced Saudi Vision 2030, an ambitious plan to build "a vibrant society, a thriving economy and an ambitious nation." One of the goals is to improve "fiscal performance with the aim to maximize oil and non-oil government revenues in conjunction with improving government spending efficiency and managing risks associated with these processes." To this end, three flagship policy measures were planned, and some of them have already been implemented.

The first measure was a value added tax (VAT) of 5% that was introduced on January 1, 2018 and applies to nearly all supplies of goods and services. The VAT is expected to become one of the Kingdom's main sources of non-oil revenues. Being an indirect tax, it represents an efficient way to pursue the goal of economic diversification, as it minimizes the deadweight loss of taxation and its implementation costs are quite low.

The second measure aims at rationalizing domestic fuel consumption by reducing electricity and transportation use, while strengthening the country's fiscal position by reducing the cost of administered energy prices. The energy price reform gradually increases domestic fuel prices to attain international reference prices by 2025. The reform started in 2016, with an increase of up to 80% for gasoline, diesel and electricity. In 2018, gasoline and electricity prices rose significantly once again. This reform also targeted cash transfers for low-income Saudi households to help mitigate the adverse impacts on the fuel price rises on their livelihoods.

The third measure, aimed at helping to reduce the use of hydrocarbons in the power generation fuel mix, is the deployment of renewable energy, a central measure of the National Renewable Energy Program (NREP). Understanding the short- and long-term macroeconomic impact of the economic reforms associated with Vision 2030 is crucial, especially because it will not only affect oil exports and the associated government revenues, but also the rest of the economy.

This paper uses a new dynamic stochastic general equilibrium model of the Saudi Arabian economy, K-DSGE, developed by KAPSARC researchers. The model is being employed primarily to assess the impact of the Vision 2030 economic reforms. It is also well suited to assessing the macroeconomic impact of the Kingdom's public policies in general, as well as the impact of stochastic shocks.

The K-DSGE model represents the most relevant characteristics of the Saudi economy as an oil and gas resource-rich economy. These include two types of household and labor forces (Saudi and non-Saudi), with different characteristics, and four productive sectors, with firms producing tradable and non-tradable final goods, electricity and energy services.

The model includes three energy sources (oil, gas and renewable energy) and different tax rates. In the model, the government maintains a balanced budget, collects tax revenues, issues bonds, provides public services and income transfers, employs Saudi nationals, and invests in oil, natural gas, and renewable energy production capacities. The difference between production and domestic consumption of hydrocarbons is exported to the rest of the world. The domestic currency is pegged to the United States dollar within a fixed exchange rate regime. The model includes an oil price reaction function to capture the potential effects of the change in global oil prices due to Saudi oil exports and the effects of these changes on Saudi Arabia's oil export revenues. The model is calibrated to match key long-run relationships of the Saudi economy from 1997-2016.

This paper presents the simulation results of three policy experiments that are key parts of the Vision 2030 economic reforms and concern the key policy measures mentioned above. First, we study the introduction of a 5% value added tax (VAT) as envisaged by the Fiscal Balance Program (FBP). This policy measure, introduced on January 1, 2018, caused an immediate 5% increase in the value of tradable goods, non-tradable goods and energy services consumed by households. The second policy experiment is the energy price reform that, in our model, we implement as an increase in the domestic prices of oil and gas from the initial level to the international benchmark level in the first period. We then keep that international level for the following periods. The third policy change is the deployment of renewable energy, in line with the National

Renewable Energy Program's plan to deploy more of renewables. We implement this policy by simulating an increase in public investment in renewables. The share of renewables in electricity generation gradually rises from 0% to 13.7% in the first five periods and remains the same in the following periods.

These policies change government revenues and expenditures. We simulate two different scenarios for restoring the fiscal balance for every policy: adjusting either government consumption or government transfers. The results are presented for all key macroeconomic variables of the model economy. In addition, we report the welfare gains and the dynamic adjustment of oil exports and GDP under the two scenarios for each policy. We find that the energy price reform would deliver a significant welfare gain, over 20% of current consumption, while the VAT entails a more modest welfare gain (roughly between 3%-4% of current consumption). The deployment of renewables does not increase welfare because it is assumed to be financed by a reduction in either government consumption or transfers to households. However, the welfare effect might be positive with a different financing scheme, e.g., private initiatives. The three policies increase oil exports, albeit with very different magnitudes. The energy price reform can increase oil exports by more than 20%, increasing real GDP by more than 5%, while the effect on non-oil GDP is mixed. In the case of VAT, both real GDP and non-oil GDP decrease by less than 1%, with a small increase in oil exports (between 0.5% and 1.4%). For the deployment of renewables, the oil export gain is about 2%, with less than a 1% increase in both real GDP and non-oil GDP in the long-run.

Introduction

In 2017, Saudi Arabia was the 13th-largest economy in terms of gross domestic product (GDP) per capita in purchasing power parity (PPP) prices.

The country is the world's second-largest holder of proved oil reserves and the second largest producer of petroleum liquids and of crude oil and lease condensate. As such, a large portion of its GDP, about 44%, depends on oil. In 2017, Saudi Arabia was the largest exporter of crude oil, with a share of 16% of total global crude oil exports. The country is also the world's 10th-largest consumer of total primary energy, according to 2016 data, of which about 63% was crude oil and petroleum liquids-based, with natural gas accounting for over 30% of consumption. Among the drivers underlying its high domestic consumption are administrated low fuel prices, which reportedly cost the Saudi government an estimated \$61 billion in 2015 (EIA 2017).

Saudi Arabia's economy is heavily dependent on oil exports, which accounted for nearly 75% of the country's total export value in 2016. Oil exports are also by far the largest source of government income, equal to 68% of government revenues in 2018. There is no personal income tax in Saudi Arabia. However, nonresidents conducting business in the Kingdom are taxed as corporations at a rate of 20% (the rate on corporations working in the natural gas sector is 30%).

On April 25, 2016, the Saudi government announced Saudi Vision 2030, an ambitious plan to build "a vibrant society, a thriving economy and an ambitious nation."¹ To achieve the strategic objectives of Vision 2030, the Council of Economic and Development Affairs established 13 Vision Realization Programs, one of them being the Fiscal Balance Program (FBP). One of the goals of the FBP is to improve "the fiscal performance with the aim to maximize oil and non-oil government revenues in conjunction with improving government spending efficiency and managing risks associated with these processes."²

To this end, three flagship policy measures were planned, and some of them have already been implemented.

The first measure is a value added tax (VAT) of 5% that was introduced on January 1, 2018 and applies to nearly all supplies of goods and services. The VAT is expected to become one of the main sources of non-oil revenues in the Kingdom. Being an indirect tax, it represents an efficient way to pursue the goal of economic diversification, as it minimizes the deadweight loss of taxation and its implementation carries low administrative costs.

The second measure, energy price reform, aims to rationalize domestic fuel consumption by reducing electricity use and transportation. It also aims to strengthen the country's fiscal position by reducing the cost of administered energy prices. The energy price reform gradually increases fuel prices until they reach international reference prices by 2025. The reform started in 2016 with price increases of up to 80% for gasoline, diesel and electricity. In 2018, gasoline, and electricity prices rose significantly once again and targeted cash transfers for low-income Saudi households, to mitigate the adverse impacts on their livelihoods.

The third measure, the deployment of renewable energy, which will help to reduce the use of hydrocarbons in the power generation fuel mix and free oil and gas for export, is a central measure of the National Renewable Energy Program (NREP).

In this paper we employ a newly developed dynamic stochastic general equilibrium model, K-DSGE (Blazquez et al. 2019), calibrated to the Saudi economy to analyze the macroeconomic impacts of the aforementioned economic policy reforms within the general framework of the Vision 2030 plan. We consider two scenarios for transferring the fiscal surplus generated by these policies back into the

economy: i) via lump-sum transfer payments to Saudi households; ii) via government spending that directly benefits the Saudi households.

DSGE models are becoming must-have research tools in energy and environmental economics (Blazquez et al. 2017). For instance, Kim and Loungani (1992) and Rotemberg and Woodford (1996) analyze the macroeconomic effects of energy price shocks. Lin and Li (2012) and Schwanitz et al. (2014) analyze the macroeconomic effects of removing fossil fuel subsidies, while Plante (2014) studies the asymmetric impact of oil subsidies on oil exporting and importing countries. De Miguel and Manzano (2006) and Golosov et al. (2014) study optimal oil taxation, while Chang et al. (2009) study optimal taxes on labor, capital income and pollution, and their impact on the business cycle in a model with market imperfections. Fischer and Springborn (2011), Annicchiarico and Di Dio (2015), and Dissou and Karnizova (2016) study different emissions mitigation policies, including cap-and-trade and carbon taxes. Heutel (2012) and Annicchiarico and Di Dio (2015) study optimal policies that dampen the procyclicality of emissions in response to a business-cycle shock. Annicchiarico and Di Dio (2017) and Holladay, Mohsin, and Pradhan (2018) study the international transmission of shocks and the emissions leakage following unilateral mitigation policies. Annicchiarico and Di Dio (2017) and Economides and Xepapadeas (2018) study the role of monetary policy, and Economides and Javorcik (2019) investigate the impact of climate change on the macroeconomic performance of a small open economy using a Keynesian DSGE model.

A number of studies have analyzed the impacts of policy changes in Saudi Arabia with reference to energy.³ A spate of papers, mostly by KAPSARC researchers, have focused on the effects of administered energy prices and of energy price

reforms. Matar et al. (2013) use the KAPSARC Energy Model (KEM), a bottom-up model of Saudi Arabia's energy-intensive sectors, to assess the consequences of energy price reforms and to design policy packages that help mitigate any adverse effects on households or industries. Matar et al. (2015) determine what combination of administered prices and investment credits reduce energy system costs while sheltering end-consumers from price increases. Matar et al. (2017) extend the analysis to a multi-period setting and stress the benefits of policy packages that combine price reforms, investment credits and feed-in tariffs. Matar (2017) studies households' electricity pricing policies and Matar and Anwer (2017) show that households' electricity price reforms induce larger gains for the energy system when they are combined with transfer-price reforms. Wogan et al. (2019) use KEM to explore how various policies can contribute to carbon dioxide emissions mitigation in the power sector. They also highlight the improved mitigation and energy system costs of price deregulation over portfolio and clean energy standards.

Top-down general equilibrium models have also been used to analyze the above issues in Saudi Arabia. Using a simple small open economy dynamic general equilibrium model, Blazquez et al. (2017) simulate the implications of the deployment of more renewable energy in Saudi Arabia, as per Vision 2030. The same model is employed by Blazquez et al. (2018) to further analyze alternative policies that would reduce the domestic consumption of oil and thus increase oil exports. Gonand et al. (2019) study energy price reforms using an overlapping generations model, representing a balanced budget and the possibility of the government using the revenue generated by the price reform for financing public investment spending. They highlight the overall beneficial impact of increasing retail energy prices. They

also stress that additional government investments can make the policy more beneficial to future generations.

Two recent studies on price reforms use multi-sectoral computable general equilibrium (CGE) models. Soummane et al. (2019) use a recursive CGE model calibrated on a 2013 social accounting matrix and on exogenous energy trajectories drawn from the KEM model. Reforms aimed at improving energy efficiency, when combined with recycling part of the additional budget revenues into supporting selected industries, can compensate for the detrimental impacts of an exogenous drop in international oil prices. Roos and Adam (2019) use a multi-period recursive CGE model of Saudi Arabia with 57 subsectors. They stress that removing subsidies improves the efficiency of resource use, and that budget-neutral compensation payments for Saudi

nationals offset the negative effect of the increases of energy prices on their real incomes.

The rest of the paper is organized as follows. In Section 2, we describe the model structure. Section 3 describes the model calibration to the Saudi economy, including the data and the selected parameters. In Section 4, we briefly describe the economic reforms and the underlying policy simulation we employ. Section 5 presents the policy experiments and simulation and discusses the results. Section 6 concludes.

The Model

We represent the Saudi economy as an oil-rich small open economy that takes as given the world prices of tradable goods, the international prices of gas, and the world interest rate on foreign bonds. The model includes an oil price reaction function to capture the potential role of Saudi oil exports in the international oil market and the effects of oil export revenues on the Saudi economy. The domestic currency is pegged to the United States dollar (US\$). The economy is populated by two representative households: Saudi and non-Saudi. There are four representative firms producing a tradable and a non-tradable final good, energy services and electricity. There is a resource sector with three energy sources – oil, gas, and renewable energy. While maintaining a balanced budget, the government collects tax revenues and provides public services and income transfers, employs Saudi nationals, and invests in oil, natural gas, and renewable energy production capacity. The economy exchanges a final good with the rest of the world, exports fossil fuels, and acquires foreign bonds. Figure 1 shows a simple illustration of the K-DSGE model structure.

Households

There are two representative households: Saudi and non-Saudi. The Saudi household maximizes its welfare, given by the present discounted value of an infinite stream of instantaneous utilities, subject to a budget constraint (the Saudi household is denoted by the superscript 's'):

$$(1) \quad \sum_{t=0}^{\infty} \beta^t U^s(C_t^s, ES_t^s, l_t^s + l_{g,t}^s, GC_t)$$

where:

$$(2) \quad U^s(C_t^s, ES_t^s, l_t^s, GC_t) = \ln\{[(C_t^s)^\sigma + \kappa(ES_t^s)^\sigma]^{1/\sigma} + \alpha_{CG} GC_t\} - \left(\frac{\eta}{1+\nu}\right) (l_t^s + l_{g,t}^s)^{1+\nu}$$

with β the discount factor, C a final consumption good, ES energy services (which include air conditioning, electrical appliance use, private transportation, and so forth), l labor supply to the private sector (tradable and non-tradable goods sectors), l_g labor supply to the public sector, and GC government consumption (which includes government-provided healthcare, education and national defense, among other services).

Labor supplied to the private and public sectors are assumed to be perfect substitutes. In addition, only Saudi households are assumed to work in the public sector and the supply of labor in the public sector is exogenous.

Final consumption C is given by a constant elasticity of substitution (CES) aggregator of consumption of tradable and non-tradable goods according to:

$$(3) \quad C_t = \left[\theta_C \frac{1}{\sigma_C} C_{T,t}^{\frac{\sigma_C-1}{\sigma_C}} + (1 - \theta_C) \frac{1}{\sigma_C} C_{NT,t}^{\frac{\sigma_C-1}{\sigma_C}} \right]^{\frac{\sigma_C}{\sigma_C-1}}$$

where C_T and C_{NT} are respectively defined by:

$$(4) \quad C_{T,t} = \theta_C \left[\frac{(1+\tau_{T,t})P_{T,t}}{(1+\tau_{C,t})P_t} \right]^{-\sigma_C} C_t$$

$$(5) \quad C_{NT,t} = (1 - \theta_C) \left[\frac{(1+\tau_{NT,t})P_{NT,t}}{(1+\tau_{C,t})P_t} \right]^{-\sigma_C} C_t$$

where τ_T and τ_{NT} are consumption taxes on tradable and non-tradable consumption goods, respectively, and τ_C is the consumption tax on the aggregate good. P_T and P_{NT} are the prices before taxes of tradable and non-tradable goods, respectively, and P is the before-tax price of the final consumption good. This is defined by:⁴

$$(6) \quad P_t = \{\theta_C P_{T,t}^{1-\sigma_C} + (1 - \theta_C) P_{NT,t}^{1-\sigma_C}\}^{\frac{1}{1-\sigma_C}}$$

The supply of labor (l) is a CES aggregate of labor supply in the tradable and non-tradable goods sectors and is given by:

The Model

Figure 1. K-DSGE model structure.

$$(7) \quad l_t = \left[\theta_L \frac{1}{\sigma_L} \frac{\sigma_L - 1}{l_{T,t}^{\sigma_L}} + (1 - \theta_L) \frac{1}{\sigma_L} \frac{\sigma_L - 1}{l_{NT,t}^{\sigma_L}} \right]^{\frac{\sigma_L}{\sigma_L - 1}}$$

where l_T and l_{NT} are labor supplied to the two sectors and defined by:

$$(8) \quad l_{T,t} = \theta_L \left[\frac{W_{T,t}}{W_t} \right]^{-\sigma_L} l_t$$

$$(9) \quad l_{NT,t} = (1 - \theta_L) \left[\frac{W_{NT,t}}{W_t} \right]^{-\sigma_L} l_t$$

where W_T , W_{NT} , and W are nominal wages in the tradable and non-tradable goods sectors and aggregate wage respectively.⁵ Finally, $(\sigma, \kappa, \alpha_{GC}, \eta, \nu, \theta_C, \sigma_C, \theta_L, \sigma_L)$ are preference parameters.

The Saudi households' budget constraint includes spending in the final consumption good, in the investment good and in energy services and the net acquisition of both government and foreign bonds.

Income includes after-tax labor income, capital income and government transfers as well as returns from government and foreign bonds. Thus:

$$(10) \quad (1 + \tau_{C,t})P_t C_t^S + P_t \left[I_{T,t} + \frac{h_T}{2} \left(\frac{I_{T,t}}{K_{T,t-1}} - \delta_T \right)^2 K_{T,t-1} \right] + P_t \left[I_{NT,t} + \frac{h_{NT}}{2} \left(\frac{I_{NT,t}}{K_{NT,t-1}} - \delta_{NT} \right)^2 K_{NT,t-1} \right] + (1 + \tau_{ES,t})P_{ES,t}ES_t^S + x_t B_t^* - (x_{t-1} + x_t i_t^*)B_{t-1}^* + B_t - (1 + i_t)B_{t-1} = (1 - \tau_{W,t}^S)[W_t^S l_t^S + W_{g,t}^S l_{g,t}^S] + (1 - \tau_{K,t})[i_{T,t}K_{T,t-1} + i_{NT,t}K_{NT,t-1}] + TR_t$$

where I is gross investment, K is the stock of capital, δ is the depreciation rate on this stock, W_g is the wage in the public sector, τ_{ES} is the consumption tax rate on energy services and P_{ES} is their price. We allow for quadratic adjustment costs in

gross investment with parameter h . The budget constraint includes government transfers TR and the households' net acquisition of government B and foreign bonds B^* . The latter stock is denominated in US\$, so that x is the nominal exchange rate between Saudi riyals (SAR) and US\$. i_T , i_{NT} are the nominal returns on capital stock for the tradable and non-tradable sectors, respectively, while i and i^* are the respective interest rates on government and foreign bonds.

We assume that the foreign interest rate is governed by the debt-elastic interest rate:

$$(11) \quad i_t^* = i^{**} + \zeta[\exp(B_{ss}^* - B_{t-1}^*) - 1]$$

where i^{**} is an exogenous foreign interest rate determined in the foreign capital market, ζ is the risk-premium parameter and B_{ss}^* is the steady-state level of foreign bonds.⁶ Capital accumulation is given by the familiar formulas:

$$(12) \quad I_{T,t} = K_{T,t} - (1 - \delta_T)K_{T,t-1}$$

$$(13) \quad I_{NT,t} = K_{NT,t} - (1 - \delta_{NT})K_{NT,t-1}$$

The solution of the above constrained welfare maximization program yields optimality conditions for the following decision variables: C_t , B_t^* , B_t , ES_t , l_t^s . Note that we take GC_t , $l_{g,t}^s$, W_g^s and TR_t to be exogenous policy variables.

The non-Saudi household consumes a final consumption good and energy services and supplies labor to tradable and non-tradable goods sectors. We assume that the non-Saudi labor supply is exogenous and that non-Saudis do not work in the public sector. The budget constraint includes only after-tax labor income for the hours of work supplied to the tradable and non-tradable goods sectors. Thus, the non-Saudi's net income is:

$$(14) \quad (1 - \tau_{W,t}^{ns})W_t^{ns}l_t^{ns}$$

where this household is denoted by the superscript 'ns'. On the expenditure side, we assume that the non-Saudi household spends a constant fraction ϕ_i of its income (14) on consumption goods and energy services. The rest of its income is saved and transferred abroad as remittances. This specification implies that the non-Saudi household does not intertemporally optimize its decisions and that the sources of income and expenditures are exogenously determined.⁷

All variables for the two representative households, Saudi and non-Saudi, were expressed on an individual basis. To obtain aggregate figures, we need to multiply them by the total labor force N in the economy, taken to be equal to the total population. This is the sum of the Saudi and non-Saudi labor forces as denoted by:

$$(15) \quad N_t = N_t^s + N_t^{ns} = (1 - xpat) * N_t + xpat * N_t$$

where $xpat$ is the share of non-Saudis in the total labor force, which we assume to be constant in our model.

Firms

We begin with the production activity of the tradable and non-tradable goods. These goods are produced by two representative firms which use labor from both Saudi and non-Saudi workers, fixed capital and energy services as inputs. In keeping with the households' representation, inputs and outputs are expressed in per capita terms (strictly speaking, per member of the labor force). We consider a Cobb-Douglas (CD) technology, with aggregate labor and a capital-energy services aggregate as inputs.

Within the labor aggregate, two types of labor inputs are assumed to be perfectly substitutable. The

capital-energy aggregate is a CES aggregator. The production function is the following:

$$y_{i,t} = z_{i,t} A_i \left[(1 - xpat) l_{i,t}^s + xpat l_{i,t}^{ns} \right]^{\alpha_i} \left\{ \theta_i \left[(1 - xpat) K_{i,t-1} \right]^{-\nu_i} + (1 - \theta_i) ES_{i,t}^{-\nu_i} \right\}^{\frac{-(1-\alpha_i)}{\nu_i}} \quad (16)$$

where $i = T, NT$ and y is the aggregate output, A is a technological index (scale) and z is a productivity shock. In addition, $(\alpha_i, \theta_i, \nu_i)$ are technology parameters.

All firms in the model are assumed to be price-taker profit maximizing agents. We note that, as the two types of labor inputs are perfectly substitutable, the corresponding marginal productivities are equal, and so are the corresponding wages.

The third firm of the model produces energy-related services – such as air conditioning, electrical appliances, lighting, and private transportation – using, for simplicity, energy sources as the only inputs. Specifically, electricity EL_{ES} , oil O_{ES} and gas G_{ES} are combined according to a CES technology with an elasticity of input substitution equal to $1/(1-\lambda)$. Specifically:

$$ES_t = [\varphi EL_t^\lambda + \psi O_{ES,t}^\lambda + (1 - \varphi - \psi) G_{ES,t}^\lambda]^{1/\lambda} \quad (17)$$

where φ and ψ are the share parameters of electricity and oil in the CES technology. Optimality requires the firm to choose the energy inputs so as to equate the marginal productivities to the input-output price ratios P_{EL}/P_{ES} , P_O/P_{ES} , P_G/P_{ES} .⁸

The last firm generates electricity using three fuels: oil, gas and a renewable source such as solar. Within the technology oil and gas inputs admit a degree of substitution, modeled as a CD fossil fuels

aggregate (with a unitary elasticity of substitution between oil and gas). This fossil fuels aggregate input is taken to be perfectly substitutable with renewables, REN . Returns to scale are assumed to be constant. Specifically:

$$EL_t = O_{EL,t}^\gamma G_{EL,t}^{1-\gamma} + REN_t \quad (18)$$

where γ is the oil elasticity in electricity generation. Maximizing profits requires the marginal rate of technical substitution between oil and gas to be equal to the corresponding price ratio, whereas the condition for renewables is:

$$P_{EL,t} = P_{R,t} \quad (19)$$

so that the price of the renewable energy P_R is equal to the electricity price.

Natural resources

Natural resources – renewable energy, oil and gas – are assumed to be produced using a simple technology that depends only on the stock of public capital. For renewable energy, this implies that the government, via the state-owned electricity company, invests directly in this technology. Renewable energy is produced according to:

$$REN_t = \left[\frac{A_R}{1 + \chi \left(\frac{REN_t}{EL_t} \right)} \right] K_{R,t-1}^g \quad (20)$$

where A_R is the productivity of public capital stock K_R^g in renewables production and χ is an integration cost parameter.⁹ For oil we have:

$$\bar{O}_t = \alpha_o u_t K_{O,t-1}^g \quad (21)$$

where α_o is the productivity of public capital stock K_O^g in oil production, u is the rate of capacity utilization of capital allocated to oil, and $\bar{O}$ is total oil production given exogenously. Finally, we assume that gas production G is proportional to oil production:

$$(22) \quad \bar{G}_t = \alpha_G \bar{O}_t$$

where α_G is the proportionality factor relative to oil. Public capital accumulation in renewables and oil is given by:

$$(23) \quad K_{j,t}^g = I_{j,t}^g + (1 - \delta_j)K_{j,t-1}^g$$

where $j = R, O$ and I_j^g is public investment and δ_j is the depreciation rate of the capital stock. Note that the gas production also depends on public capital investment through (21)-(22).

The international price of oil is assumed to evolve over time according to a mean-reverting process. Since Saudi Arabia has a significant market share (about 12%) of the global oil market, any changes to Saudi oil exports will have an impact on international prices and can significantly impact Saudi export revenues. Thus, we need to model the price changes caused by changes in Saudi exports. We consider a mean reverting process that embeds two adjustment mechanisms: i) a partial adjustment toward the price that would materialize in the long run if the previous period's level of exports remained forever, and ii) a short-run adjustment due to the current change in export levels, as given below:

$$(24) \quad \ln P_{O,t}^* = (1 - \varrho_O) \ln P_{O,ss,t-1}^* + \varrho_O \ln P_{O,t-1}^* + \frac{1}{\varepsilon_{SR}} \ln \left(\frac{OX_t}{OX_{t-1}} \right)$$

$$(25) \quad \ln \left(\frac{P_{O,ss,t}^*}{P_{O,ss}^*} \right) = \frac{1}{\varepsilon_{LR}} \ln \left(\frac{OX_t}{OX_{ss}} \right)$$

where $P_{O,t}^*$ is the international price of oil in each period, ϱ_O is the persistency of the international price, and $P_{O,ss,t}^*$ is the international price of oil that would be observed in the steady-state if Saudi oil

exports were permanently (long-run) at the level of OX_t . In our model, ε_{SR} and ε_{LR} are, respectively, the short-run and the long-run price elasticities of residual demand for Saudi oil exports.¹⁰ Given the definition of the short-term elasticity ε_{SR} , the term $\frac{1}{\varepsilon_{SR}} \ln \left(\frac{OX_t}{OX_{t-1}} \right)$ represents the change in the oil price due to the variation in export levels observed during the period. Equation (24) captures the long-run response of the international oil price to changes in Saudi oil export levels. The combination of (24) and (25) captures both the short-term effects due to contemporaneous events and the long-run effects due to past changes in export levels.¹¹

The international price of gas is assumed to be a simple mean-reverting process as follows:

$$(26) \quad \ln P_{G,t}^* = (1 - \varrho_G) \ln P_{G,ss}^* + \varrho_G \ln P_{G,t-1}^*$$

where ϱ_G is the persistency of the international gas price and $P_{G,ss}^*$ is the steady-state international price of gas.

Government

Government expenditures consist of transfers to Saudi households, public investment in renewable energy, oil and gas production, and labor compensation to public employees. On the revenue side, there are tax payments on the consumption of goods and of energy services, labor taxes paid by both Saudi and non-Saudi households, capital income taxes paid by Saudi households, and taxes on remittances paid by non-Saudi households. In addition, there are revenues from domestic sales and exports of oil and gas and net issues of government bonds. The government budget is:

$$\begin{aligned}
 (27) \quad & \tau_{C,t}P_t[(1-xpat)C_t^s + (xpat)C_t^{ns}] + \tau_{ES,t}P_{ES,t}[(1-xpat)ES_t^s + \\
 & (xpat)ES_t^{ns}] + \tau_{W,t}^s[W_t^s l_t^s + W_{g,t}^s l_{g,t}^s](1-xpat) + \tau_{W,t}^{ns}W_t^{ns}l_t^{ns}(xpat) + \\
 & \tau_{REM,t}REM_t(xpat) + \tau_{K,t}[i_{T,t}K_{T,t-1} + i_{NT,t}K_{NT,t-1}](1-xpat) + \\
 & P_{O,t}^d(O_{EL,t} + O_{ES,t}) + P_{G,t}^d(G_{EL,t} + G_{ES,t}) + P_{R,t}REN_t + x_t P_{O,t}^*(\bar{O}_t - O_{EL,t} - \\
 & O_{ES,t}) + x_t P_{G,t}^*(\bar{G}_t - G_{EL,t} - G_{ES,t}) + [B_t - (1+i_t)B_{t-1}](1-xpat) = \\
 & P_t I_{O,t}^g + P_t I_{R,t}^g + W_{g,t}^s l_{g,t}^s(1-xpat) + P_t GC_t(1-xpat) + TR_t(1-xpat)
 \end{aligned}$$

The fiscal authority controls a number of policy variables that can be used to pursue its own goals, including tax rates, government consumption and public investments. These variables are exogenous to the model. We assume that transfers keep the budget balanced in each period.

Market equilibrium, aggregation and foreign asset position

The model description is completed by the equilibrium conditions of the markets of this model economy. Firstly, equilibrium in the market for energy services requires equating the production of energy services with the demand by Saudi and non-Saudi households and by firms producing tradable and non-tradable consumption goods. That is:

$$(28) \quad ES_t = (1-xpat)ES_t^s + (xpat)ES_t^{ns} + ES_{T,t} + ES_{NT,t}$$

Secondly, note that the output of electricity generation is only used as an input to the energy services firm. This means that (18) and (19) jointly imply that the equilibrium for electricity is satisfied. Invoking Walras' law, we impose the market equilibrium in the non-tradable goods sectors. The supply of non-tradable goods is specified in (16).

This is equated to the demand for these goods by Saudi and non-Saudi households for consumption as well as for investment in fixed capital and government services. The market equilibrium condition is:

$$\begin{aligned}
 y_{NT,t} = (1-\theta_C) \left[\frac{(1+\tau_{NT,t})P_{NT,t}}{(1+\tau_{C,t})P_t} \right]^{-\sigma_C} [(1-xpat)C_t^s + (xpat)C_t^{ns}] + (1- \\
 \theta_C) \left(\frac{P_{NT,t}}{P_t} \right)^{-\sigma_C} \left\{ (1-xpat) \left[I_{T,t} + \frac{h_T}{2} \left(\frac{I_{T,t}}{K_{T,t-1}} - \delta_T \right)^2 K_{T,t-1} + I_{NT,t} + \right. \right. \\
 \left. \left. \frac{h_{NT}}{2} \left(\frac{I_{NT,t}}{K_{NT,t-1}} - \delta_{NT} \right)^2 K_{NT,t-1} \right] + (I_{O,t}^g + I_{R,t}^g) + (1-xpat)GC_t \right\}
 \end{aligned}
 \quad (29)$$

To close the model, an economy-wide constraint must hold in order to ensure that all resources used by the economic agents are equal to all resources created or available. This entails using the household budget constraint for both Saudi and non-Saudi agents and the government budget constraint, together with households' optimality conditions and firms' behavior. Denoting capital adjustment costs by $AC_{T,t}$ and $AC_{NT,t}$, for simplicity, after rearrangements, the aggregate resource constraint is as follows:

$$\begin{aligned}
 P_t[(1-xpat)C_t^s + (xpat)C_t^{ns}] + P_{ES,t}[(1-xpat)ES_t^s + (xpat)ES_t^{ns}] + (1- \\
 xpat)P_t[(I_{T,t} + AC_{T,t}) + (I_{NT,t} + AC_{NT,t})] + P_t(I_{O,t}^g + I_{R,t}^g) + (1-xpat)P_t GC_t + \\
 (1-xpat)[x_t B_t^* - (x_{t-1} + x_t i_t^*)B_{t-1}^*] + (xpat)REM_t = P_{T,t}y_{T,t} + P_{NT,t}y_{NT,t} + \\
 P_{ES,t}[(1-xpat)ES_t^s + (xpat)ES_t^{ns}] + x_t P_{O,t}^*(\bar{O}_t - O_{EL,t} - O_{ES,t}) + x_t P_{G,t}^*(\bar{G}_t - \\
 G_{EL,t} - G_{ES,t})
 \end{aligned}
 \quad (30)$$

Note that nominal GDP at current prices for this economy is given by:

$$GDP_t = P_{T,t}Y_{T,t} + P_{NT,t}Y_{NT,t} + P_{ES,t}[(1 - xpat)ES_t^S + (xpat)ES_t^{ns}] + x_t P_{O,t}(\bar{O}_t - O_{EL,t} - O_{ES,t}) + x_t P_{G,t}(\bar{G}_t - G_{EL,t} - G_{ES,t}) \quad (31)$$

In this context, non-oil GDP excludes from definition (31) the value of the sales of oil and gas abroad. Non-oil GDP therefore consists of the value of the production of durable and non-durable goods and energy services.

The foreign sector is characterized by a current account with imported goods (a component of tradable goods) and remittances on one side, and exports of tradable goods, oil and gas on the other. Net interest payments on foreign debt are included in the current account. The capital account includes net acquisitions of foreign debt and the change in official holdings (official reserves), which ensure equilibrium of the balance of payments. Thus, the trade balance, in nominal terms, is the sum of remittances by non-Saudis, the change in the foreign bond position and interest earned from the foreign bonds. That is:

$$TB_t = (1 - xpat)[x_t B_t^* - (x_{t-1} + x_t i_t^*)B_{t-1}^*] + (xpat)REM_t \quad (32)$$

To obtain real GDP and real trade balance we divide (31) and (32) by the aggregate price P of tradable and non-tradable goods obtained from equation (6).

To close the model, we need to select a normalization rule, here assumed to be the following:

$$(33) \quad P_{T,t} = x_t P_{T,t}^*$$

where $P_{T,t}^*$ is the international price of tradable good and is exogenous. As is usual in models with a tradable and a non-tradable sector, tradable goods are set as the numeraire, so that we assume $P_{T,t}^* = 1$.

Model Calibration

The model is calibrated on an annual basis, as most of the data for Saudi Arabia are in this frequency. Parameters are either obtained from the literature, independently calibrated, or jointly calibrated for the model to match some of the long-run relationships of the Saudi economy during the period 1997-2016.¹²

The parameters of Saudi households' utility (θ_c , κ , α_{cc}) and the size of the government services, GC , are jointly calibrated with other parameters to match the share of energy services expenditure over total consumption expenditure, the share of private consumption over GDP and the share of public consumption over GDP. The elasticity of substitution between aggregate consumption and energy services σ is set to -0.3333, following Plante (2014). We assume $\sigma_c=1$, implying a Cobb-Douglas aggregator for tradable and non-tradable goods. The inverse of the Frisch labor supply elasticity is set at $v = 1.429$ to represent the long-run labor supply elasticity (see Behar 2015). The weight of disutility from labor supply η is jointly calibrated to match the ratio of Saudi labor to total labor supply in the long run. The discount factor β is obtained from the first order condition for foreign bonds in steady state. The size of the foreign bonds B^* and government bonds B in the initial steady state are jointly calibrated to reproduce the ratios of trade balance and government bonds over GDP. The elasticity of substitution between tradable and non-tradable labor supply is set at $\sigma_L = -1$ (see Berg et al. 2010), while the share of labor in the tradable sector θ_L^s is jointly calibrated to match the average ratio of labor in the tradable sector to total labor.

The proportion of non-Saudis in the total labor force, $xpat$, is taken from data provided by the General Authority of Statistics (2016). We assume the same parameter values used for Saudi households as for consumption goods and labor aggregators. The parameters that define the fraction of income spent

on consumer goods ϕ_c and energy services ϕ_{ES} are jointly calibrated to match the share of energy services expenditure over total expenditure and the ratio of remittances to GDP. Following Blazquez et al. (2017), the risk-free international interest rate i^{**} is set to 4% and ζ is chosen to reproduce the volatility of trade balance over GDP observed in the data.

Turning to firms, no distinction is made between the technological parameters of the tradable and non-tradable sectors due to the lack of data at the sectoral level. Thus, we set $\alpha_T=\alpha_{NT}=0.58$, following Blazquez et al. (2017), and the elasticity of substitution between capital and energy services to $v_T=v_{NT}=-1.381$ from Koetse et al. (2008). In addition, the share of capital in the capital-energy services aggregate is set at $\theta_T = \theta_{NT} = 0.99997$.¹³ The parameters for the adjustment costs of capital h_T and h_{NT} are calibrated to match the volatility of investment relative to GDP. The technology indexes for tradable and non-tradable goods A_T and A_{NT} are jointly calibrated to reproduce the relative weight of the two sectors. We set the productivity shocks to $z_{T,t}=z_{NT,t}=1$ in all time periods.

We obtain fuel consumption in power generation from the BP Statistical Review of World Energy (2016) and the Electricity and Cogeneration Regulation Authority (2017), and the price of electricity from the Saudi Electricity Company (2018). Prices for gas and oil supply are obtained from Wogan et al. (2017). Using these data for electricity generation, we set the share of oil $\gamma = 0.47$. In energy service production we follow Blazquez et al. (2017) to set the share of electricity $\phi = 0.332$, while we assume $\psi = 0.332$, implying approximately the same weight for oil and gas in the production of energy services. The parameter governing the elasticity of substitution among oil, gas and electricity is set at $\lambda = -2.574$ (Serletis et al. 2010).

Following Blazquez et al. (2017), we take the cost of public capital invested per MW in a representative photovoltaic technology for renewable power generation as 1.34 million SAR in 2010 prices. We also take the annual capacity factor to be 19% and the depreciation rate to be 5%, which is standard for these types of technologies. Using these data, we estimate that the marginal productivity of public capital in renewable energy technology to be equal to 0.0328 tonnes of oil equivalent (toe) per thousand SAR in 2010 prices. Thus, we set $A = 0.0328$. Mai et al. (2012) find that in the U.S. the cost of the electricity system increases by as much as 5% when renewables penetrate the system by 10%. Thus, we set the renewables' integration cost parameter to $\chi = 0.5$. The depreciation of public capital in renewables μ_R is assumed to be 5% as in Blazquez et al. (2017).

The marginal product of public capital in oil production α_o is jointly calibrated to match the ratio of oil over oil and gas used in electricity generation. The depreciation of public capital in oil production δ_o is assumed to be 0.05. The exogenous value of public investment in the oil sector I_o^g is set to match the average oil production of Saudi Arabia. We normalize the rate of capital utilization u to 1. In the model we assume gas production is proportional to the production of oil, with α_g calibrated accordingly.

The average price of Brent crude during 1997-2016 is taken to be equal to $P_{O,ss}^* = 1.753$ thousand SAR per toe (which corresponds to US\$65 per barrel in 2016, at constant 2010 prices). The average Saudi

oil exports during the period were $OX_{ss} = 18.06$ billion toe (SAMA 2017). Following Pierru et al. (2018), we set the market share of Saudi oil exports in global oil output to $\rho = 0.12$. To obtain the long-run price elasticity of residual Saudi oil demand, we assume the long-run price elasticity of global oil demand to be about $\epsilon_{LR}^D = -0.6$ and the supply of non-Saudi oil to be about $\epsilon_{LR}^S = 0.3$. The long-run price elasticity of Saudi oil exports is therefore obtained to be equal to $\epsilon_{LR} = -7.2$. To obtain the short-run price elasticity of Saudi oil exports, we assume that these elasticity parameters in the short run would be about 50% of their counterparts in the long run. Hence, the short run price elasticity of residual Saudi oil demand is $\epsilon_{SR} = -3.6$. For the long-run price partial adjustment effect we estimate (24) and (25) for the period 1997-2016. The estimated coefficient is $\rho_o = 0.84$. The average international price of gas for 1997-2016 is found to be $P_{G,ss}^* = 0.815$ thousand SAR per toe (corresponding to US\$25 per barrel in 2016 at constant 2010 prices), using Henry Hub prices. The estimated coefficient of the persistency of gas prices is $\rho_g = 0.79$. The domestic prices of oil and gas P_o^d and P_g^d are jointly calibrated to match the observed ratios of oil and gas exports over production.

The jointly calibrated parameters are shown in Table 1, the ratios of the Saudi economy and corresponding ratios from the model solution are shown in Table 2, and Table 3 presents the list of remaining parameter values and their references.

Model Calibration

Table 1. Parameters from the literature or individually calibrated.

i^{**}	Risk-free international interest rate	0.04
ζ	Risk premium parameter	0.01
x_{pat}	Share of non-Saudi labor force	0.6
σ_L	Elasticity of substitution between tradable and non-tradable labor supply	-1
σ_C	Elasticity of substitution between tradable and non-tradable consumption goods	1
β	Discount factor	0.9615
σ	Elasticity of substitution between consumption and energy services	-0.3333
v	Inverse of Frisch labor supply elasticity	1.429
h_T	Capital adjustment cost tradable sector	1.2
h_{NT}	Capital adjustment cost non-tradable sector	0.02
δ_T, δ_{NT}	Capital depreciation rate	0.10
θ_T, θ_{NT}	Capital in share in the capital-energy services aggregate	0.9997
α_T, α_{NT}	Output elasticity of labor	0.582
v_T, v_{NT}	Elasticity of substitution between capital and energy services	1.381
λ	Elasticity of substitution between electricity, oil and gas	-0.2579
φ	Share of electricity	0.332
ψ	Share of oil	0.332
γ	Share of oil in fossil fuels aggregate	0.47
A_R	Productivity of public capital stock in renewables production	0.0328
χ	Integration cost parameter	0.5
δ_R	Depreciation rate of renewable sector capital stock	0.05
u	Rate of capacity utilization of public capital	1
δ_O	Depreciation rate of oil sector capital stock	0.05
I_O^g	Public investment in the oil sector	0.179
ρ_o	Persistency of oil price process	0.84
$P_{O,ss}^*$	Long-run oil price in foreign currency	1.753
ρ	Market share of Saudi oil in global oil output	0.12
ε_{LR}^D	Long-run price elasticity of global oil demand	-0.6
ε_{LR}^S	Long-run price elasticity of supply of non-Saudi oil	0.3
ε_{LR}	Long-run price elasticity of Saudi oil exports	-7.2
ε_{SR}	Short-run price elasticity of Saudi oil exports	-3.6
α_G	Proportionality factor between oil and gas production	0.185
ρ_G	Persistency of gas price process	0.79
$P_{G,ss}^*$	Long-run natural gas price in foreign currency	0.815

Table 2. Parameters and exogenous variables jointly calibrated.

θ_c	Share of tradable goods in private consumption	0.479
κ	Weight of energy services in household consumption	0.0598
α_{GC}	Weight of public services in household consumption	0.452
GC	Public services in initial steady state	0.647
$\theta_L^s, \theta_L^{ns}$	Weight of the tradable in the labor aggregator	0.736
AT	Technology index in tradable goods production	0.434
ANT	Technology index in non-tradable goods production	0.577
P_O^d	Domestic price of oil	0.292
P_G^d	Domestic price of gas	0.409
α_O	Productivity of capital in oil production	0.128
B_{ss}	Government bonds	0.466
B_{ss}^*	Foreign bonds	-10.041
φ_c	Non-Saudi share of income spent on consumption goods	0.65
φ_{ES}	Non-Saudi share of income spent on energy services	0.10
η	Weight of labor disutility	0.429

Table 3. Comparison of long-run relationships from historical data and calibrated model economy.

Long-run relationship (in ratios)	Historical data (1997-2016)	Calibrated model economy
Saudi labor to total labor supply	0.38	0.38
Share of tradable goods in total outputs	0.22	0.22
Oil exports to oil production	0.76	0.76
Gas exports to gas production	0	0
Trade-balance to nominal GDP	0.16	0.16
Private consumption to GDP	0.31	0.31
Public consumption to GDP	0.22	0.22
Public bonds to GDP	0.13	0.13
Remittances to GDP	0.05	0.05
Labor in tradable goods over total supply of labor	0.47	0.47
Energy services expenditure over total consumption expenditure for Saudis	0.11	0.11
Energy services expenditure over total consumption expenditure for non-Saudis	0.10	0.13
Share of oil in electricity demand for oil and gas	0.51	0.55

Policy Experiments in the Context of Vision 2030

In this section, we describe the policy experiments that we carry out to simulate the key economic reforms of Saudi Vision 2030.¹⁴

Introduction of a 5% value added tax (VAT):

On January 1, 2018 a 5% tax on value added to goods and services was introduced in Saudi Arabia. In our model we implement the VAT in the first period as a 5% increase, from 0% in the reference case, in the value of tradable goods, non-tradable goods and energy services consumed by households. Thus, the tax rates τ_t , τ_{NT} , τ_{ES} are set equal to 0.05 and are kept at this level in all future periods.

Energy price reform: The energy price reform in the FBP, including a water price reform, aims to reduce the domestic consumption of energy and water. Because energy products and water, which we model as energy services, are provided using mostly fossil fuels, we implement this measure by increasing the domestic prices of oil and gas P_O^d and P_G^d from their initial levels to international price levels in the first period, and then by keeping them at those international levels in the following periods.

Deployment of renewable energy: The National Renewable Energy Program (NREP) under Vision 2030 plans to deploy more renewables in Saudi Arabia. We implement this policy more by simulating an increase in public investment in renewables I_R^g , such that the share of renewables in electricity generation gradually rises from 0% to 13.7% in the first five periods, remaining at this level in the following periods.

Results

We simulate the model by perturbing the steady-state equilibrium in period zero and tracking the model economy's responses over fifty periods. In each simulation, a policy change in our model yields changes in the government's revenues. This accounts for the changes in receipts from taxes, resource rents, oil and non-oil exports. To keep the government budget balanced in each period, the surplus or deficit created by the policy change is recycled back to the economy. We consider two scenarios, depending on the channel through which the recycling takes place: a) a transfers to Saudi households (TR) scenario: the government surplus (or deficit) increases (or decreases) the payments transferred to Saudi households, and b) a government consumption (GC) scenario: the government surplus (or deficit) increases (or decreases) government consumption, which the Saudi households will directly benefit from.¹⁵

Introduction of a 5% value added tax

In this scenario, we increase the indirect tax rate on tradable goods, non-tradable goods and energy services ($\tau_T, \tau_{NT}, \tau_{ES}$) consumed by households from 0% to 5% in the first period, and keep it at that level thereafter. Oil and gas exports play a prominent role in our model. Given the importance of Saudi Arabia in the global oil market, their change has consequences for the international oil price, the effects of which are then fed back into the Saudi economy. This mechanism is captured by means of an oil price reaction function, shown in equations (24)-(25), which affects the revenue side of the government budget, as shown in equation (27).

The introduction of a 5% VAT increases government consumption in the GC scenario by

about 7% from its initial level, while government transfers increase by about 15% from their initial level in the TR scenario. A contractionary measure is therefore counteracted by an expansionary one. The results of this experiment are presented in Figures 2-7.

Households: In the GC scenario, the introduction of VAT has a negative effect on households' consumption. An increase in GC makes the consumption of goods by Saudi households – both of tradable and non-tradable goods – and of energy services fall further (Figure 2), as GC is a perfect substitute of the aggregate consumption good and energy services. In the TR scenario, the negative effect from the VAT is largely offset by a positive income effect from government transfers. Because of the net positive effect, the households' consumption of tradable and non-tradable goods and energy services increases. In both scenarios, however, the households would respond by a decrease in their labor supply, reducing savings and investment.¹⁶ These reductions in the GC scenario are slightly smaller than in the TR scenario.

The non-Saudi households' consumption of goods and energy services depends on their prices and the households' income. In both scenarios, the real income of the non-Saudi households increases, driven by higher real wages as a result of a decrease in the Saudi labor supply. However, their purchasing power decreases because of the effect of taxes. As a result, their consumption would decrease while we see an increase in remittances. However, the differences in consumption and remittances between the two scenarios are small (Figure 3).

Firms: The introduction of VAT would negatively affect the economy's non-energy production. In

the GC scenario, while government consumption stimulates the demand for non-tradables, the outputs in the sector would decrease, being largely driven by a decrease in households' consumption and their private investments. In the TR scenario, while the Saudi household increases its demand, this is not enough to offset the decrease in the households' private investment and the non-Saudi households' consumption. As a result, the outputs would decline and so would input demand. With a reduction in the supply of Saudi labor in both scenarios, the sector substitutes with expatriate (expat) labor and, as a result, real wages increase. In the GC case, the sector substitutes labor with the capital-energy aggregate, leading to an increase in the stock of capital and energy services (Figure 4). In both scenarios, the increase in production costs (wages and return of capital) increase the price of non-tradables, inducing an appreciation of the real exchange rate, which renders the Saudi economy less competitive.

In both scenarios, the noted loss of competitiveness followed by the real exchange rate appreciation leads output in tradable goods to decline, which would drive down the demand for all inputs (Figure 5). These reductions, however, are similar with little difference between the two scenarios.

Energy services and electricity: The production of energy services declines following the fall in the households' consumption and the decline of output in tradable and non-tradable goods. The demand for inputs (oil, gas and electricity) falls and so does electricity generation (Figure 6). These reductions in the GC scenario are much bigger than in the TR scenario. The decline in demand for oil and gas inputs leads to an increase in oil and gas exports. These exports in the GC scenario are slightly higher than in the TR scenario.

GDP: The VAT would negatively affect real GDP (Figure 7). Although the exports of oil and gas increase, the fall in real GDP is mainly driven by the decrease in non-oil GDP. The latter would decrease following the decline in the tradable and non-tradable outputs. The real trade balance deteriorates as a result of the interaction of two different components: the reduced exports of tradable goods (due to the appreciation of the real exchange rate) and the increase in oil and gas exports, with the former prevailing slightly over the latter. The prices dynamics are driven by the increase in the price of non-tradables, leading to an increase in the aggregate goods price.

Figure 2. VAT simulation: Saudi households.

Figure 3. VAT simulation: non-Saudi households.

Results

Figure 4. VAT simulation: non-tradables sector.

Figure 5. VAT simulation: tradables sector.

Figure 6. VAT simulation: energy sources, electricity and energy services.

Figure 7. VAT simulation: macroeconomic variables.

Energy price reform

Our second policy experiment focuses on the price reform of domestic energy as envisaged in Vision 2030's Fiscal Balance Program. In our model, households consume energy services, including mobility and water use, among others. The energy services industry uses oil, gas and electricity as inputs, and, in turn, electricity generation uses oil, gas, and renewables as inputs. Given this simplified structure, we implement an energy (and water) price reform by allowing the domestic prices of oil and gas, P_O^d and P_G^d , respectively, to increase from

their current levels to the international benchmark levels in the first period of the simulation, remaining at that level for the following periods.¹⁷ These price increases are transmitted to the price of electricity and, in turn, to the prices of energy services (see Figure 8). Since we assume that renewable energy requires public investment, the deployment of renewables is exogenous in our model. Thus, an implication – and a limitation – of our model is that the energy price reform policy experiment will have no effect on the deployment of renewables. This issue is separately discussed in Section 5.3.

Figure 8. Energy price reform: energy prices.

Since we allow the international price of oil to react to Saudi oil exports, we find that the international price of oil initially falls by about 5% before recovering to finally post a 3% permanent reduction. This is a consequence of increased Saudi oil exports. To reach international benchmark levels, the domestic price of oil increases by close to 500% and the price of gas doubles. As a result, the prices of electricity and of energy services increase by more than 200%. The domestic consumption of oil and gas decreases, leading to an increase in oil and gas exports. The additional oil and gas export revenues generate a fiscal surplus. As before, we consider two scenarios for recycling the fiscal surplus into the domestic economy, by either government consumption (GC scenario) or via transfers to Saudi households (TR scenario). The results of this experiment are presented in Figures 9-14.

Households: The price reform has a significant and mixed impact on Saudi households' consumption. Their consumption of energy services goes down by a significant amount. The decrease in the GC scenario is much larger than in the TR scenario. The reform induces a large increase in government revenues from significantly larger exports of oil and gas. In the GC scenario the households' non-energy consumption decreases. Because of the complementarity between non-energy consumption and energy services, and the substitutability with GC, the significant increase in GC, while stimulating non-energy demand, causes non-energy consumption to decline. However, in the TR scenario, the positive income effect from the government transfers to Saudi households significantly increases their non-energy consumption. In both scenarios, households significantly reduce their labor supply and real savings decrease, leading to a reduction in

investment. This reduction is slightly smaller in the GC than in the TR scenario (Figure 9).

The price reform has a mixed impact on non-Saudi households. On one hand, the large increase in energy prices causes households' consumption of energy services to decline significantly. On the other hand, the increase in real wages because of the receding Saudi labor from the labor market increases the non-Saudi households' real income. This leads to an increase in their non-energy consumption and real remittances (Figure 10). Furthermore, these increases in the GC scenario do not differ much from the TR scenario.

Firms: The outputs in the non-tradable sector fall during the initial period of the price reform, followed by increases in the following periods (Figure 11). In the GC scenario, the falling demands of Saudi and non-Saudi households primarily lead to declining output in the sector. In the TR scenario, the increase in demand for non-tradable goods due to increases in disposable income would not be enough to compensate for the reduction in investment from and the consumption of non-Saudi households. However, in the GC scenario, the government consumption-led increase in demand drives a steady positive growth of the sector's outputs in the long run. In the TR scenario, the income-led increase in demand drives the outputs in the sector. Expat labor substitutes Saudi labor, which declines. Capital substitutes energy services, which decline. This leads to an increase in the real rate of return on capital and the real wage. As a result, the price of non-tradable goods increases, leading to an appreciation of the real exchange rate (Figure 11).

In both scenarios, the outputs in the tradable goods sector significantly decline following the real exchange rate appreciation. This drives down the sector's demand for all inputs (Figure 12).

Results

Energy services and electricity: As expected, following the significant decline in the demand for energy services, input demands for electricity generation, oil and gas decline substantially. This leads to a significant fall in the domestic consumption of oil and gas. Exports of oil and gas increase significantly as a result (Figure 13).

GDP: The price reform has a positive impact on real GDP. This is mainly due to increased oil and gas exports. The increase in real GDP in the GC scenario is a little higher than the TR

scenario in the long run. Real non-oil GDP during the initial reform period increases and is mainly driven by the dynamics of tradable and non-tradable outputs as well as of final consumption of energy services. However, in the long run, real non-oil GDP decreases following the decline in the tradable outputs. In the TR scenario, the fall is slightly bigger than in the GC scenario. We note a deterioration of the trade balance even though oil and gas exports increase, and the impacts on the trade balance are similar in both scenarios (Figure 14).

Figure 9. Energy price reform: Saudi households.

Figure 10. Energy price reform: non-Saudi households. **Figure 11.** Energy price reform: non-tradables sector.

Results

Figure 12. Energy price reform: tradables sector.

Figure 13. Energy price reform: energy sources, electricity and energy services.

Figure 14. Energy price reform: macroeconomic variables.

Deployment of renewable energy

Our third policy experiment focuses on renewable energy. To reduce the Saudi economy's dependency on oil, the Vision 2030 plan aims to deploy more renewables in the country. We simulate this policy by increasing public investment in renewables, I_R^g , so that the current share of renewable energy input in electricity generation gradually rises from 0% to 13.7% over five years. In the following periods, we keep public investment to the level needed to cover the depreciation of the public capital stock, maintaining a constant level of renewable energy capacity.

The public investment needed to finance the deployment of renewable energy during the initial five years is assumed to come at the expense of a reduction in government spending or government transfer payments to Saudi households. Public investment in renewables deployment reduces government consumption by more than 15% and government transfers by 40% during the first five years. After the first five years of the deployment, the policy requires a minimal level of finance which would come from the increase in oil and gas export revenues. The results of this experiment are presented in Figures 15-20.

Results

Households: The deployment of renewables during the initial five-year period would impact Saudi household consumption in both scenarios. In the GC scenario, the impact would come from a reduction in public services, as the policy requires a substantial reduction in government spending. The decrease in the government consumption in the GC scenario would increase the Saudi households' marginal utility of private consumption. This would lead to a substantial increase in private consumption, while reducing private investment and savings (Figure 15). In the TR scenario, however, the impact would come from a reduction in government transfers. This would have a negative income effect for households, leading to their reduced consumption. In both scenarios, the households respond by supplying more labor. In the long run, the increase in oil and gas export revenues would support the financing of public investment in renewables, and the policy would have a negligible impact on the Saudi households.

The deployment of renewables would impact non-Saudi households through the impact the policy would have on their real wage. As the supply of Saudi labor increases, the real wage declines, thus decreasing the real income of non-Saudi households (Figure 16). This would lead to a decline in Saudi household remittances as well as their private aggregate consumption. In the long run, the real wage recovers to a higher level than the initial level. This eventually increases households' private consumption and remittances. We note that during the first two years of the policy's implementation, the households' consumption of energy services and tradables would increase. This dynamic arises because households would be able to afford more of these goods during the first two years because the goods' prices would not change, while prices in the economy in general would be increasing.

Firms: The policy affects the non-tradable outputs in three different stages (Figure 17). Initially, the outputs would increase. The effect reverses after a few years, with a reduction in outputs. As the renewables would be fully deployed, the outputs would start recovering. In the GC scenario, the initial increase in outputs is mainly driven by higher demand from both the Saudi household and public investment, while in the TR scenario the initial increase in outputs is mainly driven by the higher demand coming from public investment in renewables. In the long run, the policy has a positive effect on the outputs in the non-tradable goods. The demand for inputs and the price of non-tradables follow a similar pattern.

The deployment of renewables decreases the outputs in the tradable sector (Figure 18). As the increase of the price of non-tradables implies an appreciation of the real exchange rate, this is a negative shock in the tradable sector. Thus, even if the demand for tradables from consumption, private and public investment increases, this is smaller than the reduction in demand from government consumption and the foreign sector, except in the first two periods. This also implies a reduction in all inputs while the sector substitutes expat labor with Saudi labor.

Energy services and electricity: We note that the increase in renewable energy lowers the use of oil and gas in power generation in the long run but does not affect energy services much (Figure 19). However, the impacts on energy services and electricity in the two scenarios are opposite during the initial years of renewables deployment. In the GC scenario, the demand for electricity and energy services demand increases because of an increase in consumption from Saudi households. In the TR scenario, the demand for electricity and energy services decreases with the fall in households'

consumption. However, after the renewables are fully deployed, the effects reverse. The exports of oil and gas follow the same pattern. In the long run, in both scenarios, as renewables are fully deployed, oil and gas exports experience positive growth.

GDP: The deployment of renewables has a positive impact on real GDP in the long run, driven by oil and gas exports. However, during the initial deployment period, t , real GDP would initially

decline in the GC case, while it would increase in the TR scenario. Real non-oil GDP would follow the pattern of non-tradables in both scenarios. During the renewables deployment, the real trade balance deteriorates because of the appreciation of the real exchange rate. However, later on, the real trade balance improves as oil and gas exports dominate the negative performance of production in the tradable sector (Figure 20).

Figure 15. Deployment of renewable energy: Saudi households.

Results

Figure 16. Deployment of renewables: non-Saudi households.

Figure 17. Deployment of renewable energy: non-tradables sector.

Figure 18. Deployment of renewable energy: tradables sector. **Figure 19.** Deployment of renewable energy: energy sources, electricity and energy services.

Results

Figure 20. Deployment of renewable energy: macroeconomic variables.

Welfare analysis

In this section, we evaluate the welfare gains or losses of each policy experiment. Note that we only take into account the welfare of the Saudi population. There are two reasons for this: i) Saudi households are only the ones who benefit from government transfer payments or government spending, and ii) we model expats as non-Ricardian households that do not optimize intertemporally.

Recall that the welfare of a representative Saudi household is given by equations (1)-(2). For ease of exposition we denote the aggregate consumption by AGC_t^s , which is a composite of non-energy consumption and energy services $[(C_t^s)^{\sigma} + \kappa(ES_t^s)^{\sigma}]^{1/\sigma}$. The measure of welfare gains/losses compares the discounted utility flow in the initial situation (no policy change) with the discounted

utility flow once the policy has been implemented. We compute the percentage increase of aggregate consumption that would make the Saudi household indifferent between no reform and reform cases, following the equivalent variation criteria, with the change measured in terms of the initial consumption.

Denoting the variables with no policy change by $\bar{z}$, i.e., the variables at the initial steady state, and the variables under the policy change by $\tilde{z}_t$, we compute the equivalent variation as the value x that solves:

$$(34) \quad \frac{1}{1-\beta} U^s(\overline{AGC}^s(1+x), \bar{l}^s + \bar{l}_{g,t}^s, \bar{GC}) = \sum_{t=0}^{\infty} \beta^t U^s(\overline{AGC}_t^s, \bar{l}_t^s + \bar{l}_{g,t}^s, \bar{GC}_t)$$

Table 4. Policy welfare gains: equivalent variation criteria.

Policy	Recycling via	
	GC	TR
VAT simulation	2.99%	4.25%
Energy price reform	23.54%	31.84%
Deployment of renewable energy	-2.70%	-2.98%

The results are presented in Table 4.

The VAT policy creates a considerable welfare gain for Saudi households. Under the policy, an increase in government spending produces a welfare gain of around 3%, while an increase in government transfers produces a welfare gain of over 4%.

The energy price reform leads to a significant welfare gain for Saudi households. With the government spending, the equivalent variation is 23.54% and 31.84% with the transfer.

The deployment of renewables generates a welfare loss of around 3% for Saudi households. The loss is explained by the initial financial requirements of renewable investment, which significantly reduces household transfers or government consumption during the deployment phase. Although the renewables would generate considerable financial gains in the future, they would not offset the large initial costs. Thus, the deployment of renewables has a negative welfare impact on Saudi households.

Conclusions

As the Saudi economy is heavily dependent on oil exports, the magnitude of the economic impact of structural economic reforms largely depends on how the reforms affect oil export revenues. Reforms which reduce domestic energy consumption lead to increased oil exports. Therefore, the impact of economic reforms on the Saudi economy depends on how they affect the government budget and on how revenues from taxes or oil exports are recycled back into the economy.

Our results show that the VAT and energy price reform policies result in surplus fiscal revenue. If the revenue is recycled back into the economy through government spending or lump-sum transfers, Saudi households' welfare improves. The deployment of renewables for power generation requires government investment and the policy has a negative welfare effect on Saudi households.

The VAT would negatively affect real GDP, although exports of oil and gas would increase under this policy. The fall in real GDP would mainly be driven by a decrease in non-oil GDP. The energy price reform would have a positive impact on real GDP, mainly driven by a significant increase in oil and gas exports. The deployment of renewables would have a positive effect on real GDP in the long run. However, during the initial deployment phase, the effect on real GDP depends on how the government

budget would be adjusted to accommodate the public investment needed. If the public investment requires a decline in government spending, then real GDP would decline in the deployment phase. If the investment requires a decline in government transfer, then real GDP would increase during the deployment phase.

Finally, note that under the three policies, the recycling of fiscal surplus can also take place through adjustments in the government's debt. In such a scenario, our model would allocate an increase in oil export revenues associated with a policy change to a reduction in the stock of public debt. This might limit the scale of macroeconomic impacts that would otherwise be obtained. Note that in such a case, in our model the Saudi households would be affected mainly by a change in their government bond holdings which would affect their disposable income. As such, the impact on the economy would mimic the TR scenario, where we allow government transfers to recycle the fiscal surplus back into the economy. Further, the Saudi economy has not been experiencing public debt sustainability problems, making the use of extra public revenues to reduce public debt seem unrealistic. A policy experiment that allowed financing the deployment of renewables by issuing public debt could be an interesting case to analyse. However, this is beyond the scope of this paper.

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Endnotes

1. <https://vision2030.gov.sa/en>

2. <https://vision2030.gov.sa/en/programs/FBP>

3. Saudi Arabia is not the only country to have implemented an energy price reform. Besides Argentina and Mexico, for instance, other GCC countries such as the UAE have engaged in this type of reform (IMF 2015).

4. The expressions of the producer and consumer price indexes are reported in the appendix, along with the other equations of the model not reported in the main text. For detailed derivations of the model equations see Blazquez et al. (2019).

5. We assume the same tax rates (τ_w) on wages in the tradable and non-tradable goods sectors, so that the tax rate also equals the tax on aggregate wage. Note that in expressions (3) to (9) we have omitted the Saudi superscript in order not to clutter the notation.

6. Note that we induce stationarity in the model by assuming that the interest rates of foreign bonds depend on the level of external debt, which can be interpreted as a transitory change in the sovereign risk premium.

7. An important reason for this assumption is the lack of necessary data needed to calibrate the model.

8. Superscripts ‘*’, ‘d’ and ‘g’ denote foreign, domestic, and government variables, respectively.

9. The term in square brackets represents the productivity of a unit of public capital invested in renewables or, conversely, the cost of one unit of renewable energy. Note that the productivity of renewables depends negatively on renewable penetration in electricity generation, reflecting integration costs in the electricity system.

10. Mathematically, it can be proved that $\varepsilon_{SR} = \frac{\varepsilon_{SR}^D - \varepsilon_{SR}^S(1-\rho)}{\rho}$ and $\varepsilon_{LR} = \frac{\varepsilon_{LR}^D - \varepsilon_{LR}^S(1-\rho)}{\rho}$, where ρ is the market share of Saudi oil exports in the global oil market and ε_{SR}^D , ε_{SR}^S are, respectively, the price elasticity of global oil demand and price elasticity of non-Saudi oil supply, in the short-run, while ε_{LR}^D and ε_{LR}^S represent the same elasticities in the long run.

11. If the short-term price elasticity ε_{SR} and the long-term price elasticity ε_{LR} of residual demand for Saudi oil were both infinite, we would return to the standard assumption of a competitive market and (33) would simplify to the usual mean-reverting equation with a constant long-run price $\ln P_{0,t}^* = (1 - \varrho_o) \ln P_{0,ss}^* + \varrho_o \ln P_{0,t-1}^*$.

12. For the parameters that are jointly calibrated to reproduce some of the long-run characteristics of the Saudi economy, the objective of the process is to match the model's steady-state results to key empirical relationships. We follow a non-linear constrained optimization procedure that minimizes the deviation from the empirical relationships while meeting the model's system of equations as constraints. In other words, the calibration procedure involves minimizing the sum of squares of the deviations from the empirical relationships by optimally adjusting the selected parameters.

13. To determine the share of capital in the capital-energy services aggregate, we start by imposing a long-run capital-to-output ratio (K/y) equal to 2 and assume a 10% annual depreciation rate of capital, which is common in the macroeconomic literature (King and Rebelo, 1999). The capital-output ratio is consistent with 20% gross fixed capital formation over GDP, the average value between 2000 and 2017. We then estimate capital stock levels in 2017 using the ratio $K_{2017}/GDP_{2017} = 1.75$. Using the optimality condition according to which the relative demand for capital stock to energy services is a function of their price ratio, we obtain $\theta_T = \theta_{NT} = 0.99997$.

14. The model could, of course, be used to study the effects of other policy changes and to carry out the present policy experiments with different targets and changes. The changes we consider here are either precisely or very close to those envisaged by the reforms of Vision 2030, as described in the introduction. We do not report results of sensitivity analyses due to space constraints.

15. The government budget could, of course, be also balanced, also changing the stock of government bonds. However, in this paper we do not consider such an option for two main reasons: i) the increase in oil exports that arises from every policy change would be allocated to a reduction of the stock of public debt, thus limiting the macroeconomic impact of the policies (Saudi households would be affected mainly by the change in their government bonds holdings); ii) Saudi Arabia has not been experiencing public debt sustainability problems, which makes the use of extra public revenues to reduce public debt seem unrealistic.

16. Recall that in the current version of the model only voluntary unemployment is possible.

17. As explained in Section 4, the international price of oil is set equal to 1.753 thousand SAR per toe (equivalent to US\$65 per barrel in 2016, at constant 2010 prices) and the international price of gas is equal to 0.669 thousand SAR per toe (corresponding to US\$25 per barrel in 2016, at constant 2010 prices).

Appendix A: Model Equations

Aggregate tax rate on tradable and non-tradable consumption goods:

$$(1) \quad (1 + \tau_{C,t}) = \left\{ \frac{\theta_C [(1 + \tau_{T,t}) P_{T,t}]^{1-\sigma_C} + (1 - \theta_C) [(1 + \tau_{NT,t}) P_{NT,t}]^{1-\sigma_C}}{\theta_C P_{T,t}^{1-\sigma_C} + (1 - \theta_C) P_{NT,t}^{1-\sigma_C}} \right\}^{\frac{1}{1-\sigma_C}}$$

Aggregate price of tradable and non-tradable consumption goods:

$$(2) \quad P_t = \{ \theta_C P_{T,t}^{1-\sigma_C} + (1 - \theta_C) P_{NT,t}^{1-\sigma_C} \}^{\frac{1}{1-\sigma_C}}$$

Saudi labor supply in the tradable goods sector:

$$(3) \quad l_{T,t}^s = \theta_L \left(\frac{W_{T,t}}{W_t} \right)^{-\sigma_L} l_t^s$$

Saudi labor supply in the non-tradable goods sector:

$$(4) \quad l_{NT,t}^s = (1 - \theta_L) \left(\frac{W_{NT,t}}{W_t} \right)^{-\sigma_L} l_t^s$$

Non-Saudi labor supply in the tradable goods sector:

$$(5) \quad l_{T,t}^{ns} = \theta_L \left(\frac{W_{T,t}}{W_t} \right)^{-\sigma_L} l_t^{ns}$$

Non-Saudi labor supply in the non-tradable goods sector:

$$(6) \quad l_{NT,t}^{ns} = (1 - \theta_L) \left(\frac{W_{NT,t}}{W_t} \right)^{-\sigma_L} l_t^{ns}$$

Aggregate wage of tradable and non-tradable consumption goods sectors:

$$(7) \quad W_t = \left[\theta_L (W_{T,t})^{1-\sigma_L} + (1 - \theta_L) (W_{NT,t})^{1-\sigma_L} \right]^{\frac{1}{1-\sigma_L}}$$

Saudi households' marginal utility of consumption:

$$(8) \quad MUC_t^s = \frac{\partial U^s}{\partial C_t^s} = \frac{(C_t^s)^{\sigma-1} [(C_t^s)^\sigma + \kappa (ES_t^s)^\sigma]^{\frac{1-\sigma}{\sigma}}}{[(C_t^s)^\sigma + \kappa (ES_t^s)^\sigma]^{\frac{1}{\sigma}} + \alpha_{CG} GC_t}$$

Saudi households' marginal utility of energy services:

$$(9) \quad MUES_t^s = \frac{\partial U^s}{\partial ES_t^s} = \frac{\kappa (ES_t^s)^{\sigma-1} [(C_t^s)^\sigma + \kappa (ES_t^s)^\sigma]^{\frac{1-\sigma}{\sigma}}}{[(C_t^s)^\sigma + \kappa (ES_t^s)^\sigma]^{\frac{1}{\sigma}} + \alpha_{CG} GC_t}$$

Saudi households' marginal utility of leisure:

$$(10) \quad MUL_t^s = \frac{\partial U^s}{\partial l_{T,t}^s} = -\eta (l_t^s + l_{g,t}^s)^\nu$$

Dynamic condition for foreign debt:

$$(11) \quad \frac{MUC_t^s}{(1 + \tau_{C,t}) P_t} x_t = \beta E_t \frac{MUC_{t+1}^s}{(1 + \tau_{C,t+1}) P_{t+1}} (x_t + x_{t+1} i_{t+1}^*) = 0$$

Dynamic condition for government debt:

$$(12) \quad \frac{MUC_t^S}{(1+\tau_{C,t})P_t} = \beta E_t \frac{MUC_{t+1}^S}{(1+\tau_{C,t+1})P_{t+1}} (1+i_{t+1}) = 0$$

Optimal allocation of consumption and energy services:

$$(13) \quad \frac{MUES_t^S}{MUC_t^S} = \frac{(1+\tau_{ES,t})P_{ES,t}}{(1+\tau_{C,t})P_t}$$

Optimal allocation of consumption and leisure:

$$(14) \quad \frac{-MUL_t^S}{MUC_t^S} = \frac{(1-\tau_{W,t}^S)W_t}{(1+\tau_{C,t})P_t}$$

Fixed capital investment in the tradable goods sector:

$$(15) \quad q_{T,t} = P_t \left[1 + h_T \left(\frac{I_{T,t}}{K_{T,t-1}} - \delta_T \right) \right]$$

Fixed capital investment in the non-tradable goods sector:

$$(16) \quad q_{NT,t} = P_t \left[1 + h_{NT} \left(\frac{I_{NT,t}}{K_{NT,t-1}} - \delta_{NT} \right) \right]$$

Dynamic condition for fixed capital stock in the tradable goods sector:

$$(17) \quad q_{T,t} = E_t \frac{1}{1 + \frac{x_{t+1}i_{t+1}^*}{x_t}} \left[q_{T,t+1}(1 - \delta_T) + (1 - \tau_{K,t+1})i_{T,t+1} - P_{t+1} \frac{h_T}{2} \left(\frac{I_{T,t+1}}{K_{T,t}} - \delta_T \right) \left(\frac{-I_{T,t+1}}{K_{T,t}} - \delta_T \right) \right]$$

Dynamic condition for fixed capital stock in the non-tradable goods sector:

$$(18) \quad q_{NT,t} = E_t \frac{1}{1 + \frac{x_{t+1}i_{t+1}^*}{x_t}} \left[q_{NT,t+1}(1 - \delta_{NT}) + (1 - \tau_{K,t+1})i_{NT,t+1} - P_{t+1} \frac{h_{NT}}{2} \left(\frac{I_{NT,t+1}}{K_{NT,t}} - \delta_{NT} \right) \left(\frac{-I_{NT,t+1}}{K_{NT,t}} - \delta_{NT} \right) \right]$$

Saudi households' budget constraint:

$$(19) \quad x_t B_t^* - (x_{t-1} + x_t i_t^*) B_{t-1}^* + B_t - (1 + i_t) B_{t-1} + (1 + \tau_{ES,t}) P_{ES,t} ES_t^S + (1 + \tau_{C,t}) P_t C_t^S + P_t \left[I_{T,t} + \frac{h_T}{2} \left(\frac{I_{T,t}}{K_{T,t-1}} - \delta_T \right)^2 K_{T,t-1} \right] + P_t \left[I_{NT,t} + \frac{h_{NT}}{2} \left(\frac{I_{NT,t}}{K_{NT,t-1}} - \delta_{NT} \right)^2 K_{NT,t-1} \right] = (1 - \tau_{W,t}^S) [W_t^S l_t^S + W_{g,t}^S l_{g,t}^S] + (1 - \tau_{K,t}) [i_{T,t} K_{T,t-1} + i_{NT,t} K_{NT,t-1}] + TR_t$$

Appendix A: Model Equations

Capital accumulation in the tradable goods sector:

$$(20) \quad I_{T,t} = K_{T,t} - (1 - \delta_T)K_{T,t-1}$$

Capital accumulation in the non-tradable goods sector:

$$(21) \quad I_{NT,t} = K_{NT,t} - (1 - \delta_{NT})K_{NT,t-1}$$

Non-Saudi households' consumption:

$$(22) \quad (1 + \tau_{C,t})P_t C_t^{ns} = \varphi_C (1 - \tau_{W,t}^{ns})W_t l_t^{ns}$$

Non-Saudi households' energy services:

$$(23) \quad (1 + \tau_{ES,t})P_{ES,t} ES_t^{ns} = \varphi_{ES} (1 - \tau_{W,t}^{ns})W_t l_t^{ns}$$

Non-Saudi households' remittances:

$$(24) \quad (1 + \tau_{REM,t})REM_t = (1 - \varphi_C - \varphi_{ES})(1 - \tau_{W,t}^{ns})W_t l_t^{ns}$$

Production of tradable goods:

$$(25) \quad y_{T,t} = z_{T,t} A_T [(1 - xpat)l_{T,t}^s + xpat l_{T,t}^{ns}]^{\alpha_T} \\ \left\{ \theta_T [(1 - xpat)K_{T,t-1}]^{-\nu_T} + (1 - \theta_T) ES_{T,t}^{-\nu_T} \right\}^{\frac{-(1-\alpha_T)}{\nu_T}}$$

Optimal labor input in tradable goods production:

$$(26) \quad W_{T,t} = \alpha_T P_{T,t} z_{T,t} A_T [(1 - xpat)l_{T,t}^s + xpat l_{T,t}^{ns}]^{\alpha_T - 1} \\ \left\{ \theta_T [(1 - xpat)K_{T,t-1}]^{-\nu_T} + (1 - \theta_T) ES_{T,t}^{-\nu_T} \right\}^{\frac{-(1-\alpha_T)}{\nu_T}}$$

Optimal capital input in tradable goods production:

$$(27) \quad i_{T,t} = (1 - \alpha_T) \theta_T P_{T,t} z_{T,t} A_T [(1 - xpat)K_{T,t-1}]^{-\nu_T - 1} [(1 - xpat)l_{T,t}^s + \\ xpat l_{T,t}^{ns}]^{\alpha_T} \left\{ \theta_T [(1 - xpat)K_{T,t-1}]^{-\nu_T} + (1 - \theta_T) ES_{T,t}^{-\nu_T} \right\}^{\frac{-(1-\alpha_T)}{\nu_T} - 1}$$

Optimal energy services input in tradable goods production:

$$(28) \quad P_{ES,t} = (1 - \alpha_T)(1 - \theta_T) P_{T,t} z_{T,t} A_T ES_{T,t}^{-\nu_T - 1} [(1 - xpat)l_{T,t}^s + xpat l_{T,t}^{ns}]^{\alpha_T} \\ \left\{ \theta_T [(1 - xpat)K_{T,t-1}]^{-\nu_T} + (1 - \theta_T) ES_{T,t}^{-\nu_T} \right\}^{\frac{-(1-\alpha_T)}{\nu_T} - 1}$$

Production of non-tradable goods:

$$(29) \quad y_{NT,t} = \frac{Y_{NT,t}}{N_t} = z_{NT,t} A_{NT} [(1 - xpat) l_{NT,t}^s + xpat l_{NT,t}^{ns}]^{\alpha_{NT}} \left\{ \theta_{NT} [(1 - xpat) K_{NT,t-1}]^{-v_{NT}} + (1 - \theta_{NT}) ES_{NT,t}^{-v_{NT}} \right\}^{\frac{-(1-\alpha_{NT})}{v_{NT}}}$$

Optimal labor input in non-tradable goods production:

$$(30) \quad W_{NT,t} = \alpha_{NT} P_{NT,t} z_{NT,t} A_{NT} [(1 - xpat) l_{NT,t}^s + xpat l_{NT,t}^{ns}]^{\alpha_{NT}-1} \left\{ \theta_{NT} [(1 - xpat) K_{NT,t-1}]^{-v_{NT}} + (1 - \theta_{NT}) ES_{NT,t}^{-v_{NT}} \right\}^{\frac{-(1-\alpha_{NT})}{v_{NT}}}$$

Optimal capital input in non-tradable goods production:

$$(31) \quad i_{NT,t} = (1 - \alpha_{NT}) \theta_{NT} P_{NT,t} z_{NT,t} A_{NT} [(1 - xpat) K_{NT,t-1}]^{-v_{NT}-1} [(1 - xpat) l_{NT,t}^s + xpat l_{NT,t}^{ns}]^{\alpha_{NT}} \left\{ \theta_{NT} [(1 - xpat) K_{NT,t-1}]^{-v_{NT}} + (1 - \theta_{NT}) ES_{NT,t}^{-v_{NT}} \right\}^{\frac{-(1-\alpha_{NT})}{v_{NT}}-1}$$

Optimal energy services input in non-tradable goods production:

$$(32) \quad P_{ES,t} = (1 - \alpha_{NT})(1 - \theta_{NT}) P_{NT,t} z_{NT,t} A_{NT} ES_{NT,t}^{-v_{NT}-1} [(1 - xpat) l_{NT,t}^s + xpat l_{NT,t}^{ns}]^{\alpha_{NT}} \left\{ \theta_{NT} [(1 - xpat) K_{NT,t-1}]^{-v_{NT}} + (1 - \theta_{NT}) ES_{NT,t}^{-v_{NT}} \right\}^{\frac{-(1-\alpha_{NT})}{v_{NT}}-1}$$

Electricity generation:

$$(33) \quad EL_t = O_{EL,t}^\gamma G_{EL,t}^{1-\gamma} + REN_t$$

Optimal oil input in electricity generation:

$$(34) \quad \gamma P_{EL,t} O_{EL,t}^{\gamma-1} G_{EL,t}^{1-\gamma} = P_{O,t}^d$$

Optimal allocation of oil and gas in electricity generation:

$$(35) \quad \frac{\gamma}{1-\gamma} \frac{G_{EL,t}}{O_{EL,t}} = \frac{P_{O,t}^d}{P_{G,t}^d}$$

Optimal condition for renewable energy input in electricity generation:

$$(36) \quad P_{EL,t} = P_{R,t}$$

Production of energy services:

$$(37) \quad ES_t = [\varphi EL_t^\lambda + \psi O_{ES,t}^\lambda + (1 - \varphi - \psi) G_{ES,t}^\lambda]^{1/\lambda}$$

Appendix A: Model Equations

Optimal electricity input in energy services production:

$$(38) \quad P_{ES,t} = \left(\frac{EL_t^{1-\lambda}}{\varphi} \right) [\varphi EL_t^\lambda + \psi O_{ES,t}^\lambda + (1 - \varphi - \psi) G_{ES,t}^\lambda]^{\frac{\lambda-1}{\lambda}} P_{EL,t}$$

Optimal oil input in energy services production:

$$(39) \quad P_{ES,t} = \left(\frac{O_{ES,t}^{1-\lambda}}{\psi} \right) [\varphi EL_t^\lambda + \psi O_{ES,t}^\lambda + (1 - \varphi - \psi) G_{ES,t}^\lambda]^{\frac{\lambda-1}{\lambda}} P_{O,t}^d$$

Optimal gas input in energy services production:

$$(40) \quad P_{SE,t} = \left(\frac{G_{ES,t}^{1-\lambda}}{1-\varphi-\psi} \right) [\varphi EL_t^\lambda + \psi O_{ES,t}^\lambda + (1 - \varphi - \psi) G_{ES,t}^\lambda]^{\frac{\lambda-1}{\lambda}} P_{G,t}^d$$

Renewable energy production:

$$(41) \quad REN_t = \left[\frac{A_R}{1+\chi \left(\frac{REN_t}{EL_t} \right)} \right] K_{R,t-1}^g$$

Public capital accumulation in the renewable energy sector:

$$(42) \quad I_{R,t}^g = K_{R,t}^g - (1 - \delta_R) K_{R,t-1}^g$$

Oil production:

$$(43) \quad \bar{O}_t = \alpha_O u_t K_{O,t-1}^g$$

Public capital accumulation in the oil sector:

$$(44) \quad I_{O,t}^g = K_{O,t}^g - (1 - \delta_O) K_{O,t-1}^g$$

Gas production:

$$(45) \quad \bar{G}_t = \alpha_G \bar{O}_t$$

International price of oil:

$$(46) \quad \ln P_{O,t}^* = (1 - \varrho_O) \ln P_{O,ss,t-1}^* + \varrho_O \ln P_{O,t-1}^* + \frac{1}{\varepsilon_{SR}} \ln \frac{OX_t}{OX_{t-1}}$$

Equilibrium in market for energy services:

$$(47) \quad ES_t = (1 - xpat) ES_t^s + (xpat) ES_t^{ns} + ES_{T,t} + ES_{NT,t}$$

Government budget constraint:

$$(48) \quad \begin{aligned} & \tau_{C,t}P_t[(1-xpat)C_t^s + (xpat)C_t^{ns}] + \tau_{ES,t}P_{ES,t}[(1-xpat)ES_t^s + (xpat)ES_t^{ns}] + \\ & \tau_{W,t}^s[W_t^s l_t^s + W_{g,t}^s l_{g,t}^s](1-xpat) + \tau_{W,t}^{ns}W_t^{ns}l_t^{ns}(xpat) + \tau_{REM,t}REM_t(xpat) + \\ & \tau_{K,t}[i_{T,t}K_{T,t-1} + i_{NT,t}K_{NT,t-1}](1-xpat) + P_{O,t}^d(O_{EL,t} + O_{ES,t}) + P_{G,t}^d(G_{EL,t} + \\ & G_{ES,t}) + P_{R,t}REN_t + x_t P_{O,t}^*(\bar{O}_t - O_{EL,t} - O_{ES,t}) + x_t P_{G,t}^*(\bar{G}_t - G_{EL,t} - G_{ES,t}) + [B_t - \\ & (1+i_t)B_{t-1}](1-xpat) = P_t I_{O,t}^g + P_t I_{R,t}^g + W_{g,t}^s l_{g,t}^s(1-xpat) + P_t GC_t(1-xpat) + TR_t(1-xpat) \end{aligned}$$

Equilibrium in market for non-tradable goods:

$$(49) \quad \begin{aligned} & y_{NT,t} = (1-\theta_C) \left[\frac{(1+\tau_{NT,t})P_{NT,t}}{(1+\tau_{C,t})P_t} \right]^{-\sigma_C} [(1-xpat)C_t^s + (xpat)C_t^{ns}] + (1-\theta_C) \left(\frac{P_{NT,t}}{P_t} \right)^{-\sigma_C} \left\{ (1-xpat) \left[I_{T,t} + \frac{h_T}{2} \left(\frac{I_{T,t}}{K_{T,t-1}} - \delta_T \right)^2 K_{T,t-1} + I_{NT,t} + \frac{h_{NT}}{2} \left(\frac{I_{NT,t}}{K_{NT,t-1}} - \delta_{NT} \right)^2 K_{NT,t-1} \right] + (I_{O,t}^g + I_{R,t}^g) + (1-xpat)GC_t \right\} \end{aligned}$$

Nominal gross domestic product (GDP), nominal trade balance and nominal foreign interest rate:

$$(50) \quad GDP_t = P_t y_t + P_{ES,t}[(1-xpat)ES_t^s + (xpat)ES_t^{ns}] + x_t P_{O,t}^*(\bar{O}_t - O_{EL,t} - O_{ES,t}) + x_t P_{G,t}^*(\bar{G}_t - G_{EL,t} - G_{ES,t})$$

$$(51) \quad i_t^* = i^{**} + \zeta[\exp(B_{ss}^* - B_{t-1}^*) - 1]$$

$$(52) \quad TB_t = (1-xpat)[x_t B_t^* - (x_{t-1} + x_t i_t^*)B_{t-1}^*] + (xpat)REM_t$$

Price indexes:

$$(53) \quad P_t = \{\theta_C P_{T,t}^{1-\sigma_C} + (1-\theta_C)P_{NT,t}^{1-\sigma_C}\}^{\frac{1}{1-\sigma_C}}$$

$$(54) \quad P_{agg,t} = \left[P_t^{\frac{\sigma-1}{\sigma}} + \left(\kappa^{\frac{1}{\sigma}} \right) P_{ES,t}^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}}$$

Normalization:

$$(55) \quad P_{T,t} = x_t P_{T,t}^*$$

Appendix B: Introduction of a 5% Value Added Tax With No Recycling of Fiscal Surplus and No International Oil Price Reaction

To better grasp the implications of the introduction of a value added tax (VAT), we assume here that the government budget surplus created by the 5% VAT is left unused, as if it were wasted money or accumulated in a fund with no productive use. By doing this, we can isolate the effect of the tax increase. In this discussion we keep the international oil price fixed at its initial level.

Households: As expected, the introduction of VAT results in an increase in prices, and Saudi households' consumption of goods and energy services falls (Figure B.1). Households respond by decreasing their supply of labor. Their real savings decline and so do their investments, while their borrowing increases (foreign bonds are negative).

Under the policy, with an increase in prices, the non-Saudi households' consumption would fall. The households' consumption would also be negatively affected by a decrease in real wages (Figure B.2), leading to the decrease in their disposable incomes. This leads to a reduction in their savings and thus remittances.

Firms: With the fall in demand, the non-tradable goods' outputs decline. The demand for inputs follows suit (Figure B.3). As a result, the price of non-tradables declines and the real wage decreases.

Under the VAT policy, the real exchange rate, given by the price of non-tradables in our model, depreciates, making tradable goods more competitive. This effect induces a reallocation of inputs from the non-tradable to the tradable sector, increasing outputs. As a result, the demand for labor, capital and energy services would increase (Figure B.4), as would the real wage.

Energy services and electricity generation: The production of energy services would decrease as the increase in the tradable sector is not enough to offset both the reduction of energy services in the non-tradable sector and household consumption (Figure B.5). This leads to a reduction in inputs (electricity, oil and gas) and, thus, reduces the domestic use of oil and gas. This would allow an increase in oil and gas exports.

GDP: The VAT policy has a positive effect on real gross domestic product (GDP) (Figure B.6). This is primarily driven by the exports of oil and gas. In our model, real GDP is given by the sum of the production of tradables and non-tradables, and the final consumption of energy services and oil and gas exports, with all the components expressed in units of the aggregate good.

Real non-oil GDP would decline, as the increase in outputs in the tradable sector would not be enough to offset the decrease in outputs in the non-tradable sector and the consumption of energy services. The policy has a positive effect on the trade balance.

Appendix B: Introduction of a 5% Value Added Tax With No Recycling of Fiscal Surplus and No International Oil Price Reaction

Figure B.1. VAT simulation – no recycling – Saudi households.

Figure B.2. VAT simulation – no recycling – non-Saudi households.

Appendix B: Introduction of a 5% Value Added Tax With No Recycling of Fiscal Surplus and No International Oil Price Reaction

Figure B.3. VAT simulation – no recycling – non-tradables sector.

Figure B.4. VAT simulation – no recycling – tradables sector.

Appendix B: Introduction of a 5% Value Added Tax With No Recycling of Fiscal Surplus and No International Oil Price Reaction

Figure B.5. VAT simulation – no recycling – energy sources, electricity and energy services.

Figure B.6. VAT simulation – no recycling – macroeconomic variables.

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About the Project

The objective of this project is to develop a dynamic stochastic general equilibrium (DSGE) model tailored to the Saudi economy. The model focuses on analyzing the dynamic effects of structural and stochastic shocks, addressing not only the long-term impacts but also the short-term adjustments. Moreover, this project aims to provide a dynamic modeling platform to simulate the impacts of economic reforms within the general framework of Saudi Vision 2030.

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