# Estimating the Impact of Energy Price Reform on Saudi Arabian Intergenerational Welfare using the MEGIR-SA Model

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**ABSTRACT**

This paper investigates the intergenerational welfare impact of raising administered retail energy prices in Saudi Arabia, an example of an oil-exporting country with a fast growing population. To achieve this, we develop a dynamic model with overlapping generations (called MEGIR-SA), which we believe is the first empirical application of its type to be developed for an oil-exporting country. The model is used to analyze the effects of the increase in some Saudi administered energy prices implemented at the end of December 2015. In particular, the model analyzes how these price increases might affect the welfare of Saudis through a direct increase in energy expenditures, an indirect rise in Saudi public income stemming from a lower domestic demand for oil that fosters oil exports at a given level of domestic oil production, and a direct increase of the turnover of the energy sector. The two latter effects can be redistributed by the Saudi public authorities to private agents through higher current public spending and/or public investment. The analysis suggests that the increase in end-user energy prices results in a net overall favorable effect on the intertemporal welfare of all households. This mirrors the impact on the income of private agents of the surplus in public oil income associated with lower domestic consumption of oil products and recycled to private agents. Moreover, it is shown that the additional oil income associated with the increase in domestic energy prices tends to be relatively more beneficial to future generations if it is recycled through public investment. This is reinforced if the future price of oil remains relatively low. In a possible future situation of declining oil prices and domestic production, a policy that would help meet the Saudi Arabian objectives may consist of gradually increasing the fraction of the additional oil income that is recycled through public capital spending.

**Key words:** Energy prices, Oil-exporting country, Overlapping generations, General equilibrium

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## 1. INTRODUCTION

At the end of December 2015, the Saudi Arabian government raised some of its administered retail energy prices. For example, the price of automotive diesel fuel increased from 0.25 Saudi Arabian Riyal (SAR) per liter (l) to 0.45 SAR/l (*resp*. 0.07US$/l and 0.12US$/l) while the price of 95 gasoline increased from 0.60 SAR/l to 0.90 SAR/l (*resp*. 0.16US$/l and 0.24US$/l)—increases of 80% and 50%, respectively (Platts, 2015). In addition, the price of natural gas increased from $0.75/MMBtu to $1.25/MMBtu (*resp*. 2.81 SAR/MMBtu and 4.69 SAR/MMBtu), an increase of 67% (Platts, 2015). In the Kingdom of Saudi Arabia (KSA), the retail prices of energy (oil products, natural gas, and power) have traditionally been set by public authorities resulting in the retail prices being below the international market price (ECRA, 2015). This has allowed Saudis to benefit directly from the relatively low domestic marginal cost of oil production. A drawback of these implicit subsidies was that it potentially encouraged an inefficient use of energy, thus reducing the amount of oil available for exports and revenue for the Saudi government.

The rationale for raising retail energy prices at the end of 2015 is due to the need to improve energy efficiency and the plummeting price of oil on world markets in 2015, given that oil income accounts for 88% of Saudi public revenue (SAMA, 2016) and thus impacts on Saudi public finances. The rapid drop in the price of crude oil resulted in a public deficit of around 15% of GDP in 2015 and triggered cuts of 12% in total public expenditures implemented in 2015 (SAMA, 2016). In this context, additional revenues can usefully contribute to improving Saudi public finances. For instance, higher retail energy prices increase the turnover of the public oil sector and also raise oil exports since higher retail prices lessen domestic oil consumption.

Given these developments, this paper investigates the possible aggregate effects—positive and negative, current and intertemporal—of raising Saudi retail administered energy prices, as in December 2015, with respect to public finances, private income/activity, and generations. In particular, it assesses how these price increases might affect the welfare of Saudis through a direct increase in energy expenditures; an indirect rise in Saudi public income stemming from a lower domestic demand for oil that fosters oil exports at a given level of domestic oil production; and a direct increase in the turnover of the public energy sector. Moreover, given that these two latter effects can be redistributed by public authorities to the Saudi private agents through either higher current public spending or public investments, the different effects of the different redistributions are also considered.

To achieve this, we develop an energy sector augmented, dynamic macroeconomic model with overlapping generations for the KSA (called MEGIR-SA, *Model with Energy, Growth and Intergenerational Redistribution—Saudi Arabia*). This, as far as we know, is the first model of this type developed specifically for Saudi Arabia (in fact we believe that this is the first model of this type developed for any Gulf region country).[1] MEGIR-SA is therefore a bespoke model for the KSA that builds on and develops the overlapping generation (OLG) model of Gonand and Jouvet (2015) by specifically including the particular characteristics of the Saudi economy. MEGIR-SA compares the costs of the higher end-use energy price policy introduced in the KSA with the potential economic gains that come from lower oil domestic consumption from higher energy prices, thus higher oil exports, energy sector turnover and public income recycled in the economy. One advantage of using a numerical general equilibrium model is that it allows for a realistic assessment of the size of

1. It should be noted that there have been some previous attempts to generically model such oil-producing countries, (such as Balke et al., 2015), which are considered in the next section; however, MEGIR-SA is developed specifically for the KSA in order to analyze recent Saudi energy policy developments and proposals.

the macroeconomic effects, not just their sign as in a theoretical model. Another advantage is that it allows us, in some cases, to measure the net macroeconomic effects when different implied mechanisms partially offset one another. Furthermore, MEGIR-SA computes the net effect on Saudi's intertemporal welfare to capture the potential inter generation effect of the policy. Lastly, we focus on measures triggering directly and exclusively intergenerational redistributive effects. Recent price hikes in 2018 for energy products in KSA have been partially offset by systems of cash transfer for poorer citizens (called "citizens' account") for which clear data are not yet available and which trigger *intra*-redistributive effects. In this context, we consider different scenarios for the KSA. Note we produce simulations, *not* forecasts so that the results do not suggest the most probable economic path for the KSA in the long run given current information; instead, the possible impact on growth and welfare in the KSA in the long run arising from the increased retail energy prices is analyzed. We consider polar simulations, with future reality probably being somewhere in-between.

The paper is therefore structured as follows. Section 2 provides a survey of empirical GE-OLG models with energy and KSA Macroeconomic modeling chronology followed by Section 3 that presents the model. Section 4 provides the results. Section 5 concludes and outlines the key policy considerations.

## 2. LITERATURE REVIEW

### 2.1. Empirical GE-OLG models with energy

The study of the aggregate impacts of energy policy often involves the use of general equilibrium (GE) models. Solow (1978) popularized the use of the GE framework for analyzing energy and environmental public policies and since then, energy-related GE models have been commonly used (e.g., Parry and Williams, 1999, Böhringer and Löschel, 2006, Knopf et al., 2010). However, most of these models do not account for intergenerational redistributive effects, despite Solow's (1986) argument that it is essential to capture both intra and intergenerational effects of environmental policies. He further points out that intergenerational issues ought to be analyzed within OLG models because such models simulate the behavior of different cohorts of different age, living in the same economy at the same time. Hence, the OLG model framework has been adopted for the analysis in this paper.

An important body of literature within an OLG framework has developed since John and Pecchenino (1994) and John et al. (1995); however, most of this has been within a theoretical framework involving only two generations. Therefore, the literature on numerical dynamic general equilibrium models using numerous overlapping generations in order to analyze the effects on intergenerational equity of energy policies is scarce and relatively new; such as Carbone et al. (2012), Carbone et al. (2013), Rausch (2013), and Gonand and Jouvet (2015). This paper therefore contributes to this literature by introducing MEGIR-SA (as detailed in Section 3 below).

### 2.2. Previous KSA Macroeconomic Modeling

There appears to be little previous research considering the macroeconomic modeling of the KSA, despite the Kingdom's crucial role and importance in world energy markets. Table 1 details, as far as we are aware, all the previous research using general equilibrium macroeconomic

**Table 1: Survey of macroeconomic models for the Kingdom of Saudi Arabia.**

| Papers | Calibrated* or econometric models | Energy content | Summary of use |
|---|---|---|---|
| Ezzati (1976)** | Combined dynamic in intertemporal, multi-sectoral, empirical linear programing model and macroeconometric model | Oil price, production and demand | Investigates the impact of oil price and production on macroeconomic indicators.. |
| Looney and Fredericksen (1985) | Macroeconometric model with Optimal Control | Has an oil sector with oil revenues and the oil price | Investigates oil revenue impact on macroeconomic indicators. |
| Looney (1986) | Macroeconometric model with Optimal Control | Oil price and production | Investigates the impact of oil price on macroeconomic variables. |
| Looney (1988) | Macroeconometric model with Optimal Control | Oil revenues | Investigates impact of oil revenues on macroeconomic indicators. |
| Bjerkholt (1993) | Combined Input-output model and applied GE model and macroeconometric model | Includes the production, demand, and prices of energy | Paper discusses modeling and data issues only. |
| Cappelen and Magnussen (1996) | GE Model | No standalone energy sector interacting with other sectors in the economy; however, includes electricity, gas, and water sector as well as an oil sector with refineries and the consumption of fuel and power. | Not used directly to analyze the energy sector |
| Johansen and Magnussen (1996) | Macroeconometric model | Behavioral equation and identity for electricity, gas, and water sector. Oil sector broken down into crude oil and natural gas from the supply side with consumption of fuel and power on the demand side. | Not used directly to analyze the energy sector. |
| De Santis (2003) | GE model | Includes crude oil price, demand, and supply. | Investigates the impact of crude oil price, demand, and supply shocks on prices, output, profits, and welfare. |
| Alam (2007) | Two-sector GE model | No discussion of the energy sector. | Not used to analyze energy issues |
| Nakov and Nuno (2013) | GE model | Oil demand, supply and price | Investigates the impact of oil indicators on macroeconomic environment and investigates oil taxes and subsidies. |
| OEGEM (2017) | Macroeconometric model | Model includes relationships between energy products and other sectors of the KSA economy and has the ability to investigate the impact of the world economy and the KSA's economy on the KSA's energy sector. | Commercial model available for subscribers to use for own analysis. |
| KGEMM (2017) | Macroeconometric model | Model includes an energy sector with 14 modeled secondary energy products for the industrial, commercial, transportation, and residential sectors—that interacts with other sectors of the macro economy. | Used by KAPSARC for in house analysis and policy advice. |
| Blazquez et al. (2017) | DSGE model | Model includes energy and energy services sectors | Investigates the macroeconomic impact of the KSA deploying more renewables, coupled with reductions in implicit energy subsidies. |

*Notes:* * Calibrated models include CGE, DSGE, Hybrid, etc. ** Ezzati (1976) uses a combined model for OPEC members that includes the KSA.

models for the KSA.[2] This shows that that there is a mixture of calibrated models and econometric models, most of which have an energy component to some degree or a full energy module. Despite this, Blazquez et al. (2017) appears to be the only study that utilized a macro model to investigate explicitly the possible impact of implicit energy subsidy cuts in the KSA. Blazquez et al. (2017) suggest that if integration costs of renewable technology were high in the KSA, then households' welfare would be maximized at around 30–40% renewables penetration. Furthermore, a policy favoring renewable energy would increase the dependence of the KSA on oil, given that a larger share of GDP would be linked to oil exports and so, potentially, to oil price shocks.

Plante (2014) and Balke et al. (2015) also considered the impact of fuel subsidies, but not explicitly for the KSA. Instead, Plante (2014) and Balke et al. (2015) developed a generic open economy calibrated model for net oil importing and exporting countries; thus, the KSA is included only within groups of similar oil-exporting countries. Plante (2014) suggests that fuel subsidies distort the macroeconomic environment and increase aggregate welfare costs. Balke et al. (2015) finds that the removal of subsidies would be welfare improving for the oil-exporting countries, but the optimal subsidy from the point of view of oil exporters is not necessarily zero. However, as indicated these are generic conclusions, not specifically for the KSA. Therefore, although Plante (2014), Balke et al. (2015) and Blazquez et al. (2017) considered the impacts of fuel subsidies on welfare, they did not consider the intergenerational welfare effects of the reductions in energy subsidies, which are considered in detail in this analysis.[3]

In summary, although some macro models have been developed for the KSA there has been little published work using such models to analyze the impact of the recent increased administrative prices of energy. Moreover, none, as far as we are aware, has addressed intergenerational wealth effects of the changes. These are the points that we address in our research here as detailed below.

## 3. THE MODEL

This section outlines the construction of MEGIR-SA. The main features of the OLG setting are first presented followed by a discussion of the details of the Saudi economic characteristics that the modeling of MEGIR-SA takes into account. Annex 1 in the Online Appendix contains further detailed information.

### 3.1. The overlapping generations framework

This framework allows for detailed modeling of the interactions between the consumption/savings and work/leisure arbitrages.[4] The main output of the OLG framework for Saudi private

2. Given the focus of the research here, Table 1 includes only general equilibrium models for the KSA and omits Vector Autoregression and Vector Error Correction models (for example, see Cashin et al., 2014 and Alshehry and Belloumi, 2015). Similarly, other holistic type models (such as Olatunji et al.'s, 2013 KSA artificial neural networks model) are excluded.

3. Note, Matar et al. (2015; 2017) also consider the impact of reducing the implicit energy subsidies in the KSA using a Mix Complementary Bottom-Up Optimization Model, but given the analysis is not based on a macroeconomic model they are excluded from Table 1. Generally, Matar et al. (2015; 2017) find that higher energy prices in the KSA would significantly reduce the consumption of oil and natural gas; however, like Blazquez et al. (2017), they do not consider intergenerational welfare effects.

4. In OLG models, contrary to models incorporating an ILA (infinitely lived agent) where Ricardian equivalence holds, saving behavior is only partially influenced by anticipated future tax liabilities. The OLG framework leads to a consideration of the implications of generational overlap on energy policy in terms of distributional effects across different generations with a finite elasticity of capital supply, and without a full Ricardian equivalence effect (see Jouvet et al., 2000).

agents is an intertemporal vector of private supply of capital per efficient unit of labor. MEGIR-SA builds upon the Gonand and Jouvet (2015) OLG setting by designing MEGIR-SA to ensure that it is consistent with the specific characteristics of the KSA economy in particular, with regards to:

- a major oil exporter (according to SAMA (2016), 87% of public income in 2014 flowed from the oil exports);
- with a rapidly growing population (according to General Authority for Statistics, 2016a the KSA's population has grown by about 2.5 % a year since the beginning of this decade);
- a relatively high proportion of expatriates who work but do not invest their saving in the KSA;
- electricity produced almost exclusively from fossil fuels;
- administered retail energy prices below international market prices with no non-price rationing of domestic demand; and
- the need for public infrastructures to still be developed.

Saudi private agents are modeled by a standard, separable, time-additive, constant relative risk aversion (CRRA) utility function, and an intertemporal budget constraint. Each cohort is represented by a representative individual who does not take account of the utility of subsequent generations. In the model, private agents are assumed to have perfect foresight. The utility function has two arguments (consumption and leisure):

$$U_{t,0} = \frac{1}{1-\sigma}\sum_{j=0}^{\Psi_{t,0}}\left\{\frac{1}{(1+\rho)^j}\left[\left(\left(c_{t+j,j}\right)^{1-1/\xi} + \chi\left(H_j\left(1-\ell_{t+j,j}\right)\right)^{1-1/\xi}\right)^{\frac{1}{1-1/\xi}}\right]^{1-\sigma}\right\}$$

where $c_{t+j,j}$ is the consumption level of the average individual of a cohort of age j in year t+j, $\ell_{t+j,j} \in [0;1]$ is his/her optimal fraction of time devoted to work. $\sigma$ is the relative risk aversion coefficient and is equal to the inverse of the intertemporal substitution coefficient. $\Psi_{t,0}$ stands for the average life expectancy at birth of a cohort born (a=0) in year t. $\rho$ is the subjective rate of time preference. $1/\xi$ is the elasticity of substitution between consumption and leisure. $\chi$ is the preference for leisure relative to consumption. $H_j$ is a parameter whose value depends on the age of an individual and whose annual growth rate is equal to the annual gains of labor-augmenting technical change (with $H_0$=1) (see Annex 1). The intertemporal budget constraint is:

$$y_{t,0} + \sum_{j=1}^{\Psi_{t,0}}\left[y_{t+j,j}\prod_{i=1}^{j}\frac{1}{\left(1+r_{t+i}\right)}\right] = c_{t,0} + \sum_{j=1}^{\Psi_{t,0}}\left[c_{t+j,j}\prod_{i=1}^{j}\frac{1}{\left(1+r_{t+i}\right)}\right]$$

where $y_{t+j,j}$ stands for the total income net of taxes of the average individual representative of a cohort, such that $y_{t,a} = \ell_{t,a} w_t \varepsilon_a \left(1-\tau_{t,NA}-\tau_{t,P}\right) + d_{t,NA} - d_{t,energy} + \Phi_{t,a}$. In the latter expression, $w_t$ stands for the gross wage per efficient unit of labor, which stems from the maximization of the production function. The parameter $\varepsilon_a$ links the age of a cohort to its productivity. The variable $d_{t,NA}$ is used as a monetary proxy for public goods and services in kind brought in a lump sum fashion to Saudi private agents, irrespective of age and income. In the baseline, no-reform Scenario A (see Section 3.3. below), it is defined as $d_{t,NA} = \Theta_{current,t} / \sum_a \mathrm{N}_{t,a,Saudis}$ where $\Theta_{current,t}$ is the aggregate current public expenditure (in billion real SAR, see public finances section), and $\mathrm{N}_{t,a,Saudis}$ the number of Saudi individuals in the cohort aged a at year t.

All the sources of public income that are not directly related with oil exports or energy prices are modeled by one aggregate tax on private agents that is proportional to their income ($\tau_{t,NA}$) because this public revenue is assumed to be on average proportional to growth in the long run at unchanged policies.

The variable $d_{t,energy}$ stands for the energy expenditures paid by one Saudi individual (see Annex 1). The variables $\tau_{t,P}$ and $\Phi_{t,a}$ relate to an implicit pension regime in the KSA. Given the current Saudi demographics characterized by a relatively very young population, their empirical values in the model for the next few decades remain small but tend to increase over time in line with demographic ageing. Parameter $\tau_{t,P}$ represents a proportional tax rate financing the PAYG pension regime. In this expression, $\Phi_{t,a}$ stands for the pension income received by the retirees of a cohort.

As explained in section 3.2.3., higher public infrastructures bolster the households' utility insofar as they raise the levels of $r_t$ and of $w_t$, the marginal productivities of savings and (resp.) labor.

Having computed the optimal path of consumption and leisure for all the cohorts of the model over their whole life-cycle, we derive the average saving of each cohort ($s_{t,a} = y_{t,a} - c_{t,a}$) and its accumulated wealth ($\Omega_{t,a} = (1+r_t)\Omega_{t-1,a-1} + s_{t,a}$). The annual saving is assumed to be invested in the capital market, yielding the interest rate $r_t$. The interest payments are capitalized into individual wealth.

The total capital supplied by Saudi households is computed as $W_t = \sum_a (\Omega_{t,a} N_{t,a,Saudis})$. It corresponds to the total capital supplied by private agents to the domestic economy. Given the experience over many years, expatriates are assumed to send all their savings abroad. Total efficient labor supply is aggregated in the same way, using the optimal labor supplies of the average individuals ($\ell_{t,a}$'s), although without distinguishing between Saudis or expatriates, since both work in the KSA. By dividing the stock of capital supplied by nationals to their domestic economy $W_t$, by the optimal labor supply, the intertemporal vector of private Saudi supply of capital per efficient unit of labor can be arrived at. The total income of Saudi private agents corresponds to a modeled GNP. Annex 1 contains further information on this OLG framework.

### 3.2. Saudi economic specificities encapsulated in the MEGIR-SA model

#### *3.2.1. Demographics*

The main outputs of the module for demographics are, for every year, the population by age, the Saudi employed population by age, and the employed population of expatriates by age. MEGIR-SA encapsulates between 50 and 60 cohorts, depending on the year and the average life expectancy. The model is built using annual data and thus captures the detailed dynamics of the population structure. Each cohort is characterized by its age at year t, has $N_{t,a}$ members and is represented by one average individual. The average individual's economic life begins at 20 years (a=0) and ends with certain death at $\Psi_{t,0}$ ($a = \Psi_{t,0} - 20$), where $\Psi_{t,0}$ stands for the average life expectancy at birth of a cohort born in year t.

The population of the KSA consists of nationals and expatriates, with 56.5% of the active population in the KSA in 2016 being non-Saudi (General Authority for Statistics, 2016b). The model assumes that Saudis provide the domestic economy with savings as well as labor, whereas expatriates provide only labor to the domestic economy with savings sent to foreign countries as remittances. Accordingly, this distinction allows the model to take account of, and compute, the macroeconomic effects of Saudization—a preference for Saudis when hiring for a job - and notably its upward influence on the capital per unit of labor.

The specification of the demographic module breaks up each cohort into working and non-working individuals, Saudis, or expatriates. In each Saudi sub cohort, a proportion $\nu_{t,a}$ of individuals is working and earn wages. Labor participation rates in the model are an average of the different rates for men and women. The Saudi inactive population is divided into two components. A first component corresponds to individuals who never work nor receive any pension during their lifetime. The second component, i.e., $\pi_{t,a}$ which is the proportion of pensioners in a cohort, is computed as a residual.

### *3.2.2. The energy module*

#### 3.2.2.1. The oil production sector

The main output of the module for the oil production sector is an intertemporal vector of public revenues from oil exports ($Y_{oil,t}$) expressed in billions of 2005 Saudi Riyals. For future periods, $Y_{oil,t}$ is computed as $Y_{oil,t} = Y_{oil,t-1} \frac{EXP_{oil,t}}{EXP_{oil,t-1}} \frac{barrel_{oil,t}}{barrel_{oil,t-1}}$ where $EXP_{oil,t}$ represents the national exports of crude oil (in MMbbl) in year t, and $barrel_{oil,t}$ is the price of a barrel of Arabian Light on world markets in year t. The dynamics of the exports of refined oil products are not considered and we assume that there will be no Saudi exports of natural gas in the future. We also assume that the nominal exchange rate between the US dollar and the Saudi Riyal will remain constant (as has been the case since 1987).

Depending on the parameterization of the model, the future price of a barrel of Arabian Light on world markets ($barrel_{oil,t}$) can be simulated as being influenced (or not) by the level of Saudi exports of oil. Moreover, there are several theoretical models and examples over recent decades that suggest a change in Saudi Arabi's oil exports has an impact on the international oil price (cf. Bhattacharyya, 2011). Therefore, in the short to medium run, there are good reasons to assume that the KSA is not a price taker on the world market of oil (although, some recent literature suggests that this market power may have somewhat faded away in the late 2000s, for example Huppman and Holz, 2012). However, in this research we analyze the very long run, the time horizon being somewhat longer than one considering relatively short-run phenomena related to spare capacity, for instance. Furthermore, the analysis by Kilian (2009) and Kilian and Hicks (2013) suggest that an oil supply shock does not necessarily trigger a sizeable and long lasting influence on the international price of oil. Therefore, given that MEGIR-SA is a long-run model (due to the OLG framework) and that we are interested in analyzing the very long-run, we assume for the main model simulations presented here that the international oil price does not react to the variations of Saudi oil exports. However, in order to check the robustness of this assumption we also undertook an indicative econometric exercise to estimate the elasticity of the international oil price with respect to Saudi oil exports. This suggested that in the long-run it would be about –0.5 (although, this is the "long-run' in a time series context based on about 30 observations thus not necessarily consistent with the very long-run analysis of this research). We then re-ran the model simulations using this estimated elasticity as a robustness check. We found only a very small change in the quantitative results and no change in the qualitative results. The full details of the econometric estimation and the model simulation results are given in Annex 2 in the Online Appendix.

By definition, $EXP_{oil,t} = P_{oil,KSA,t} - CONS_{oil,t}$ where $P_{oil,KSA,t}$ is the national annual production of crude oil at year t (in MMbbl) and the variable $CONS_{oil,t}$ is the endogenous national consumption of oil (in MMbbl). Since the model is parameterized on KSA data, $P_{oil,KSA,t}$ is assumed to be set exogenously by public authorities (in MMbbl). $CONS_{oil,t}$ is such that $CONS_{oil,t} = D_{oil,t} + D_{elec,crude\ oil,t} + D_{elec,refined\ oil,t}$ where $D_{oil,t}$ is the national demand for oil, crude or refined, in the non-power sector (in MMbbl);

$D_{elec,crude\ oil,t}$ the demand for crude oil in the power sector (in MMbbl), and $D_{elec,refined\ oil,t}$ the demand for refined oil products in the power sector (in MMbbl). The three latter variables are endogenous and depend on the level of activity, the macroeconomic characteristics of the general equilibrium in the model, demographics, administered domestic prices, and public policies (discussed in the next section).

3.2.2.2. The end-use prices of energy and domestic demands for different energies

The main outputs of the module for the energy sector are an intertemporal vector of average weighted real price of energy for end-users $q_{energy,t}$ , along with the dynamics of the energy mix between different sources of energy (domestic demand for oil $D_{oil,t}$, domestic demand for natural gas $D_{natgas,t}$, and domestic demand for electricity $D_{elec,t}$).

The **average weighted real end-use price of energy** is computed as an average of exogenous, regulated end-use prices of natural gas, oil products and electricity, weighted by the proportions such as $q_{energy,t} = \sum_{i=1}^{3}\left( q_{i,t} * D_{i,t-1} / \sum_{i} D_{i,t-1} \right)$ where $q_{energy,t}$ stands for the average real weighted end-use price of energy at year t (in real 2005 SAR/MWh), $D_{i,t-1}$ for the final consumption in volume for natural gas (i=1), oil products (i=2)($D_{oil,t}$=$D_{2,t}$) and electricity (i=3),(all in ktoe), and where $q_{i,t}$ is the weighted price, at year t, of natural gas (i=1), oil products (i=2) and electricity (i=3)(all in real 2005 SAR/MWh).

The real end-use prices of natural gas and oil products ($q_{i,t}$, i∈{1;2}) in turn are computed as weighted averages of regulated end-use prices of different sub categories of energy products: $\forall i \in \{1;2\}, q_{i,t} = \sum_{j=1}^{n} a_{i,j,t} q_{i,j,t}$. . $q_{i,j,t}$. stands for the real end-use price of the product j of energy i at year t. For natural gas (i=1), we assume that the end-use price of natural gas for households (j=1) and for industry (j=2) are equal, on average. For oil products (i=2), three sub-categories j are modeled: the end-use price of automotive diesel fuel (j=1), the end-use price of light fuel oil (j=2) and the end-use price of premium unleaded 95 (j=3) (all expressed in real SAR/l). This structure for energy products covers the major part of the energy demand for fossil fuels. For electricity (i=3), two sub-categories j are modeled: the end-use price of electricity for households (j=1), and the end-use price of electricity for industry (j=2).

All retail energy prices are set directly by the Saudi government. Thus, shifts in demand for energy in the KSA do not necessarily result in changes in the domestic prices of energy, as observed in the KSA during the last few decades. This policy aimed to maintain price stability, secure the needs and welfare of consumers, and preserve important social interests in the country. As a consequence, energy users benefit from "low' prices administered by government agencies as compared to international prices. These administered prices do not require direct government expenditures to keep domestic prices below international prices. Although they are low compared to international prices, retail energy prices in Saudi Arabia cover domestic production costs, and were set to values very close to the marginal cost of production on average up to 2015. The regulated, real end-use price of electricity $q_{3,t}$ also covers the costs of production of power in the KSA (see, for instance, ECRA, 2014), which is consistent with the long-run characteristics of the model.

The **volumes of energy demands** from 1985 onwards are broken down into demand for oil products ($D_{oil,t}$=$D_{2,t}$), demand for natural gas ($D_{natgas,t} = D_{1,t}$}) and demand for electricity ($D_{elec,t} = D_{3,t}$) (in ktoe). Data come from the IEA database. In this model, they are used mainly to compute the average weighted real energy price for end-users $q_{energy,t}$ from 1984 onwards.

The computation of the overall energy mix in the future (i.e., $D_{natgas,t} = D_{1,t}$, $D_{oil,t} = D_{2,t}$, $D_{elec,t} = D_{3,t}$) is endogenous based on a framework commonly used in the literature (e.g., Leimbach et al., 2010) which derives the future energy mix using a nest of interrelated, constant elasticity of substation (CES) functions. This nest allows for the level in the future of each component of the energy mix—i.e., $D_{oil,t}$, $D_{natgas,t}$ and $D_{elec,t}$—to vary over time according to changes in the relative regulated end-use prices of their associated energy vectors, i.e., $q_{1,t}$, $q_{2,t}$ and $q_{3,t}$. The more the relative price of one source of energy increases, the more its relative demand declines. The mix of technologies used to produce power is directly influenced by the decisions of public authorities and the mix of fuels used to produce electricity in the KSA is driven by policy that may not necessarily mirror economic optima. Given that no official KSA long-run forecasts for the technology mix in the power sector exist, we assume, consistent with regular statements from Saudi authorities, that any additional demand for electricity in the future will not be covered by power plants using oil.

This setting allows to derive the total domestic consumption of oil $CONS_{oil,t} = D_{oil,t} + D_{elec,crude\ oil,t} + D_{elec,refined\ oil,t}$. Annex 1 contains further information.

### *3.2.3. The production function*

*The main outputs of the module with the production function are an intertemporal vector of marginal productivity of capital ($r_t$), of wage per unit of efficient labor ($w_t$), of total energy demand ($E_t$), and of demand for capital per unit of efficient labor.*

The production function is a Constant Elasticity of Substitution (CES) nested one, with two levels: one linking the stock of productive capital and labor, the other relating the composite of the two latter with energy. We follow Glomm and Ravikumar (1997) for the method of including the stock of public capital in the production function. We checked that our results were robust to other ways of inserting the stock of public capital in the function. The production function refers here to the non-oil sector of Saudi Arabia. The K-L module of the nested production function is:

$$C_t = K^{\varsigma}_{KSA\ pub,t}\left[\alpha\left(K_{KSA\ priv,t}\right)^{1-\frac{1}{\beta}} + (1-\alpha)\left[A_t\overline{\varepsilon}_t\Delta_t L_t\right]^{1-\frac{1}{\beta}}\right]^{\frac{1}{1-\frac{1}{\beta}}}$$

The parameter $\alpha$ is a weighting parameter; $\beta$ is the elasticity of substitution between physical capital and labor; $L_t$ is the total labor force; and $A_t$ stands for an index of total factor productivity gains which are assumed to be labor augmenting, *i.e.*, Harrod neutral. The parameter $\overline{\varepsilon}_t = \sum_{a}^{\max(a,t)} \varepsilon_a \frac{\nu_{t,a} N_{t,a}}{L_t}$ links the aggregate productivity of the labor force at year *t* to the average age of active individuals at this year. $N_{t,a}$ is the total number of individuals aged *a* at year *t*. $\Delta_t$ corresponds to the average optimal working time in *t* (defined by households to maximize their lifetime utility) Thus $\Delta_t L_t$ corresponds to the total number of hours worked, and $A_t\overline{\varepsilon}_t\Delta_t L_t$ is the labor supply expressed as the sum of efficient hours worked in *t*, or, as an equivalent, the total flow of efficient labor in a year *t*—*i.e.*, the total labor supply brought by Saudis and expatriates.

The stock of physical capital available to the non-oil sector comprises a demand for capital by private agents $K_{KSA\ priv,t}$ and a public stock of capital $K_{KSA\ pub,t}$ that stands for the infrastructure that benefits the private sector. Profit maximization of the production function in its intensive form, i.e., with $k_{KSA\ priv,t} = \frac{K_{KSA\ priv,t}}{A_t\overline{\varepsilon}_t\Delta_t L_t}$, yields optimal factor prices, namely, the cost of physical capital:

$r_t = k^{\varsigma}_{KSA\ pub,t}\left[\alpha\left(k_{KSA\ priv,t}\right)^{\frac{\beta-1}{\beta}}+1-\alpha\right]^{\frac{1}{\beta-1}}\left[\alpha k^{\frac{-1}{\beta}}_{KSA\ priv,t}\right]$ and the gross wage per unit of efficient labor:

$$w_t = k^{\varsigma}_{KSA\ pub,t} A_t\left[\alpha\left(k_{KSA\ pub,t}\right)^{1-\frac{1}{\beta}}+1-\alpha\right]^{\frac{1}{\beta-1}}\left[1-\alpha\right].$$

These equilibrium relationships show the influence of the stock of public infrastructures $k_{KSA\ pub,t}$ on the income of private agents (through $r_t$ and $w_t$). Once parameterized on empirical data, they suggest that a higher level of $k_{KSA\ pub,t}$ also triggers, all else being equal, a higher level of $r_t$ and $w_t$—whereas a higher level of $k_{KSA\ priv,t}$ fosters $w_t$ but lessens $r_t$ (see Rioja, 2001). More infrastructure enhances the income of both factors of production, and thus bolsters activity.

Introducing energy demand $E_t$. in a CES function, as Solow (1974), yields another production function $Y_t$ in volume:

$$Y_t = \left[\alpha\left(B_t E_t\right)^{\gamma_{en}} + (1-\alpha)\left[C_t\right]^{\gamma_{en}}\right]^{\frac{1}{\gamma_{en}}}$$

where $a$ is a weighting parameter, $\gamma_{en}$ is related to the elasticity of substitution between factors of production ($C_t$) and energy (with $\gamma_{en} = 1-1/\text{elasticity}$), $E_t$ is the total demand for energy, and $B_t$ stands for an index of (increasing) energy efficiency. The cost function is the solution of $\min_{E_t,C_t} q_t B_t E_t + p_{C_t} C_t$ under the constraint $Y_t^{\gamma_{en}} = a\left(B_t E_t\right)^{\gamma_{en}} + (1-\alpha)\left[C_t\right]^{\gamma_{en}}$.

In the latter objective function, $q_t$ refers to the price of energy services, these services being measured by $B_t E_t$. The price of energy services $q_t$ is related to the price of energy computed in the energy module $q_{energy,t}$ by the relationship: $q_t = B_t q_{energy,t}$. Given that the stock of capital, the labor supply, the cost of capital, the wage per unit of efficient labor, the deflator $p_{C_t}$ and the real price of energy $q_{energy,t}$ are all known and that $B_t$ is exogenous, it is possible to derive the total energy demand: $E_t = q_t^{\frac{1}{\gamma_{en}-1}} a^{\frac{-1}{\gamma_{en}-1}} C_t \Big/ \left(p_{C_t}^{\frac{1}{\gamma_{en}-1}}(1-a)^{\frac{-1}{\gamma_{en}-1}}\right)$. It can be checked that when $C_t$ increases, the demand (in volume) for energy $E_t$ rises. When the price of energy services $q_t = B_t q_{energy,t}$ increases, the demand for energy $E_t$ diminishes. When energy efficiency $B_t$ accelerates, the demand for energy $E_t$ is lower. In this framework, the production function also takes account of the fact that developing public infrastructures $K_{KSA\ pub,t}$ is an energy intensive policy with an upward effect on the domestic demand for energy (since $\partial E_t/\partial K_{KSA\ pub,t}>0$).

### *3.2.4. Saudi public finances*

The public budget constraint is $\Upsilon_{oil,t} + \Upsilon_{others,t} = \Theta_{current,t} + \Theta_{capital,t}$. For future periods, $\Upsilon_{oil,t}$ is computed as $\Upsilon_{oil,t} = \Upsilon_{oil,t-1}\dfrac{\text{EXP}_{oil,t}}{\text{EXP}_{oil,t-1}}\dfrac{\text{barrel}_{oil,t}}{\text{barrel}_{oil,t-1}}$ as explained in Section 3.2.2.1. above. By definition, $\text{EXP}_{oil,t} = \text{P}_{oil,KSA,t} - \text{CONS}_{oil,t}$ where $\text{P}_{oil,KSA,t}$ is the national annual production of crude oil (in MMbbl). $\text{CONS}_{oil,t}$ is the endogenous national consumption of oil (in MMbbl)(crude or refined products), such as $\text{CONS}_{oil,t} = \text{D}_{oil,t} + \text{D}_{elec,crude\ oil,t} + \text{D}_{elec,refined\ oil,t}$. It depends notably on the retail price of oil products $\left(q_{2,t}\right)$ through $\text{D}_{oil,t}$. Annex 1 provides the formula for $\text{D}_{oil,t}$.[5]

5. The assumption that any future additional demand for electricity will not be covered by power plants burning oil (see end of Section 3.2.3.2.) implies that $\text{D}_{elec,crude\ oil,t}$ and $\text{D}_{elec,refined\ oil,t}$ are constant in the future.

The other public revenues ($Y_{others,t}$)(in real terms) refer in the model to all the sources of public income that are not directly related to oil exports. In the Saudi context, these may include notably corporate tax, *zakat* (Muslim alms-giving), customs import duties and user fees. Insofar as these other public revenues are on average proportional to growth in the long run at unchanged policies, our model simulates them as evolving over time along with the long-term Solow-type growth rate (i.e., the growth rate of the efficient labor force), augmented by possible additional income flowing from higher retail price changes decided by public authorities. Annex 1 provides the formula. At unchanged energy prices, all these public revenues are on average proportional to economic activity in the long run, our model simulates them as financed by an aggregate tax on private agents that is proportional to their income.

Public revenue is used to finance public current expenditures ($\Theta_{current,t}$) or public capital expenditures ($\Theta_{capital,t}$). Current public spending $\Theta_{current,t}$ is redistributed in a lump sum fashion in the model, as a proxy for public services. Each Saudi private agent receives public transfers, with a variable $d_{t,NA}$ standing for public expenditures that one individual benefits from irrespective of its age and income. It is a monetary proxy for goods and services in kind bought by the public sector and consumed by households.

Public capital expenditure $\Theta_{capital,t}$ feeds into a gross stock of public capital $K_{KSA\ pub,t}$, representative of public infrastructures. Public revenue can also finance an effort of fiscal consolidation implemented from 2015 onwards.

Saudi government in the future is assumed to face a fiscal consolidation constraint. All scenarios incorporate a fiscal consolidation from 2016 onwards during which the respective levels of current public spending ($\Theta_{current,t}$) and of public investments ($\Theta_{capital,t}$) are adjusted downwardly in order to get the Saudi public deficit back to 0. These adjustments are proportional to the respective weights of $\Theta_{current,t}$ and $\Theta_{capital,t}$ in total public expenditures. Fiscal consolidation is assumed to benefit foreign investors/lenders only (and not Saudi agents). The duration of the consolidation period in the model is 10 years. Sensitivity analysis carried out with a length of five years shows that our results are robust to this assumption (see Section 4, Result 4).

New, higher public capital investments trigger two macroeconomic mechanisms in the model: they enhance the marginal productivity of labor and private capital over decades as shown in the production function, and they redistribute directly some income to Saudi agents (see Annex 1 for more precisions on this latter item). Accordingly, the amount of income benefiting Saudi when public infrastructures are built depends notably on a) the proportion of Saudis among the total employed population, and b) the amount of intermediate consumption that is produced domestically. The former stems from the demographic module and is exogenous in the model. The latter mirrors the level of diversification of the Saudi economy: the more the KSA provides the intermediate consumption needed to build its own infrastructure, the more Saudi agents benefit from public investments. Annex 1 provides additional details and explains why we consider that the cash effect for private agents of public investments is around 70% of the amount of the public capital spending each year. Sensitivity analysis will be carried out as concerns this parameter in Section 4.

### 3.3. Policy scenarios

In the model, the increases in administered retail energy prices influence the income and welfare of private Saudi agents through different channels:

- a direct increase in energy expenditures $d_{t,energy}\left(E_t\right)$ weighing on the private net income;

- an indirect rise in Saudi public income $Y_{oil,t}\left(E_t\left(q_{energy,t}\right)\right)$ stemming from a lower domestic demand for oil which fosters oil exports at a given level of domestic oil production;
- a direct increase of the turnover of the public energy sector, which increases $Y_{others,t}\left(q_{energy,t}\right)$.

The two latter effects can be redistributed by public authorities to the Saudi private agents either through higher current public spending ($\Theta_{current,t}$) or public investments ($\Theta_{capital,t}$).

We define $Publinc_t = \left\{Y_{oil,t,ref} + Y_{others,t,ref} - Y_{oil,t,noref} - Y_{others,t,noref}\right\} > 0$ as the increase in the future total public income associated with energy price hikes in a reform scenario as compared to a no-reform scenario. We then define the parameter $\overline{y}$ as the fraction of $Publinc_t$ that is recycled through higher public *capital* spending. It is exogenously set by public authorities. In this context, we consider two policies, each with two different future paths for the Saudi oil sector:

- The *future paths for the Saudi oil sector* depend on the value of the price of a barrel of oil (Arabian light) on world markets in the future ($\text{barrel}_{oil,t}$) and the future level of Saudi production of oil. We distinguish two polar simulations (see Figure 1):
  - *Future oil income increasing and future oil production stable (Scenarios B, i.e., scenario $B_0$ and scenario $B_{100}$, see Table 2):* the simulated value of $\text{barrel}_{oil,t}$ follows a temporal trend over time which is increasing by 4% per annum. Depending on the parameterization of the model, this trended value can in turn be influenced by Saudi oil

**Figure 1: Simulations of the future oil price and Saudi oil production in scenarios**

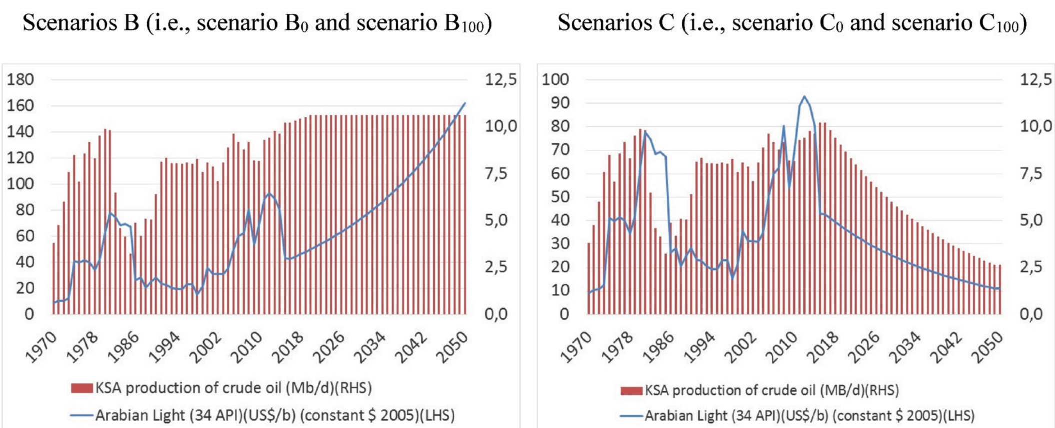



**Table 2: Reform scenarios in the model**

| | y | |
|---|---|---|
| | ***0%*** | ***100%*** |
| ***Future oil prices increasing + future oil production stable*** | $B_0$ | $B_{100}$ |
| ***Future oil prices and oil production declining*** | $C_0$ | $C_{100}$ |

exports, with an elasticity of –0.5 (see Annex 2 for further details and a presentation of the associated results).[6] Additionally, the Saudi production of oil decided by public authorities is assumed to remain stable in the future and close to its current, historically high levels (*i.e.*, 10.6MMbb/d).

- ○ *Future oil income and oil production declining (Scenarios C, i.e., scenario $C_0$ and scenario $C_{100}$, see Table 2):* the temporal trend is declining by 4% per annum up to 2050 before stabilizing. Depending on the parameterization of the model, this trended value can in turn be influenced by Saudi oil exports (see Annex 2). The Saudi level of oil production is also assumed to diminish by 4% per annum up to 2050, before stabilizing. This refers to a pessimistic—although not unrealistic—scenario in which the world demand for Saudi oil diminishes (up to 2.5MMbb/d in 2050) and the price converges gradually to the Saudi marginal cost of production in 2050 (*i.e.*, around 10US$). In this case, we assume that the anticipations of Saudi households changed during the 2010s, with the associated impact on their optimal economic behavior.

- The policies considered are distinguished according to the level of recycling of additional public income through higher public capital spending in the future (*i.e.*, the value of $\overline{y}$).[7] We distinguish two polar simulations: either 0% or 100%.[8] Hence, Scenario $B_0$ refers to a rise in retail energy prices in end 2015 in a context of high and stable future Saudi production of oil and of increasing future oil prices that is anticipated by private agents, and where the additional public income is recycled through public current sending ($\overline{y} = 0\%$). Scenario $B_{100}$ is the same as $B_0$ except that the additional public income is recycled through higher public capital expenditures ($\overline{y} = 100\%$). The same applies to scenario $C_0$ and scenario $C_{100}$ (see Table 2).

The baseline Scenario *A* refers to a situation where *no* increase in retail energy prices is decided in December 2015, future Saudi production of oil is stable, future oil prices increase by 4% per annum, and all Saudi cohorts anticipate these paths and define their intertemporal optimal behaviors accordingly.[9]

In dynamic GE models where, by construction, all variables interact at all years, assessing the influence of one variable or policy (*e.g.*, the rise of retail energy prices and its implication for fiscal policy) on any other variable (*e.g.*, households' welfare) requires a comparison of two scenarios where the only difference is the level of the variable or policy. Accordingly, results for Scenario $B_0$ (resp. $B_{100}$) present the difference between the level of intertemporal welfare of different cohorts of households in Scenario $B_0$ (resp. $B_{100}$) and the same level as in baseline Scenario A. The same holds for Scenarios $C_0$ and $C_{100}$ as compared to the baseline Scenario A with the same assumption concerning the future decline in the prices and production of oil. Our strategy thus allows us to ana-

6. Formally, the price of the barrel of oil in the simulations of the model is defined as $\text{barrel}_{oil,t} = \left[\text{barrel}_{oil,t-1}\left(1+trend_{barrel}\right)\right]\left(1-\varepsilon_{barrel/oilexp}\left[\frac{\text{EXP}_{oil,t}}{\text{EXP}_{oil,t-1}}\right]\right)$ where $\varepsilon_{barrel/oilexp}$ is the long-run elasticity of the price of a barrel of Saudi exports.

7. Reform scenarios all assume that the increase in the future total public income associated with rising energy prices ( $Publinc_t$) is entirely recycled in the Saudi economy through higher public spending.

8. In the baseline scenarios with no energy price increase in 2016, the proportions of current and capital expenditures as a fraction of total public spending remain constant once the consolidation period is over: $\frac{\Theta_{current,t}}{\text{Y}_{oil,t}+\text{Y}_{others,t}} = \frac{\Theta_{current,t-1}}{\text{Y}_{oil,t-1}+\text{Y}_{others,t-1}}, \forall t \geq 2026$. In scenarios with an increase on the price of retail energy prices, the future paths of $\Theta_{current,t}$ and $\Theta_{capital,t}$ depend notably on the value of $\overline{y}$.

9. This path is for instance close to what is forecasted by Oxford Economics in 2015 up to 2040. Cf. OEGEM (2017), "Oxford Economics Global Economic Model', 2015.

lyze the impact of a permanent increase in administered retail energy prices, assuming that all other exogenous elements remain constant (notably, the future prices and quantities of oil).

The increase in regulated retail energy prices from 2016 onwards is an informational surprise for the forward-looking private agents, who redefine accordingly their optimal behaviors (consumption and labor supply) over their remaining life cycle. This assumption about anticipations fits well with the announcements of the Saudi government. Higher end-user energy prices lessen the future net income of individuals, thus influence their consumption and savings, the stock of capital, growth, and total energy demand.

Incidentally, once the model has converged to its intertemporal general equilibrium, the average weighted retail price ($q_{energy,t}$) increases by close to 50% and triggers in the long run a downward impact on the total energy demand ($E_t$) in general equilibrium between 13% and 18%, depending on the way the additional oil income is recycled in the economy.[10]

Reform scenarios all assume that the increase in the future total public income associated with rising energy prices ($Publinc_t$) is entirely recycled in the Saudi economy through higher public spending. Sensitivity analysis in Section 4 investigates the sensitivity of our results to this specific assumption.

Sensitivity analysis to the main exogenous parameters is carried out and commented in Section 4 below (see Table 3). Annex 1 provides additional details about the parameterization of the model.

## 4. RESULTS

***Result 1**: In Saudi Arabia, the analysis suggests that the permanent increase in the KSA's end-user energy prices implemented in December 2015 will trigger a net overall favorable effect on the intertemporal welfare of all households. This mirrors the impact on the income of private agents of the surplus in public oil income associated with lower domestic consumption of oil products and recycled to private agents.*

Figures 2 and 3 illustrate the impact of higher energy prices on the intertemporal welfare of each cohort in Scenarios $B_0$, $B_{100}$, $C_0$ and $C_{100}$, respectively. It appears that even for declining future oil prices and domestic production of oil (as in $C_0$ and $C_{100}$), lower domestic consumption of energy implied by higher retail prices fosters oil exports, raises oil income and, in case of immediate recycling to private agents, increases overall their income and welfare. This result flows from the fact that, even after the price hike, Saudi private agents keep paying a price for oil products that is below the price that would be implied by prices of fossil fuels on world markets. Note, administered energy prices in Saudi Arabia do cover the costs of production and although there is no explicit subsidy

10. By definition, Scenarios C ($C_0$ and $C_{100}$) incorporate a decline in the future levels of oil prices and Saudi oil production that is non anticipated by Saudi households before the 2010's. They simulate a possible very different future state of the Saudi economy with much lower oil income, growth, and welfare. Accordingly, comparing scenarios $C_0$ and $C_{100}$ with scenario A would not allow for assessing the sole influence of the rise in retail energy prices and its implication for fiscal policy on the cohorts' intertemporal welfare, but mostly the influence of much lower oil income on Saudis' welfare. Thus, assessing the sole influence of the rise in retail energy prices and its implication for fiscal policy on the cohorts' intertemporal welfare requires the comparison of scenarios $C_0$ and $C_{100}$ with scenario $A_{low\ oil}$ which is the same as scenario A with no rise in retail energy prices unless that it incorporates a previously non-anticipated decline in the future oil price and level of production from 2016 onwards. Accordingly, results for scenario $C_0$ (resp. $C_{100}$) present the difference between the level of intertemporal welfare of different cohorts of households in scenario $C_0$ (resp. $C_{100}$) and the same level in scenario $A_{low\ oil}$. They measure the impact, in our dynamic general equilibrium, of increasing retail energy prices in a context of lower future prices and production of oil, which is precisely what this paper aims at.

**Figure 2: Impact on the intertemporal welfare of Saudi cohorts of higher retail energy prices (with higher future oil prices and immediate recycling of the additional oil income)**

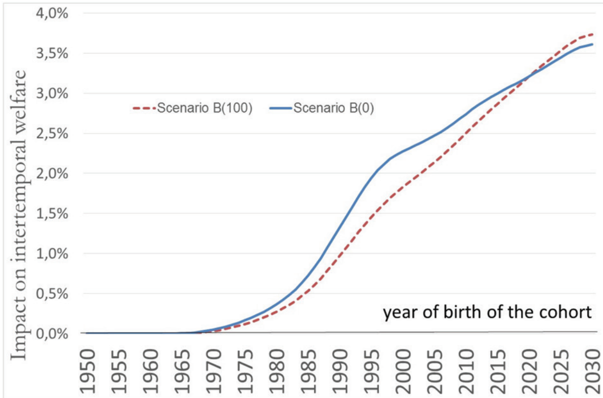
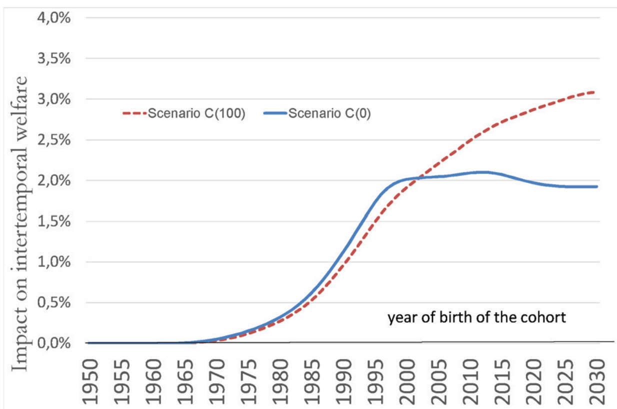



**Figure 3: Impact on the intertemporal welfare of Saudi cohorts of higher retail energy prices (with lower future oil prices and production, and immediate recycling of the additional oil income)**




there is an implicit cost for the public finances. Moreover, the 2015 prices were set at a level much lower than the price of oil on international markets. Accordingly, raising energy prices in 2015 only resulted in higher prices (and no lower transfer to the energy sector, because these transfers were already inexistent before the increase in administered energy prices). In this context, Result 1 stands out since the impact of raising retail energy prices remains positive on the households' welfare, because of higher oil exports—a situation that would not have been observed in a non-oil producing country.

***Result 2****: The analysis suggests that the additional oil income associated with the increase in energy domestic prices tends to be relatively more beneficial to future generations if it is recycled through public investments ($\bar{y}$=100% as in $B_{100}$* and *$C_{100}$) and relatively more to currently living cohorts if it is recycled through current spending.*

Public capital expenditures involve less transfer of income to private agents in the short run than higher current public spending. However, they foster the marginal productivity of labor and capital in the long run in the aggregate production function. Figures 2 and 3 show that, for given additional oil income stemming from lower domestic consumption, recycling with higher public investment would trigger higher economic activity in the long run. Depending on the future price and production of oil, the relative situation of the cohorts between the scenarios changes. In scenarios B (with higher future oil prices on world markets), only generations born from 2015 onwards are better off in scenario $B_{100}$ than in scenario $B_0$ as far as their intertemporal welfare is concerned. This result stands out insofar as the current generations have no incentive to raise public investments since the welfare effect will most predominantly benefit future generations—but not them.

For less favorable prospects concerning oil prices and domestic oil production, all generations born after 2005 are better off in scenario $C_{100}$ than in scenario $C_0$. This points to Result 3.

***Result 3****: The lower the future price of oil and Saudi oil income (as in* $C_0$ and $C_{100}$*), the more the future cohorts benefit relatively from a recycling of the additional oil income through public investments.*

This result relates to how Saudi private agents adapt when they anticipate that future oil income in the KSA may be less favorable than they expected up to a few years ago. Revised downward expectations increase the private saving rate in order to smooth the impact of lower oil income on the future consumption profile. Private capital accumulation accelerates. Since higher public investment bolsters the productivity of private capital and labor, if the prospects for the KSA's oil income deteriorate, public investments will increasingly bolster welfare in relative terms.

***Result 4****: Sensitivity analysis: these results can be influenced—but not dramatically changed—by other assumptions about the parameterization of the model, or assumptions about the use of the additional oil income during the fiscal consolidation period or the short term cash impact of higher public investments.*

**Table 3: Robustness checks of the results depending on the values of some exogenous parameters**

| Difference of intemporal welfare in scenario B(0) (in %) | Value in the standard parameterization | Cohort born in... 1950 | 1970 | 1990 | 2010 |
|---|---|---|---|---|---|
| **B(0) with the standard parameterization** | | **0,00%** | **0,05%** | **1,32%** | **3,61%** |
| Parameter of preference for leisure relative to consumption equal to 0,5 | *0,25* | 0,00% | 0,05% | 1,22% | 3,37% |
| Capital share in value added equal to 0,2 | *0,30* | 0,00% | 0,05% | 1,23% | 3,16% |
| Capital share in value added equal to 0,4 | *0,30* | 0,00% | 0,05% | 1,42% | 4,12% |
| Intertemporal elasticity of substitution equal to 1,01 | *1,33* | 0,00% | 0,04% | 1,34% | 3,62% |
| Elasticity of substitution capital/labour equal to 1,3 | *0,80* | 0,00% | 0,05% | 1,32% | 3,63% |
| Parameter associated with the public stock of capital in the production function equal to 0,075 | *0,15* | 0,00% | 0,05% | 1,28% | 3,47% |
| Elasticity of substitution capital-labour / energy equal to 0,2 | *0,40* | 0,00% | 0,04% | 1,06% | 2,70% |
| Psychological discount rate equal to 1% | *2%* | 0,00% | 0,05% | 1,34% | 3,59% |
| Length of fiscal consolidation equal to 5 years | *10* | 0,00% | 0,05% | 1,34% | 3,58% |

Table 3 provides some robustness checks of the results depending on the values for a set of exogenous parameters in the model. This shows that the dynamics of the model are reasonably robust to different, while still relatively realistic, values for the psychological discount rate, the elasticity of substitution between capital and labor, the elasticity of substitution between capital/labor and energy, and the parameter of the preference for leisure relative to consumption. Assuming also a shorter period for the fiscal consolidation implemented from the mid-2010s onwards (five years instead of 10 years as assumed here) would also not substantially modify the results.

The dynamics of the model are, as anticipated, impacted more by different values for parameters directly linked with the dynamics of the accumulation of physical capital, *i.e.*, the elasticity of capital-labor.

Reform scenarios all assume that the increase in the future total public income associated with rising energy prices ($Publinc_t$) is entirely recycled in the Saudi economy through higher public spending. We investigated the sensitivity of our results to this assumption, running scenarios where $Publinc_t$ is used to finance (and thus accelerate) the fiscal consolidation, with no redistribution to Saudi agents during that period. Accordingly, it implies no upward effect on public spending (current or capital) during the next years). Figure 4 provides the results of sensitivity scenarios where the additional oil income is fully used to accelerate the reduction of the public deficit during the fiscal consolidation period (so up to the 2020s only). Illustrative results are presented for scenarios $C_0$ and $C_{100}$ (scenarios $B_{100}$ and $B_0$ would give similar outcomes). Whether the additional oil income associated with the increase in energy domestic prices is used (or not) to finance a fiscal consolidation in the short-run, triggers significant reduced effects on the intertemporal welfare of current generations. However, the change for future generations is mechanically lower and tends to disappear for future cohorts born in the 2020s.

Figure 5 shows the impact of a lower assumption for the short term cash injection associated with public investments (i.e., instead of our standard assumption of 70%, we use 50% here, an order of magnitude that would be reached if only one third of intermediate consumption goods used in public investments were produced domestically). Illustrative results are presented for scenario $C_{100}$ (scenario $B_{100}$ would give similar outcomes). Not surprisingly in this context, the positive impact of recycling through higher public investments is lower for each current and future generation.

**Figure 4: Sensitivity analysis (with additional oil income fully used to accelerate the reduction of the public deficit during the fiscal consolidation period up to the 2020s)**

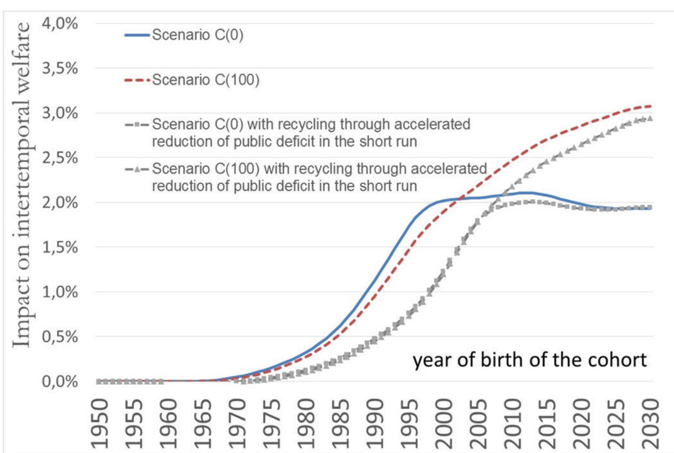
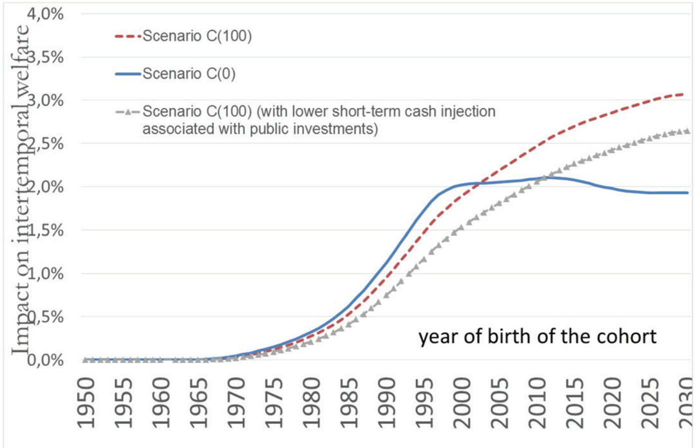


**Figure 5: Sensitivity analysis (with lower short term cash injection associated with public investments)**




However, in the long run, future generations remain better off with recycling through higher public investments, as in result 2.

So far, the results suggest that the choice by public authorities of the value of $\overline{y}$, the fraction of the additional public oil income recycled through capital expenditures, imply different outcomes as concerns the welfare of current cohorts and future generations, and also as regards short-term and long-run growth. In this context, a possible choice consists in changing the value of $\overline{y}$ over time in order to benefit as much as possible from the short-run impact of increasing current public spending and the long-run effect of higher public investments. Accordingly, we define $\overline{y}^*$ as an intertemporal vector of $\overline{y}_t$'s changing every five years such as:

$$\min_{\overline{y}_t}\left[\sum_{i\epsilon[1950;2030]}\left|\max\left(W_{intertemp,i,\overline{y}=0\%};W_{intertemp,i,\overline{y}=100\%}\right)-W_{intertemp,i,\overline{y}_t\epsilon[0\%;100\%]}\right|\right]$$

where $W_{intertemp,i,\overline{y}=0\%}$ stands for the intertemporal welfare of the cohort born at year i and in a scenario with $\overline{y}=0\%$. With such a framework, the values of $\overline{y}_t$ minimize the sum of the absolute values of the differences, for each cohort, between its intertemporal welfare in the most favorable case between the two polar recycling scenarios ($\overline{y}=0\%$ and $\overline{y}=100\%$) and its intertemporal welfare with the variable $\overline{y}_t$. The intertemporal vector of $\overline{y}_t$ is obtained through numerical convergence.

***Result 5****: In case of declining future oil prices and domestic production of oil, a desirable policy may consist of increasing gradually the fraction of the additional oil income stemming from lower domestic demand up to 100% in the future. In case of future higher oil prices and high Saudi production of oil, a desirable policy may consist in recycling the additional oil income stemming from lower domestic demand mainly through current public spending.*

In scenario B, where by assumption future oil prices on world markets keep increasing and Saudi oil production remains high, the value of $\overline{y}_t$ as defined above is 0% over the next three decades. Hence, in the admittedly relatively favorable exogenous context of scenario B, recycling the additional oil income increases public current expenditures because its effects on the welfare of current and of (most of) future cohorts would be higher on average than with higher capital spending.

**Figure 6: Optimized percentage of recycling the additional oil income through public capital spending (assuming declining future oil prices and domestic production—Scenario C)**

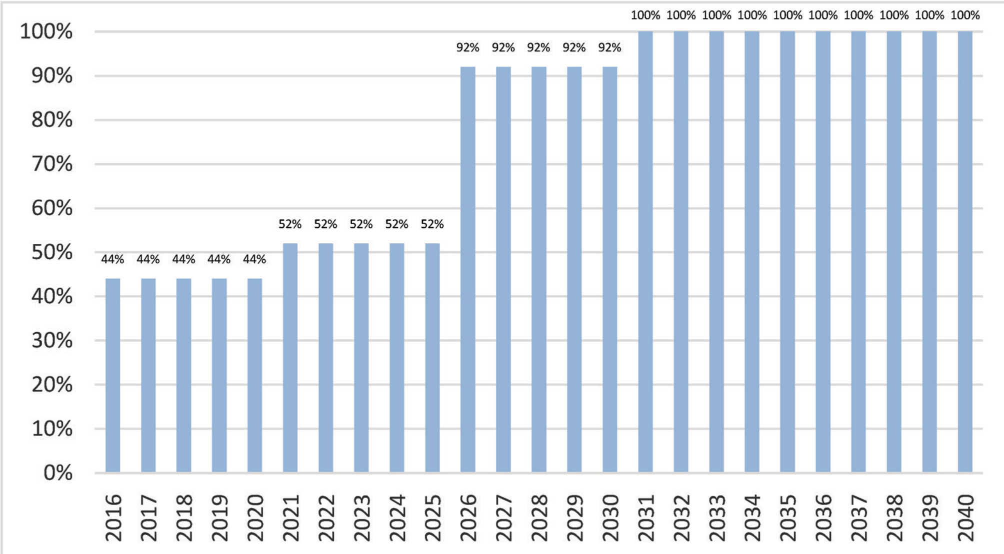



Figure 6 displays the values of $\overline{y}_t$ in scenario C, a case with lower oil prices on world markets and Saudi production. It suggests that recycling the additional oil income would favor progressively more public capital spending.

Overall, Result 5 suggests that the fraction of the additional oil income that could be recycled through higher public investment, depends very much on the expected world oil price and the level of Saudi oil production in the future. It also qualifies, more precisely, the implications of Results 1 to 3. Whatever the future context for oil prices on world markets and Saudi domestic production, the analysis here suggests that there is a rather strong case for recycling through higher current spending, a significant amount of additional oil income stemming from higher energy retail prices and the associated lower domestic energy demand—at least in the coming years. Increased public investment could balance pessimistic expectations of future oil prices and Saudi domestic production. However, Result 5 suggests that there may not be high urgency for doing so, unless public authorities decide to favor the welfare of future generations at a significant cost for current ones.

## 5. CONCLUSION

This paper investigates the intergenerational welfare impact of raising retail energy prices in Saudi Arabia—a major oil-exporting country. Like other oil-exporting countries, Saudi Arabia has started to increase the administered end-user prices for energy. Based on an OLG model specifically developed for the KSA, we show that the sizeable price increases implemented at the end of December 2015 may in fact increase the welfare and therefore benefit all current and living Saudi cohorts due to the favorable impact of oil exports for a given level of domestic production of oil. The question arises, however, as to how to recycle this additional oil income in the economy, either through public investment or through public current spending. Our analysis suggests that this choice may trigger important intergenerational redistributive effects. It is all the more relevant for the KSA's policymakers to consider this intergenerational dimension of energy policy choices as

81% of the current Saudi population is under 40 (General Authority for Statistics, 2016a). Another policy implication of the results is that, in this context, the anticipations about future oil prices significantly influence the impact of current recycling policies. More precisely, our modeling suggests that focusing exclusively on higher public investments is not an ideal policy to adopt. Progressively raising public capital expenditures may well function as a desirable mechanism, however, if the future oil income in the KSA happens to diminish over time, whether because of lower prices on world markets and/or lower domestic production mirroring lower world demand.

While our results are in line with the partial equilibrium analysis of welfare effects of price reforms (Davis, 2017), our paper confirms that the result holds in general equilibrium. More importantly, our paper provides additional insights into intergenerational redistributive effects of higher retail energy prices that are especially useful for oil-exporting countries with young and fast-growing populations. More generally, the analysis critically informs important current debates with high policy relevance. In many oil-exporting countries, retail energy prices on the domestic market are below what prices on international markets would imply—and this is an important element of a social contract in these countries. This paper argues that higher retail prices of energy—especially in the KSA—can nevertheless increase welfare for households, through lower domestic consumption and thus higher oil exports that can be redistributed in the economy.

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## REFERENCES

Alam, M.S. (1982). "The basic macro-economics of oil economies." *The Journal of Development Studies* 18(2): 205–216. https://doi.org/10.1080/00220388208421827.

Alshehry, A.S. and M. Belloumi (2015). "Energy consumption, carbon dioxide emissions and economic growth: The case of Saudi Arabia." *Renewable and Sustainable Energy Reviews* 41: 237–247. https://doi.org/10.1016/j.rser.2014.08.004.

Arrow, K.J. (1973). "Some ordinalist-utilitarian notes on Rawls Theory of Justice." *The Journal of Philosophy* 70(9): 245–263. https://doi.org/10.2307/2025006.

Auerbach, A. and Kotlikoff, L. (1987). *Dynamic fiscal policy*. Cambridge University Press.

Balke, N.S., M. Plante, and M. Yücel (2015). "Fuel Subsidies, the Oil Market and the World Economy." *The Energy Journal* 36(SP1): 99–127. https://doi.org/10.5547/01956574.36.SI1.nbal.

Bjerkholt, O. (1993). "Reviews of Macroeconomic Modeling Needs of the Ministry of Economy and Planning in the Kingdom of Saudi Arabia." Research Department, Statistics Norway, 93/25, August 1993. Available at https://www.ssb.no/a/histstat/not/not_9325.pdf

Blazquez, J., L.C. Hunt, and B. Manzano (2017). "Oil Subsidies and Renewable Energy in Saudi Arabia: A General Equilibrium Approach." *The Energy Journal* 38(SP1): 29–45. https://doi.org/10.5547/01956574.38.SI1.jbla.

Böhringer, C. and A. Löschel (2006). "Computable General Equilibrium Models for Sustainability Impact Assessment: Status Quo and Prospects." *Ecological Economics* 60(1): 49–64. https://doi.org/10.1016/j.ecolecon.2006.03.006.

Börsch-Supan, A., F. Heiss, A. Ludwig, and J. Winter (2003). "Pension Reform, Capital Markets, and the Rate of Return." *German Economic Review* 4(2): 151–181. https://doi.org/10.1111/1468-0475.00077.

Broer, D.P., E. Westerhout, and L. Bovenberg (1994). "Taxation, pensions and saving in a small open economy." *Scandinavian journal of economics* 96(3): 403–424. https://doi.org/10.2307/3440500.

Cappelen, A. and K.A. Magnussen (1996). "The Selection Model. A General Equilibrium Model for Saudi Arabia." Research Department, Statistics Norway, 96/14, June 1996. https://www.ssb.no/a/histstat/doc/doc_199614.pdf.

Carbone, J.C., R.D. Morgenstern, and R. Williams III (2012). "Carbon Taxes and Deficit Reduction." *unpublished paper*. Available at http://www.colorado.edu/Economics/seminars/SeminarArchive/Recruitment_12-13/Carbone.pdf .

Carbone, J.C., R.D. Morgenstern, R. Williams III, and D. Burtraw (2013). "Deficit Reduction and Carbon Taxes: Budgetary, Economic, and Distributional Impacts." *Resources for the Future*. Available at http://www.rff.org/files/sharepoint/WorkImages/Download/RFF-Rpt-Carbone.etal.CarbonTaxes.pdf.

Cashin, P., K. Mohaddes, M. Raissi, and M. Raissi (2014). "The differential effects of oil demand and supply shocks on the global economy." *Energy Economics* 44: 113–134. https://doi.org/10.1016/j.eneco.2014.03.014.

CDSI (2014). *Household expenditure and income survey 2013*. Central Department of Statistics and Information, Saudi Arabia. Available at https://www.stats.gov.sa/sites/default/files/household_expenditure_and_income_survey_2013.pdf .

Coopers & Lybrand (1981). *A Social Accounting Matrix for the Kingdom of Saudi Arabia 1396/97*. Ministry of Planning.

Davis, L.W. (2017). "The Environmental Cost of Global Fuel Subsidies." *The Energy Journal* 38: 7–27. https://doi.org/10.5547/01956574.38.SI1.ldav.

De Santis, R.A. (2003). "Crude oil price fluctuations and Saudi Arabia's behaviour." *Energy Economics* 25(2): 155–173. https://doi.org/10.1016/S0140-9883(02)00106-8.

ECRA (2014). *Annual report 2013*. Riyadh. Available at http://www.ecra.gov.sa/en-us/MediaCenter/DocLib2/Pages/SubCategoryList.aspx?categoryID=4.

ECRA (2015). *Annual report 2014*. Riyadh. Available at http://www.ecra.gov.sa/en-us/MediaCenter/DocLib2/Pages/SubCategoryList.aspx?categoryID=4.

Epstein, L.G. and S.E. Zin (1991). "Substitution, risk aversion and the temporal behavior of consumption and asset returns: An empirical analysis." *Journal of Political Economy* 99(2): 263–286. https://doi.org/10.1086/261750.

Espinoza, R. (2012). "Factor Accumulation and the Determinants of TFP in the GCC." Oxford Centre for the Analysis of Resource Rich Economies of University of Oxford (& IMF for Espinoza), *OxCarre Research Paper 94*. Available at https://www.oxcarre.ox.ac.uk/files/oxcarrerp201294.pdf.

Ezzati, A. (1976). "Future OPEC price and production strategies as affected by its capacity to absorb oil revenues." *European Economic Review* 8(2): 107–138. https://doi.org/10.1016/0014-2921(76)90008-8.

General Authority for Statistics (2016a). *Demography Survey*. Riyadh. Available at https://www.stats.gov.sa/sites/default/files/en-demographic-research-2016_4.pdf.

General Authority for Statistics (2016b). *Labor Force Survey—2016, 3rd quarter*. Riyadh. Available at https://www.stats.gov.sa/sites/default/files/labour_force_survey_2016_q3en.pdf.

Gonand, F. and P.-A. Jouvet (2015). "The 'second dividend' and the demographic structure." *Journal of Environmental Economics and Management* 72: 71–97. https://doi.org/10.1016/j.jeem.2015.04.007.

Glomm, G. and B. Ravikumar (1997). "Productive government expenditures and long-run growth." *Journal of Economic Dynamics and Control* 21(1): 183–204. https://doi.org/10.1016/0165-1889(95)00929-9.

Gourinchard, P.-O. and J. Parker (2002). "Consumption over the life-cycle." *Econometrica* 70(1): 47–89. https://doi.org/10.1111/1468-0262.00269.

Hogan, W. and A. Manne (1977). "Energy economy interactions: the Fable of the Elephant and the Rabbit?" in C.J. Hitch ed. (1977). "Modeling energy-economy interactions: five approaches." *Resources for the Future*, Washington.

Huppmann, D. and F. Holz (2012). "Crude oil market power—a shift in recent years?" *The Energy Journal* 33(4): 1–22. https://doi.org/10.5547/01956574.33.4.1.

IMF (2013). Saudi Arabia: Selected Issues, *IMF country report*, 13/230. Available at https://www.imf.org/external/pubs/ft/scr/2013/cr13230.pdf.

Johansen, P.R. and K.A. Magnussen (1996). "The Implementation Model. A Macroeconomic Model for Saudi Arabia." *Research Department, Statistics Norway*, 96/13, June 1996. https://www.ssb.no/a/histstat/doc/doc_199613.pdf.

John, A. and R. Pecchenino (1994). "An Overlapping Generations Models of Growth and the Environment." *The Economic Journal* 104: 1393–1410. https://doi.org/10.2307/2235455.

John, A., R. Pecchenino, D. Schimmelpfennig, and S. Schreft (1995). "Short-lived agents and the long-lived environment." *Journal of Public Economics* 58(1): 127–141. https://doi.org/10.1016/0047-2727(94)01459-2.

Jouvet, P.-A., P. Michel, and P. Pestieau (2000). "Altruism, voluntary contributions and neutrality. The case of environmental quality." *Economica* 67: 465–475. https://doi.org/10.1111/1468-0335.00220.

KGEMM (2017). “The KAPSARC Global Energy Macroeconometric Model.” King Abdullah Petroleum Studies and Research Center (KAPSARC). https://www.kapsarc.org/research/projects/the-kapsarc-global-energy-macroeconometric-model-kgemm/

Knopf, B., O. Edenhofer, C. Flachsland, M.T.J. Kok, H. Lotze-Campen, G. Luderer, A. Popp, and D.P. van Vuuren (2010). “Managing the Low-Carbon Transition—From Model Results to Policies.” *The Energy Journal* 31(1): 223–245. https://doi.org/10.5547/ISSN0195-6574-EJ-Vol31-NoSI-9.

Kotlikoff, L. and A. Spivak (1981). “The family as an incomplete annuities market.” *Journal of Political Economy* 89(2): 372–391. https://doi.org/10.1086/260970.

Leimbach, M., N. Bauer, L. Baumstark, M. Lüken, and O. Edenhofer (2010). “Technological Change and International Trade—Insights from REMIND-R.” *The Energy Journal* 31(1): 109–136. https://doi.org/10.5547/ISSN0195-6574-EJ-Vol31-NoSI-5.

Looney, R.E. (1986). “Socio-Economic Tradeoffs in Saudi Arabia’s Third Five Year Plan (1980–1985).” *Socio-Economic Planning Sciences* 20(4): 181–192. https://doi.org/10.1016/0038-0121(86)90009-1.

Looney, R.E. (1988). “Saudi Arabia’s Fiscal Options: 1986–1992.” *Socio-Economic Planning Sciences* 22(3): 109–123. https://doi.org/10.1016/0038-0121(88)90012-2.

Looney, R.E. and P.C. Frederiksen (1985). “The Evolution and Evaluation of Saudi Arabian Economic Planning.” *Journal of South Asian and Middle Eastern Studies* IX(2): 3–19.

Matar, W., F. Murphy, A. Pierru, and B. Rioux (2015). “Lowering Saudi Arabia’s fuel consumption and energy system costs without increasing end consumer prices.” *Energy Economics* 49: 558–569. https://doi.org/10.1016/j.eneco.2015.03.019.

Matar, W., F. Murphy, A. Pierru, B. Rioux, and D. Wogan (2017). “Efficient industrial energy use: The first step in transitioning Saudi Arabia’s energy mix.” *Energy Policy* 105: 80–92. https://doi.org/10.1016/j.enpol.2017.02.029.

Miles, D. (1999). “Modelling the Impact of Demographic Change Upon the Economy.” *The Economic Journal* 109(452): 1–36. https://doi.org/10.1111/1468-0297.00389.

Nakov, A. and G. Nuno (2013). “Saudi Arabia and the oil market.” *The Economic Journal* 123(573): 1333–1362. https://doi.org/10.1111/ecoj.12031.

Normandin, M. and P. St-Amour (1998). “Substitution, Risk Aversion, Taste Shocks and Equity Premia.” *Journal of Applied Econometrics* 13: 265–281. https://doi.org/10.1002/(SICI)1099-1255(199805/06)13:3<265::AID-JAE475>3.0.CO;2-Z.

Olatunji, S.O., M.S. Al-Ahmadi, M. Elshafei, and Y.A. Fallatah (2013). “Forecasting the Saudi Arabia stock prices based on artificial neural networks model.” *International Journal of Intelligent Information Systems* 2(5): 77–86. https://doi.org/10.11648/j.ijiis.20130205.12.

OECD (2015). *Pensions at a glance*. Available at http://www.oecd.org/publications/oecd-pensions-at-a-glance-19991363.htm.

OEGEM (2017). Oxford Economics Global Economic Model. http://www.oxfordeconomics.com/forecasts-and-models/countries/scenario-analysis-and-modeling/global-economic-model/overview.

Parry, I. and R.C. Williams (1999). “A second-best evaluation of eight policy instruments to reduce carbon emissions.” *Resource and Energy Economics* 21: 347–373. https://doi.org/10.1016/S0928-7655(99)00008-1.

Plante, M. (2014). “The long-run macroeconomic impacts of fuel subsidies.” *Journal of Development Economics* 107: 129–143. https://doi.org/10.1016/j.jdeveco.2013.11.008.

Platts (2015). http://www.platts.com/latest-news/natural-gas/dubai/saudi-arabia-hikes-price-of-gas-for-power-production-26323825

Rausch, S. (2013). “Fiscal consolidation and climate policy: An overlapping generations perspective.” *Energy Economics* 40: S134–S148. https://doi.org/10.1016/j.eneco.2013.09.009.

Rioja, F.K. (2001). “Growth, Welfare, and Public Infrastructure: A General Equilibrium Analysis of Latin American Economies.” *Journal of Economic Development* 26(2): 119–130.

SAMA (2016). *Annual Statistical Yearbook*. Riyadh. Available at http://www.sama.gov.sa/en-US/EconomicReports/Pages/YearlyStatistics.aspx.

Solow, R. (1974). “Intergenerational Equity and Exhaustible Resources.” *Review of Economic Studies* Special Issue, 41(128): 29–45. https://doi.org/10.2307/2296370.

Solow, R. (1978). “Resources and economic growth.” *American Economist* 22(2): 5–11. https://doi.org/10.1177/056943457802200201.

Solow, R. (1986). “On the intergenerational allocation of resources.” *Scandinavian Journal of Economics* 88: 141–149. https://doi.org/10.2307/3440280.