The impact of higher retail energy prices on intergenerational welfare in Saudi Arabia

Frédéric Gonand[a]

Fakhri Hasanov[b]

Lester C. Hunt[c]

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Abstract: This paper investigates the intergenerational welfare impact of raising retail energy prices in Saudi Arabia, 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 a Gulf region country. The model is used to analyze the effects of the administered increase in Saudi energy prices implemented in December 2015. In particular, the model analyses how these price increases might impact on 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 which 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 December 2015 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 holds even more if the future price of oil remains relatively low. In a possible future situation of declining oil prices and domestic production, a desirable policy may consist of gradually increasing the fraction of the additional oil income that is recycled through public capital spending.

JEL Codes: D58 - D63 - E62 - L7 - Q28 - Q43.

Key words: Energy prices; Saudi Arabia; overlapping generations; general equilibrium.

[a] University Paris-Dauphine, PSL Research University, LEDa-CGEMP, 75016 Paris, France; and King Abdullah Petroleum Studies And Research Center (KAPSARC) (Riyadh, Saudi Arabia) (Frederic.Gonand@dauphine.fr)

[b] King Abdullah Petroleum Studies and Research Center (KAPSARC) (Riyadh, Saudi Arabia) (fakhri.hasanov@kapsarc.org) and Institute of Control Systems, B. Vahabzade Street 9, Baku AZ1141, Azerbaijan.

[c] King Abdullah Petroleum Studies and Research Center (KAPSARC) (Riyadh, Saudi Arabia); and University of Surrey, United Kingdom; (Lester.Hunt@kapsarc.org; L.Hunt@surrey.ac.uk)

1. INTRODUCTION

In December 2015, the Saudi Arabian government raised most 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 was 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 of petroleum products 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 is that it potentially encourages energy wastage with domestic energy demand continuing to rise rapidly, thus reducing the amount of oil available for exports at a given level of oil production and a resulting loss in revenue for the government.

The rationale for raising retail energy prices at the end of 2015 is closely related to the plummeting price of oil on world markets from 2015 onwards, given that oil income accounts for 88% of Saudi public revenue (SAMA, 2016) and thus impacts on Saudi public finances. In this context, 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 improve Saudi public finances, like higher retail energy prices benefitting to the oil public sector - either through a higher turnover on the domestic market but also from more 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 effect of the different redistributions are also considered.

To achieve this, we develop a dynamic energy model with overlapping generations (called MEGIR-SA, *Model with Energy, Growth and Intergenerational Redistribution – Saudi Arabia*), which we believe is the first model of this type to be developed for a Gulf region country. MEGIR-SA builds on Gonand and Jouvet (2015) with respect to the overlapping generation (OLG) setting but is specifically adapted to reflect the characteristics of the Saudi economy. The model compares the costs of the policy (higher end-use price of energy) with its economic gains (lower oil domestic consumption from higher energy prices, thus higher oil exports, energy sector turnover and public income recycled in the economy) and computes the net effect on Saudi's intertemporal welfare.

In this context, we consider different scenarios. These depend on: a) the fraction of the increase in the future total public income – associated with domestic energy price hikes and lower domestic demand - that is recycled through higher public investments; and b) the future price of a barrel of oil on world markets along with the future Saudi domestic production of oil – which both influence the total public income associated with domestic energy price hikes and lower domestic demand. Note this produces simulations, *not* forecasts. Therefore, the results from the analysis do not suggest the most probable economic path for the KSA in the long run given current information; instead, the impact on growth and welfare in the KSA in the long run arising from the increased retail energy prices is analyzed.

We show that in the KSA, the permanent increase in end-user energy prices decided in December 2015 triggers in the model a net overall favorable effect on the intertemporal welfare of all households. We also show that the additional oil income associated with the increase in energy domestic prices tends to be more beneficial to future generations if recycled through public investment and more beneficial to currently living cohorts if recycled through current spending. We suggest that in the case of declining future oil prices and domestic production of oil, it is more desirable to increase over time the fraction of the additional oil income that is recycled through public capital spending.

The paper is therefore structured as follows. Section 2 provides some background about the issue in the literature 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 policies 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 aim at accounting for intergenerational redistributive effects while Solow (1986) suggests that it is essential to capture both intra and intergenerational effects of environmental policies and points out that intergenerational issues ought to be analyzed within OLG models. OLG models simulate the behavior of different cohorts of different age, living in the same economy at the same time. Since John and Pecchenino (1994) and John et al. (1995), an important body of literature has been developing within an OLG framework. However, most of this literature develops a theoretical framework that involves only two generations. The literature that relies on empirical dynamic general equilibrium models with numerous overlapping generations in order to analyze the effects on intergenerational equity of energy policies is scarce and relatively new. This includes Carbone et al. (2012), Carbone et al. (2013), Rausch (2013), and Gonand and Jouvet (2015) – which this paper builds upon by introducing MEGIR-SA (as explained 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 holistic full equilibrium macroeconomic models for the KSA.[1] This shows that that there is a mixture of collaborated models and econometric models, most of which have an energy component to some degree or a full energy module. Despite this, it appears that only Blazquez et al. (2017) is the only study using a macro model to

[1] Given the focus of the research here, Table 1 includes only full 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.

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

Papers	Calibrated* or econometric models	Energy content	Summary of use	Notes**
Ezzati (1976)	Dynamic intertemporal, multi-sectoral, empirical linear programing model Macroeconometric model	Oil price, production and demand	Investigates the impact of oil price and production on macroeconomic indicators.	Model is for OPEC members so includes the KSA.
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)	Input-output model and applied GE model Macroeconometric model	Includes the production, demand, and prices of energy	Investigates the impact of energy on macroeconomic indicators.	
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.	
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	No	Model is for Kuwait, Libya, Iran, Algeria, Nigeria, and the KSA.

Pissarides and Varoudakis (2007)	Economic Growth Model	Oil price	No	Model is for a group of MENA countries and includes the KSA.
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.	
OEF (2017)	Macroeconometric model	Energy sector	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 – but not *vice versa*.	
KEM (2016)	Mix Complementary Bottom Up Optimization Model	The model has sectorial energy components.	Model can investigate the impacts of energy price and demand on residential and industrial sectors such as petrochemical, refining, water desalination, cement. It is designed for sectoral purposes and hence, cannot address macroeconomic issues of the energy.	
KGEMM (2017)	Macroeconometric model	Energy sector	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 – but not vice versa.	
Blazquez et al. (2017)	DSGE model	Energy sector	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. ** Unless stated, the models are for the KSA only.

investigate explicitly the possible impact of the recent cuts in energy subsidies 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. Blazquez et al. (2017) do not however, consider the intergenerational welfare effects of the reductions in energy subsidies, considered here.

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 discussion of details the Saudi economic characteristics that the modeling of MEGIR-SA takes into account. The Annex 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. The main output of the OLG framework for Saudi private agents is an intertemporal vector of private supply of capital per efficient unit of labor at each year. 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; 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. 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. σ 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. ρ is the subjective rate of time preference. $1/\xi$ is the elasticity of substitution between consumption and leisure. χ 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). The intertemporal budget constraint is:

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

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 ε_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. 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 modelled by one aggregate tax on private agents that is proportional to their income ($\tau_{t,NA}$) because these public revenues are 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). 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.

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.

Then the total capital supplied by Saudi households is computed as $W_t = \Sigma_a(\Omega_{t,a}\mathrm{N}_{t,a,Saudis})$. It corresponds to the total capital supplied by private agents to the domestic economy. Expatriates are assumed to send all their savings abroad, a realistic assumption in Saudi Arabia. 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 at year t can be arrived at. The total income of Saudi private agents corresponds to a modeled GNP. The Annex 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 in a detailed way the dynamics of the population structure. Each cohort is characterized by its age at year t, has $\mathrm{N}_{t,a}$ 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 $\Psi_{t,0}$ ($\mathrm{a} = \Psi_{t,0} - 20$), where $\Psi_{t,0}$ stands for the average life expectancy at birth of a cohort born in year t.

The population of the KSA in 2014 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 in according jobs (Vision 2030, 2016) - 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. 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 proportion $\pi_{t,a}$ 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 ($\Upsilon_{\mathrm{oil,t}}$) expressed in billions of 2005 Saudi Riyals. For future periods, $\Upsilon_{oil,t}$ is computed as $\Upsilon_{oil,t} = \Upsilon_{oi\ ,t-1} \frac{\mathrm{EXP}_{oil,t}}{\mathrm{EXP}_{oil,t-1}} \frac{\mathrm{barrel}_{oil,t}}{\mathrm{barrel}_{oil,t-1}}$ where $\mathrm{EXP}_{oil,t}$ stands for the national exports of crude oil (in MMbbl) in year t, and $\mathrm{barrel}_{oil,t}$ is the price of a barrel of Arabian Light on world markets in year t. We neglect here the dynamics of the exports of refined oil products and consider that there will be no Saudi exports of natural gas in the future. We assume the nominal exchange rate between the US dollar and the Saudi Riyal will remain constant (as has been the case since the late 1980's).

The future price of a barrel of Arabian Light on world markets ($\mathrm{barrel}_{\ oil,t}$) is exogenous. Indeed this paper always deals with simulations, and not forecasts. It does not aim at figuring out the most probable economic path for the KSA in the long run given current information, but to analyze the main aggregate mechanisms involved in the KSA in the long run by rises in retail energy prices. Accordingly, sensitivity analysis in the paper will prominently deal with the future price of oil.

Since MEGIR-SA is a long-run model, the possible short-run impact of the level of Saudi oil exports on the international price of oil, and the short-run phenoma related with spare capacity, can be neglected. That oil supply shocks do not trigger sizeable and long lasting influence on the price of oil is in line with Kilian (2009) and Kilian and Hicks (2013).

By definition, $\mathrm{EXP}_{oil,t} = \mathrm{P}_{oil,KSA,t} - \mathrm{CONS}_{oil,t}$ where $\mathrm{P}_{oil,KSA,t}$ is the national annual production of crude oil at year t (in MMbbl) and the variable $\mathrm{CONS}_{oil,t}$ is the endogenous national consumption of oil (in MMbbl). Since the model is parameterized on KSA data, we consider that $\mathrm{P}_{oil,KSA,t}$ is set exogenously by public authorities (in MMbbl). $\mathrm{CONS}_{oil,t}$ is such that $\mathrm{CONS}_{oil,t} = \mathrm{D}_{oil,t} + \mathrm{D}_{elec,crude\ oil,t} + \mathrm{D}_{elec,refined\ oil,t}$ where $\mathrm{D}_{oil,t}$ is the national demand for oil, crude or refined, in the non power sector (in MMbbl); $\mathrm{D}_{elec,crude\ oil,t}$ the demand for crude oil in the power sector (in MMbbl), and $\mathrm{D}_{elec,refined\ oil,t}$ 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, prices and public policies (see below, Section 3.2.3.2.).

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 $\mathrm{q}_{\mathrm{energy,t}}$ *, along with the dynamics of the energy mix between different sources of energy (domestic demand for oil* $\mathrm{D}_{\mathrm{oil,t}}$*, domestic demand for natural gas* $\mathrm{D}_{\mathrm{natgas,t}}$*, and domestic demand for electricity* $\mathrm{D}_{\mathrm{elec,t}}$*).*

The **average weighted real end-use price of energy** $\mathrm{q}_{energy,t}$ is computed as an average of exogenous, regulated end-use prices of natural gas, oil products and electricity, weighted by the proportions $\mathrm{D}_{i,t-1}/\sum_i \mathrm{D}_{i,t-1}$ such as $\mathrm{q}_{energy,t} = \sum_{i=1}^{3}(\mathrm{q}_{i,t} * \mathrm{D}_{i,t-1}/\sum_i \mathrm{D}_{i,t-1})$ where $\mathrm{q}_{energy,t}$ stands for the average real weighted end-use price of energy at year t (in real 2005 SAR/MWh), $\mathrm{D}_{i,t-1}$ for the final consumption in volume for natural gas (i=1), oil products (i=2)($\mathrm{D}_{oil,t}$=$\mathrm{D}_{2,t}$) and electricity (i=3),(all in ktoe), and where $\mathrm{q}_{i,t}$ 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 ($\mathrm{q}_{i,t}$, i∈{1;2}) in turn are computed as weighted averages of regulated end-use prices of different sub categories of energy products: ∀i∈{1;2}, $\mathrm{q}_{i,t} = \sum_{j=1}^{n} \mathrm{a}_{i,j,t}\mathrm{q}_{i,j,t}$. $\mathrm{q}_{i,j,t}$ 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 th 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 does not prevent our model from being a general equilibrium model, since this only takes into account the characteristics of the Saudi economy, where general equilibrium is not always obtained through prices.

The real end-use price of electricity $\mathrm{q}_{3,t}$ is assumed to cover the costs of production of power in the KSA, i.e., there can be some implicit subsidies but no significant explicit subsidies in line with the data in ECRA (2014), for instance. We assume that price subsidies in the Saudi energy sector are on average implicit, i.e., that they do not increase public spending but rather weigh on public income because the prices are supposed to cover the domestic costs of production and transport. This assumption is in line with the long-run characteristics of the model.

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

The computation of the overall energy mix in the future (i.e., $\mathrm{D}_{natgas,t} = \mathrm{D}_{1,t}$, $\mathrm{D}_{oil,t}$=$\mathrm{D}_{2,t}$, $\mathrm{D}_{elec,t} = \mathrm{D}_{3,t}$) relies 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., $\mathrm{D}_{oil,t}$, $\mathrm{D}_{natgas,t}$ and $\mathrm{D}_{elec,t}$ -- to vary over time according to changes in the relative regulated end-use prices of their associated energy vectors, i.e., $\mathrm{q}_{1,t}$, $\mathrm{q}_{2,t}$ and $\mathrm{q}_{3,t}$. The more the relative price of one source of energy increases, the more its relative demand declines.

The mix of technologies used to produce *electricity* is exogenous in the model. This is a realistic assumption: the electricity mix is mostly and directly influenced by political decisions that may not mirror economic optima. Knowing that no official forecasts for the technology mix in the power sector in the long run exists for the KSA, we assume that any additional demand for electricity in the future will *not* be covered by power plants burning oil (but by natural gas or renewables, for instance). This idea is implicitly expressed in the KSA's the strategic document, Vision 2030 (2016).

This setting allows to derive the total domestic consumption of oil $\mathrm{CONS}_{oil,t} = \mathrm{D}_{oil,t} + \mathrm{D}_{elec,crude\ oil,t} + \mathrm{D}_{elec,refined\ oil,t}$. The Annex 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, all at each year t in the model.

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:

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

The parameter α is a weighting parameter; β 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 $\overline{\varepsilon_t} = \sum_a^{\max(a,t)} \varepsilon_a \frac{\mathrm{v}_{t,a}\mathrm{N}_{t,a}}{\mathrm{L}_t}$ links the aggregate productivity of the labor force at year t to the average age of active individuals at this year. $\mathrm{N}_{t,a}$ is the total number of individuals aged a at year t. Δ_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: $w_t = k^{\varsigma}_{KSA\,pub,t}A_t\left[\alpha\left(k_{KSA\,pub,t}\right)^{1-\frac{1}{\beta}}+1-\alpha\right]^{\frac{1}{\beta-1}}[1-\alpha]$.

These equilibrium relationships show the influence of the stock of public infrastructures $k_{KSA\,pub,t}$ on the income of private agents (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:

$$Y_t = [a(B_tE_t)^{\gamma_{en}} + (1-\alpha)[C_t]^{\gamma_{en}}]^{\frac{1}{\gamma_{en}}}$$

where a is a weighting parameter, γ_{en} is related to the elasticity of substitution between factors of production (C_t) and energy (with γ_{en} =1-1/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 $\min_{E_t,C_t} q_tB_tE_t + p_{C_t}C_t$ under the constraint $Y_t^{\gamma_{en}} = a(B_tE_t)^{\gamma_{en}} + (1-\alpha)[C_t]^{\gamma_{en}}$.

In the latter objective function, q_t refers to the price of energy services, these services being measured by B_tE_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: $q_t = B_tq_{energy,t}$. 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: $E_t = q_t^{\frac{1}{\gamma_{en}-1}}a^{\frac{-1}{\gamma_{en}-1}}C_t/\left(p_{C_t}^{\frac{1}{\gamma_{en}-1}}(1-a)^{\frac{-1}{\gamma_{en}-1}}\right)$. It can be checked that when C_t increases, the demand (in volume) for energy E_t rises. When the price of energy services $q_t = B_tq_{energy,t}$ 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 writes: $\Upsilon_{oil,t} + \Upsilon_{others,t} = \Theta_{current,t} + \Theta_{capital,t}$. For future periods, $\Upsilon_{oil,t}$ is computed as $\Upsilon_{oil,t} = \Upsilon_{oil,t-1}\frac{\mathrm{EXP}_{oil,t}}{\mathrm{EXP}_{oil,t-1}}\frac{\mathrm{barrel}_{oil,t}}{\mathrm{barrel}_{oil,t-1}}$ as explained in section 3.2.2.1. above. By definition, $\mathrm{EXP}_{oil,t} = \mathrm{P}_{oil,KSA,t} - \mathrm{CONS}_{oil,t}$ where $\mathrm{P}_{oil,KSA,t}$ is the national annual production of crude oil (in MMbbl). $\mathrm{CONS}_{oil,t}$ is the endogenous national consumption of oil (in MMbbl)(crude or refined products), such as $\mathrm{CONS}_{oil,t} = \mathrm{D}_{oil,t} + \mathrm{D}_{elec,crude\ oil,t} + \mathrm{D}_{elec,refined\ oil,t}$. It depends notably on the retail price of oil products $(q_{2,t})$ through $\mathrm{D}_{oil,t}$. The Annex provides the formula for $\mathrm{D}_{oil,t}$.[2]

The other public revenues ($\Upsilon_{othe\quad,t}$)(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. The Annex 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 are 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 of public services. Each Saudi private agent receives public transfers, with a variable $\mathrm{d}_{t,NA}$ 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

[2] 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 $\mathrm{D}_{elec,crude\ oil,t}$ and $\mathrm{D}_{elec,refined\ oil,t}$ are constant in the future.

assumed to benefit to foreign investors/lenders only (and not to Saudi agents). The duration of the consolidation period 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. Indeed, new public investments are assumed to finance the purchases of intermediate consumptions used to build infrastructures, wages and shareholders - and thus raise the income of Saudi agents (see Annex for more precisions). 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. The Annex 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 energy prices influence the income and welfare of private Saudi agents through different channels:

- a direct increase in energy expenditures $d_{t,energy}(E_t)$ weighing on the private net income;
- an indirect rise in Saudi public income $\Upsilon_{oil,t}\left(\mathrm{E}_t(q_{energy,t})\right)$ 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 $\Upsilon_{others,t}\left(q_{energy,t}\right)$.

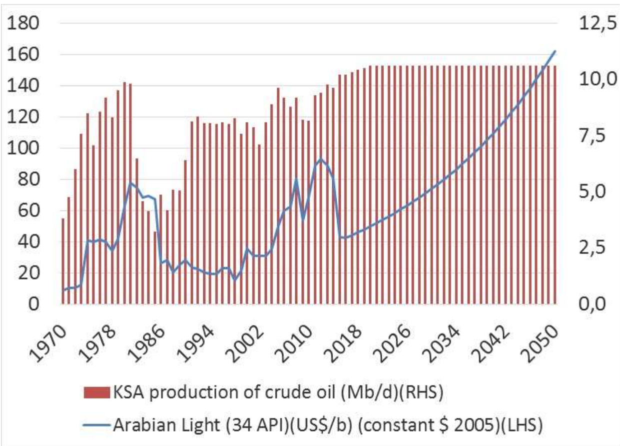
The two latter effects can be redistributed by public authorities to the Saudi private agents either through higher current public spending ($\Theta_{current,t}$) or public investments ($\Theta_{capital,t}$).

We define $Publinc_t = \{\Upsilon_{oil,t,ref} + \Upsilon_{other\ ,t,ref} - \Upsilon_{oil,t,noref} - \Upsilon_{other\ ,t,noref}\} > 0$ 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 $\bar{y}$ 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:

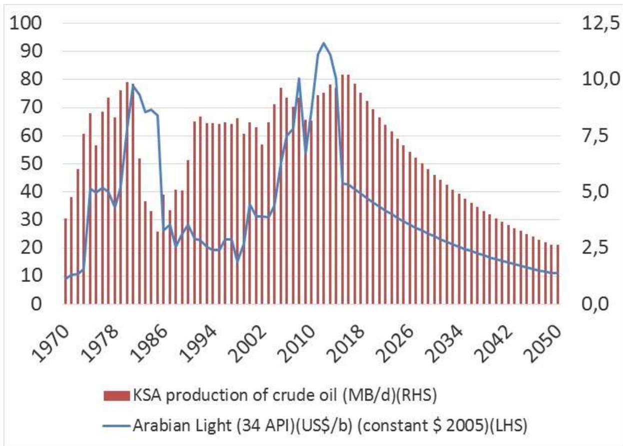
- The *future paths for the Saudi oil sector* depend on the value of the price of a barrel of oil (Arabian light) on world markets in the future ($\mathrm{barrel}_{oil,t}$) and the future level of Saudi production of oil. We distinguish two polar simulations (see Figure 1):
    - *Future oil income increasing and future oil production stable (Scenarios B, i.e., scenario B_0 and scenario B_{100}, see Table 2):* the simulated value of $\mathrm{barrel}_{oil,t}$ increases by 4% per annum and reaches US$188/bbl in 2050. This could be seen as a simulated proxy of a Hotelling rule. 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).

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

Scenarios B (*i.e., scenario B_0 and scenario B_{100}*)



Scenarios C (*i.e., scenario C_0 and scenario C_{100}*)



- - *Future oil income and oil production declining (Scenarios C, i.e., scenario C_0 and scenario C_{100}, see Table 2):* the real future price of oil (Arabian light), and the Saudi level of oil production, are assumed to diminish by 4% per annum up to 2050, before stabilizing. This refer to an admittedly pessimistic – though not unrealistic by Saudi standards – 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 agents changed during the 2010's, 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 $\bar{y}$).[3] We distinguish two polar simulations here: either 0% or 100%.[4] 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 ($\bar{y} = 0\%$). Scenario B_{100} is the same as B_0 except that the additional public income is recycled through higher public capital expenditures ($\bar{y} = 100\%$). The same applies to scenario C_0 and scenario C_{100} as shown in Table 2.

Table 2: Reform scenarios in the model

	$\bar{y}$	
	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}

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.[5]

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 to compare two scenarios where the only difference is the level of the variable or policy. Accordingly, results for Scenario B_0 (resp.

[3] 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.

[4] 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: $\frac{\Theta_{current,t}}{Y_{oil,t}+Y_{others,t}} = \frac{\Theta_{current,t-1}}{Y_{oil,t-1}+Y_{oth\quad,t-1}}$, $\forall t \geq 2026$. 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 $\bar{y}$.

[5] This path is for instance close to what was forecasted by Oxford Economics in 2015 up to 2040. After 2050, we assume that the price of oil stabilizes at 195US$/bbl.

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 in Scenario A.

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 KSA's Vision 2030 (2016). 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.

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.

Incidentally, once the model has converged to its intertemporal general equilibrium, the average weighted retail price $\left(q_{energy,t}\right)$ 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% an 18%, depending on the way the additional oil income is recycled in the economy.

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 assumption (see Figure 3). The Annex details 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 1 and 2 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, raise 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, Saudis private agents keeps paying oil products below the price that would be involved by prices of fossil fuels on world markets.

Figure 1: 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)

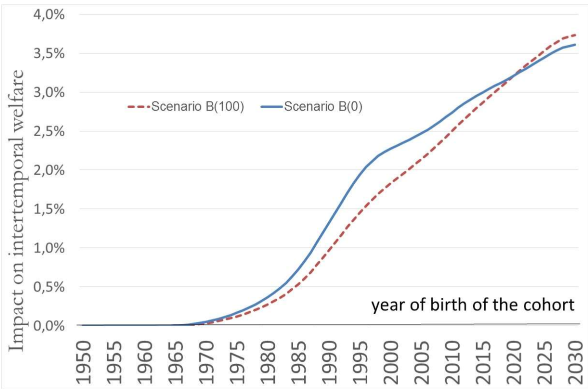
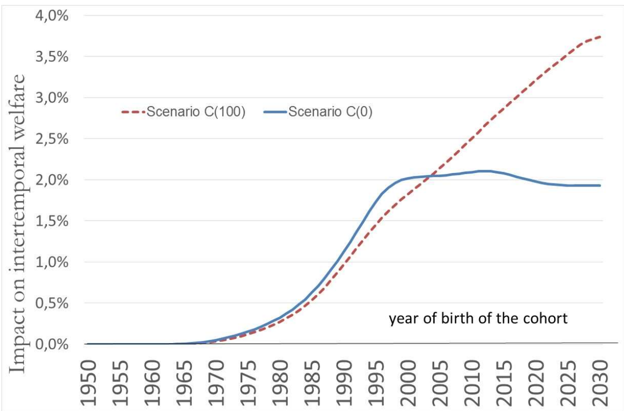


Figure 2: Impact on the intertemporal welfare of Saudi cohorts of higher retail energy prices (with lower future oil prices and production, and immediate recycling of the additional oil income)



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 medium-long run in the aggregate production function. Figure 1 and 2 show that, for a 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. For less favourable 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 consumption profile in the future. Private capital accelerates. Since higher public investment bolsters the productivity of private capital and labor, the less favorable the prospects for the KSA's oil income in the future and the more public investments will bolster welfare in relative terms.

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

Table 3 provides some robustness checks of the results depending on the values for a set of exogenous parameters in the model. As can be checked, the dynamics of the model is 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, or the parameter of the preference for leisure relative to consumption. Assuming also a shorter period of time for the fiscal consolidation implemented from the mid-2010's on (five years instead of 10 years as assumed here) would also not modify sizably over results.

The dynamics of the model is, 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.

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

Difference of intertemporal welfare in scenario B(0) (in %)	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 *(instead of 0,25)*	0,00%	0,05%	1,22%	3,37%
Capital share in value added equal to 20% *(instead of 30%)*	0,00%	0,05%	1,23%	3,16%
Capital share in value added equal to 40% *(instead of 30%)*	0,00%	0,05%	1,42%	4,12%
Intertemporal elasticity of substitution equal to 1,01 *(instead of 1,33)*	0,00%	0,04%	1,34%	3,62%
Elasticity of substitution capital/labour equal to 1,3 *(instead of 0,8)*	0,00%	0,05%	1,32%	3,63%
Parameter associated with the public stock of capital in the production function equal to 0,075 *(instead of 0,15)*	0,00%	0,05%	1,28%	3,47%
Elasticity of substitution capital-labour / energy equal to 0,2 *(instead of 0,4)*	0,00%	0,04%	1,06%	2,70%
Psychological discount rate equal to 1% *(instead of 2%)*	0,00%	0,05%	1,34%	3,59%
Length of fiscal consolidation equal to 5 years (*instead of 10 years*)	0,00%	0,05%	1,34%	3,58%

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 3 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 2020's only). Results are presented for scenarios C_0 and C_{100} for illustrative purpose (using B_{100} and B_0 would deliver 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 relatively downward 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 2020's.

Figure 3: Sensitivity analysis (with additional oil income fully used to accelerate the reduction of the public deficit during the fiscal consolidation period up to the 2020's)

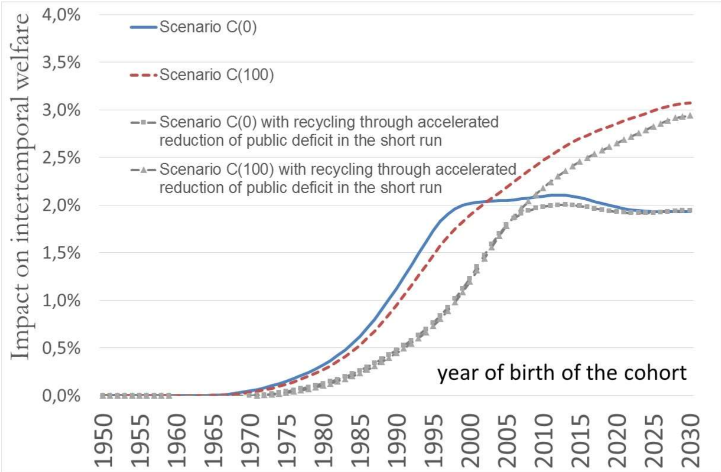
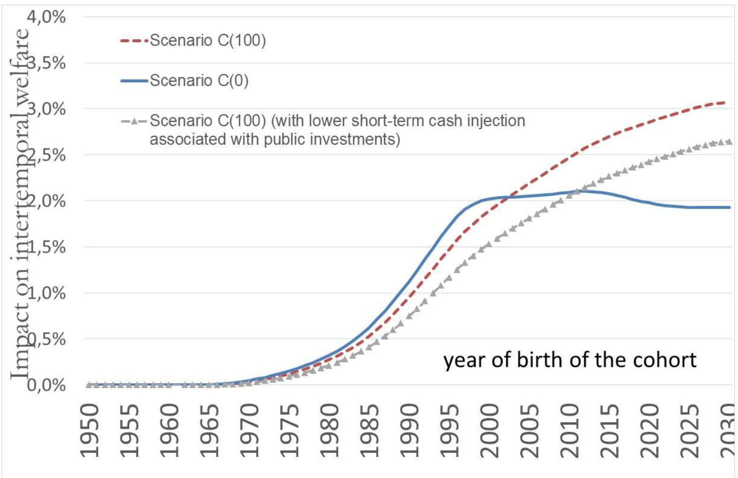


Figure 4 shows the impact of a lower assumption as concerns the short term cash injection associated with public investments (i.e., instead of our standard assumption of 70%, we use 50% here, an order of magnitude that would be reached if only one third of intermediate consumptions used in public investments were produced domestically). Results are presented for scenario C_{100} for illustrative purpose (using B_{100} would deliver similar outcomes). It is no surprise that in this context the positive impact of recycling through higher public investments is lower for each current and future generation. However, in the long run, future generations remain better off with recycling through higher public investments, as in result 2.

Figure 4: Sensitivity analysis (with lower short term cash injection associated with public investments)



So far, results suggest that setting the value of $\bar{y}$, the fraction of the additional public oil income recycled through capital expenditures, may imply a trade-off between the welfare of current cohorts and future generations, between short-term growth and long-run activity. In this context, a possible choice consists in changing the value of $\bar{y}$ 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 $\bar{y}^*$ as an intertemporal vector of $\bar{y}_t$'s changing every five years such as:

$$\min_{\bar{y}_t}\left[\sum_{i\epsilon[1950;2030]}\left|\max\left(W_{intertemp,i,\bar{y}=0\%};W_{intertemp,i,\bar{y}=10\ \%}\right)-W_{intertemp,i,\bar{y}_t\epsilon[0\%;100\%]}\right|\right]$$

where $W_{intertemp,i,\bar{y}=0\%}$ stands for the intertemporal welfare of the cohort born at year i and in a scenario with $\bar{y}=0\%$. With such a framework, the values of $\bar{y}_t$ 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 ($\bar{y}=0\%$ and $\bar{y}=100\%$) and its intertemporal welfare with the variable $\bar{y}_t$. The intertemporal vector of $\bar{y}_t$ is obtained through numerical convergence.

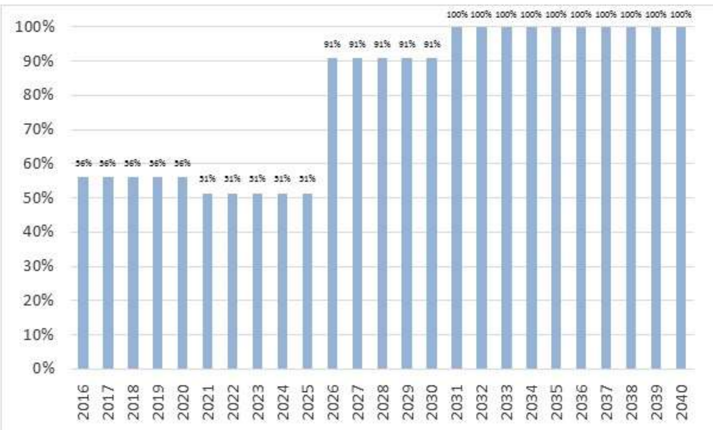
Result 5*: In case of declining future oil prices and domestic production of oil, a desirable policy may consists of increasing gradually the fraction of the additional oil income stemming from lower domestic demand up to 100% in the future. In case of future higher oil prices and high Saudi production of oil, a desirable policy may consists 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 $\bar{y}_t$ as defined above is 0% over the next decades. Hence, in the admittedly relatively favorable exogenous context of scenario B, recycling the additional oil income should always favor increasing 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 5 displays the values of $\bar{y}_t$ in scenario C, a case with lower oil prices on world markets and Saudi production. It suggests that recycling the additional oil income should favor progressively more and more public capital spending, while public current spending should not be neglected in the short run.

Overall, Result 5 suggests that the fraction of the additional oil income, which should be recycled through higher public investments, 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. The more pessimistic the current expectations about the future context for oil prices on world markets and Saudi domestic production, the higher the efforts in the future should concentrate on public investments. 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.

Figure 5: Optimized percentage of recycling the additional oil income through public capital spending (assuming declining future oil prices and domestic production – Scenario C)



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 recently increased the administered end-user prices for energy. We show that the sizeable price increase implemented in Saudi Arabia at the end of December 2015 may in fact increase the welfare and therefore benefit all current and living cohorts, thanks to the favorable impact of oil exports for a given level of domestic production of oil. The questions 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 Saudi Arabia given that currently 81% of the population are 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 definition on current recycling policies. More precisely, focusing exclusively on higher public investments never appears to be an accurate policy idea in our model. Progressively raising public capital expenditures may well function as a desirable mechanism, however, if the future oil income in the Kingdom of Saudi Arabia happens to diminish over time, whether because of lower prices on world markets and/or lower domestic production mirroring lower world demand.

More generally, this article sheds light on some 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. Therefore, it is noteworthy to the policymakers – in this case, in the KSA – to have evidence to show that current price changes increase welfare. While this is in line with the partial equilibrium analysis of welfare of price reforms (Davis, 2017), our paper confirms that the result holds in general equilibrium and provides with additional insights as concerns intergenerational redistributive effects of higher retail energy prices, that are especially useful for oil-exporting countries with young and fast growing populations.

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ANNEX

(*note to the Editor: we suggest this annex should be on-line only)*

The model used here does not account explicitly for effects stemming from the external side of the economy. Accounting for external linkages would smooth the impact of a shock on the Saudi economy, but only to a limited extent in the long run. Home bias in investment -- described as the Feldstein-Horioka puzzle -- financial systemic risk and the fact that many countries in the world have aging populations and are thus competing for the same limited pool of capital all suggest, for instance, that the possible overestimation of the impact of aging on capital markets due to the assumption of a closed economy is small. And given that MEGIR-SA is a simulation model for the very long run, at that horizon the Feldstein-Horioka puzzle may hold robustly true. As far as we know, no empirical GE-OLG model with an external sector has been developed up to now, probably because introducing the external side of the economy would add a new dimension of complexity to an already detailed modeling.

OLG framework

A feature of our OLG is that it allows for taking account of a rebound effect resulting from higher energy efficiency. Indeed, a rise in energy efficiency (B_t, see below) weighs on the total demand for energy (E_t), all else being equal, thus on $d_{t,energy}$, and consequently triggers an upward effect on $y_{t,a}$ and also on aggregate income, which in turn feeds into a higher E_t. The net effect on E_t is endogenously computed by the model through the numerical convergence when computing the intertemporal general equilibrium.

Another property of this OLG framework is that it can model the aggregate effects of a progressive Saudization of the labor market. Saudization in this setting triggers a boost to the stock of non-oil private capital per unit of efficient labor. Saudization leads to more capital accumulation, since the savings of natives are kept in the domestic economy and benefit it. Expatriates are assumed not to participate in the accumulation of capital in the KSA.

The OLG framework abstracts from heterogeneity *within* cohorts. GE-OLG models in general concentrate on intergenerational redistribution, because this is their focus, and less on intragenerational redistribution – which is better analyzed, for example, using dynamic microsimulations.

Justification of the introduction of parameter H_j in the private agents' utility function: with total factor productivity gains and a Harrod-neutral technological progress, the optimal level of consumption increases over time. Without parameter H_j, the contribution of consumption to the instantaneous utility would be all the higher as the individual would be older and/or born further in the future. To cope with this problem, Auerbach and Kotlikoff (1987) consider that the only solution is to use a parameter of relative preference for leisure that changes over time, i.e., increases with age at the rate of the technological progress. This is done here by using such H_j parameter, which allows for stabilizing the relative contributions to utility of consumption and leisure over time in a context of a strictly positive technological progress. This setting can be traced back to Broer et al. (1994). On the problems arising with intertemporal utilities and technological progress, see Arrow (1973).

As concerns the parameter ε_a which links the age of a cohort to its productivity, we use a quadratic function: $\varepsilon_a(a) = exp^{0.05(\mathrm{a}+20)-0.0006(\mathrm{a}+20)^2}$ (Miles, 1999).

The energy expenditures paid by one Saudi individual $d_{t,energy}$ is such that $d_{t,energy} = C_{en}\frac{\sum_a(w_t\varepsilon_a \mathrm{v}_{t,a}\mathrm{N}_{t,a}+\Phi_{t,a}\pi_{t,a}\mathrm{N}_{t,a})}{\sum_a \mathrm{N}_{t,a}}\frac{\mathrm{q}_{energy,t}\mathrm{E}_t}{\mathrm{A}_t}$ where $(w_t\varepsilon_a \mathrm{v}_{t,a}\mathrm{N}_{t,a} + \Phi_{t,a}\pi_{t,a}\mathrm{N}_{t,a})$ is the aggregate tax base, C_{en} is a constant of calibration and $\frac{\mathrm{q}_{energy,t}\mathrm{E}_t}{\mathrm{A}_t}$ captures the dynamics of energy expenditures for one efficient unit of labor. Here the formula uses $\mathrm{N}_{t,a}$, i.e., the total population, Saudi or expatriates, because the domestic consumption of energy in Saudi Arabia mirrors the energy consumption of Saudis and expatriates as well. Data from CDSI (2014) suggest that the fraction of consumption devoted to energy is the same for Saudis and for expatriates on average.

The model only deals with the effects of the public finances and the productivity of labor and capital for Saudi households and their welfare. In the model, non-Saudis only provide their labor force in the production function (the labor force in the production function includes Saudis and non-Saudis as well). It is assumed that non-Saudis send all their savings abroad and accordingly do not contribute, at least significantly, to the accumulation of productive capital in the KSA. This is rather in line with the specificities of the contact of Saudi Arabia. It is assumed that remittances sent back to the KSA by Saudis living in foreign countries are negligible at the aggregate scale.

Energy module

In MEGIR-SA, there are fewer items in the energy mix of GCC countries than in Gonand and Jouvet (2015) for western countries. The model encapsulates demand for crude oil, refined products, natural gas and electricity, but not for coal, hydro, photovoltaics, nuclear, biomass, or wind. We disregard KSA consumption of coal in this version of the model because the Kingdom consumed only 7 ktoe of coal in 2012.

The $\mathrm{a}_{i,j,t}$ weighting coefficients used to compute the weighted energy prices ($\mathrm{q}_{i,t}$) are computed using observable data of demand from past periods. For future periods, they are frozen at their level in the latest published data available: whereas the model takes account of interfuel substitution effects (see below), it does not model possible substitution effects between sub-categories of energy products, for which data about elasticities are not easily available.

Since end-user prices of energy are set by the government, this version of MEGIR-SA does not model -- as Gonand and Jouvet (2015) do -- the real supply price at year t of the product j of energy i, or the cost of transport and distribution and/or refinery for the different energy products for natural gas and oil, or the taxes paid by an end-user of a product j of energy i at year t, the more so since there are no such taxes in the KSA.

Regulated prices of electricity: as from 2000 -- when a specific royal decree was signed -- we use a calibration procedure, because the tariffs become progressive and we lacked some precise data about the structure of consumption for households. In this context, we rely on the dynamics of the tariffs for households consuming close to 1.8 MWh/month. To obtain a realistic level for the average price of electricity for households over the last 15 years, we multiply this tariff by a constant of calibration to obtain an average price received by the power suppliers of SAR 0.141/kWh, which is as listed in ECRA (2014).

Derivation of the energy mix between oil, natural gas and electricity: using a CES function and knowing the levels of $\mathrm{D}_{non\ elec,t-1}$, $\mathrm{D}_{elec,t-1}$, of the endogenous annual variations of E_t, provided by the general production function of the economy, along with the retail energy prices $\mathrm{q}_{i,t}$'s and the exogenous elasticity of substitution between $\mathrm{D}_{non\ elec,t}$ and $\mathrm{D}_{elec,t}$, the variables $\mathrm{D}_{non\ elec,t}$

and $\mathrm{D}_{elec,t}$ can be derived. This operation is iterated for each year over the whole period of simulation of the model to obtain all $\mathrm{D}_{non\ elec,t}$'s and $\mathrm{D}_{elec,t}$'s for future years. The method is then used to split, at any year in the future, each $\mathrm{D}_{non\ elec,t}$ into $\mathrm{D}_{oil,t}$ and $\mathrm{D}_{natgas,t}$.

Formally, one derives the demand for electricity as: $\mathrm{D}_{elec,t} = \mathrm{E}_t - \mathrm{D}_{non\ elec,t}$

with $\mathrm{D}_{non\ elec,t} = \mathrm{D}_{non\ elec,t-1}\left\{\left[\frac{\mathrm{E}_t}{\mathrm{E}_{t-1}}\right] - elast_{subst\ elec,non\ elec}\left(\frac{\Xi_t}{\Xi_{t-1}} - \frac{1+\Xi_t}{1+\Xi_{t-1}}\right)\right\}$ with $\Xi_t = \frac{\mathrm{D}_{elec,t-1}}{\mathrm{D}_{non\ elec,t-1}}\frac{\mathrm{q}_{non\ elec,t}}{\mathrm{q}_{3,t}}$ where $\mathrm{q}_{non\ elec,t}$ is the average weighted price of non electric energy in the KSA (i.e., the average weighted price of oil products and natural gas). Then $\mathrm{D}_{non\ elec,t} = \mathrm{D}_{oil,t} + \mathrm{D}_{nat\ gas,t}$

with the recursive formula $\mathrm{D}_{oil,t} = \mathrm{D}_{oil,t-1}\left\{\left[\frac{\mathrm{D}_{non\ elec,t}}{\mathrm{D}_{non\ elec,t-1}}\right] - elast_{subst\ oil,nat\ gas}\left(\frac{\mathrm{X}_t}{\mathrm{X}_{t-1}} - \frac{1+\mathrm{X}_t}{1+\mathrm{X}_{t-1}}\right)\right\}$ where $\mathrm{X}_t = \frac{\mathrm{D}_{nat\ gas,t-1}}{\mathrm{D}_{oil,t-1}}\frac{\mathrm{q}_{2,t}}{\mathrm{q}_{1,t}}$ and $\mathrm{q}_{2,t}$ is the end-use price of oil products and $\mathrm{q}_{1,t}$ is the end-use price of natural gas in the KSA.

In such a framework, the dynamics of the energy mix depends largely on the changes in the relative prices of oil, natural gas and electricity. The more the relative price of one source of energy increases, the more its relative demand declines.

We assume that the structure of production of electricity from oil, crude or refined products, remains constant in the future. Then $\mathrm{D}_{elec,crude\ oil,t} = \mathrm{D}_{elec,crude\ oil,t-1} * \frac{\mathrm{D}_{elec,t}/\mathrm{D}_{elec,t-1}}{\mathrm{Eff}_{el,2,t,therm}/\mathrm{Eff}_{el,2,t-1,therm}}$, where $\mathrm{Eff}_{el,2,t,ther}$ stands for the thermal efficiency, in percent, of producing power from oil. Thus defined, the demand for oil in the power sector is influenced by the level of activity in the country, through $\mathrm{D}_{elec,t}$ or through any other variable that modifies the intertemporal general equilibrium of model, such as demographics, policies, etc. The overall energy efficiency index, the total demand for energy and the elasticity of substitution between physical capital and energy are dealt with in the section covering the production function.

Production function

In the expression of C_t, Δ_t corresponds to the average optimal working time in t. 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 optimal total flow of efficient labor in a year t -- i.e., the optimal total labor supply brought by Saudis and expatriates. The Saudi labor supply is partially endogenous, insofar as Δ_t is endogenous.

As mentioned in the section on the model's energy module, the variable E_t is the main input for a nest of CES functions allowing for computing the relative importance in the future of each component of the energy mix -- i.e., $\mathrm{D}_{oil,t}$, $\mathrm{D}_{natgas,t}$ and $\mathrm{D}_{elec,t}$, depending on changes in their relative prices (computing using the $q_{x,t}$'s) and exogenous public policy for some renewables. Thus the energy mix derives, through the total energy demand, from total activity in general equilibrium and from changes in energy prices which trigger changes in the relative demands for oil, natural gas, coal, electricity and renewables. Accordingly, the modeling allows for a) energy prices to influence the total demand for energy, and b) the total energy demand, along with energy prices, to define in turn the demand for different energy vectors.

Saudi public finances

The other public revenues ($\Upsilon_{others,t}$)(in real terms) are computed for future periods according to the formula:

$$\begin{cases} \forall t > 2016;\ \Upsilon_{othe\quad,t} = \Upsilon_{others,t-1} \frac{A_t \overline{\varepsilon_t} \Delta_t L_t}{A_{t-1} \overline{\varepsilon_{t-1}} \Delta_{t-1} L_{t-1}} \\ \Upsilon_{othe\quad,2016} = \Upsilon_{others,2015} \frac{A_{2016} \overline{\varepsilon_{2016}} \Delta_{2016} L_{2016}}{A_{2015} \overline{\varepsilon_{2015}} \Delta_{2015} L_{2015}} + \sum_{i=1}^{3} ([(\mathrm{q}_{i,2016} - \mathrm{q}_{i,2015}) * \mathrm{D}_{i,2016}]) \end{cases}$$

where $A_t \overline{\varepsilon_t} \Delta_t L_t$ is the total efficient labor force and $\sum_{i=1}^{3} ([(\mathrm{q}_{i,2016} - \mathrm{q}_{i,2015}) * \mathrm{D}_{i,2016}])$ is the initial, permanent surplus of public income in real terms which stems from the one-off permanent increase in retail Saudi energy prices as decided in 2016, that benefits the public energy sector and feeds into the "other revenues" ($\Upsilon_{othe\quad,t}$) of the Saudi government.

This model delivers simulations over several decades into the future, during which the populations of the GCC countries will probably experience aging. This will impact the financial situation of public PAYG schemes. The model takes this phenomenon into account by modeling a PAYG system that is financed by social contributions $\tau_{t,P}$ that are proportional to gross labor income $w_j \varepsilon_j$. The full pension $\Phi_{t+j,j}$ is itself proportional to past labor income, depends on the age of the individual and on the age at which an individual is entitled to obtain a full pension. The pension of the average representative individual is flat over time -- i.e., not wage indexed -- but is adjusted each year by the change in the number of pensioners in each cohort. In all scenarios, the future imbalances of the PAYG regime, caused by demographic aging, are covered by a rise in $\tau_{t,P}$.

Parameterization

Oil and energy sector: unless otherwise stated, the domestic production of crude oil $\mathrm{P}_{oil,KSA,t}$ is set exogenously in the model by authorities close to its current level, i.e., 10.6 MMbbl/d in the future.

The elasticity of substitution between oil and natural gas is 0.3 in the model. For future periods, we assume that the USD/SAR exchange rate remains constant at its current levels. The thermal efficiency of producing electricity from fossil fuels is constant at 35 percent.

Demographics: all matrices are first computed with five-year age groups, then linearly interpolated to obtain annual data. Total population data come from the World Bank. For the labor force projection, our research uses participation rates by age group as computed by the International Labor Organization. We checked that this method of computing is compatible with data provided by the World Bank relating to the KSA labor force. In figures for the employed population, we use employment rates by age group provided by the International Labor Organization. We checked that this method of computing is compatible with data provided by the IMF relating to the employed population in the KSA. The structure of each matrix by age group is assumed to remain constant after 2050, with only the levels increasing at a rate set at +2 %%every five years -- i.e., close to +0.4 %%per year after 2050, slightly above demographic growth rates currently experienced by most western countries.

OLG framework/households' program: the households' psychological discount rate ρ is set at 2 %per annum, in line with much of the empirical literature (Gourinchas and Parker, 2002). Parameter χ -- the preference for leisure relative to consumption -- is set to 0.25, in line with empirical literature. The elasticity of substitution between consumption and leisure in the instantaneous utility function ($1/\xi$) is equal to 1, so as to avoid a temporal trend in the conditions for the optimal working time (see Auerbach and Kotlikoff, 1987, p.35). The risk aversion parameter σ in the CRRA utility function is assumed equal to 1.33, implying an intertemporal substitution elasticity of 0.75. A standard result in financial and behavioral economics is to consider this parameter as greater than unity (cf. Kotlikoff and Spivak, 1981). Kotlikoff and Spivak (1981) use 1.33. Epstein and Zin (1991) suggest values between 0.8 and 1.3 while Normandin and Saint-Amour (1998) use 1.5.

Production function: the elasticity of substitution between capital and labor is set at 0.8. A wide but still inconclusive body of empirical literature has attempted to estimate the elasticity of substitution between capital and labor in the CES production function. On average, these studies suggest a value close to unity.

The elasticity of substitution between energy and capital (γ_{en}) is 0.4. Hogan and Manne (1977) have suggested that the elasticity of substitution between energy and capital in a CES function could be proxied by the price elasticity of energy demand, which is easier to assess. It is generally agreed that physical capital and energy can be partial substitutes, especially in the long run.

The weighting parameter (a) in the CES production function with energy is set at 0.1. In the CES nest, Y_t refers to aggregate production in volume, and thus takes account of intermediate consumption (here, B_t). Accordingly, the weighting parameter (a) should not be computed as the share of the value added of the energy sector in GDP but, preferably, as the share of intermediate consumption in energy items, as a fraction of private non-oil GDP. In developed countries, this yields around 10 percent, a figure relatively stable over time.

The weighting parameter α in the K-L production function is set at 0.3. In models incorporating a depreciation rate (Börsch-Supan et al., 2003), the value for this parameter is usually higher, e.g., 0.4, corresponding approximately to the ratio -- gross operating surplus/value added including depreciation -- in the business sector. Assuming this figure of 0.4 and a standard depreciation rate as a percentage of added value of 15 % yields a net profit ratio of around 0.3, this is close to Miles (1999) where 0.25 is used.

For annual gains of labor augmenting technical change in the non-oil sector, we use -0.4 %per year from 1990 until 2010, in line with IMF (2013) and Espinoza (2012). From 2010 onwards, we assume a value of +1.0 %per year. Other assumptions relating to future gains of labor augmenting technical change would not greatly affect our policy conclusions, since our results rely on differences between scenarios using the same assumptions for A_t, thus offsetting the impacts on the levels of the variables of different values of A_t. For energy efficiency parameter B_t, we rely on a decomposition of GDP produced by KAPSARC, which suggests that average annual energy efficiency gains over past decades were slightly negative, at -0.2 percent.

Over past periods, we compute the stock of non-oil private and public capital using SAMA data on gross fixed capital formation and then use the perpetual inventory method to derive stocks of capital. The base year of the model corresponds to 2000, when the output gap in the KSA was close to 0 (IMF, 2013). The parameter ς that is associated with the public stock of capital in the production function is set at 0.15 in line with Glomm and Ravikumar (1997).

Public finances: the impact of new, higher public capital investments ($\Theta_{capital,t}$) on the income of the Saudi private agents (through the variable $d_{t,NA}$) depends notably on the proportion of Saudis among the employed population in the construction sector, and the degree of diversification of the Saudi economy, as explained in the main text. In this dynamic GE-OLG model which by construction has no input-output matrix, we use a proxy to assess this impact (and do some sensitivity analysis in the model on that parameter). On average, the intermediate consumptions typically represent 60 %of the total turnover of the construction sector. The rest is shared between workers and providers of capital. Assuming that one third of the intermediate consumptions of the construction sector are not produced by Saudi agents, that the shareholders of the construction sector in the KSA are all Saudis and that half of the workers in the construction sector are non-Saudis, yields a cash effect for Saudi private agents from public investments of around 70% of the current amount of the public capital spending.

The average effective age of retirement is set at 61 years. The level of the average replacement rate is computed as the ratio of pensions received per capita over gross wages received per capita. It is set at 100 %on Saudi data (OECD, 2015).

Calibration and numerical convergence of the model: as in Gonand and Jouvet (2015), and contrary to other studies, the model is not calibrated on some technical parameters -- e.g., relative aversion to risk -- so as to produce broadly observed variations in the stock of capital around the base year. This procedure can bias the results. MEGIR-SA is calibrated on a real average cost of capital in the base year 2000 (r_{2000}) set at 6 percent. This level incorporates -- as suggested by the life cycle theory -- gains of labor augmenting technical change, discount rate, a spread mirroring risk on capital markets, and also the fact that it is higher in relatively low capital intensive emerging countries than in well capitalized, developed countries. (Gonand and Jouvet (2015) calibrate their OLG-GE model on French and German data on 6 percent). It fits well with the KSA data relating to the stock of private non-oil capital over the last 15 years.

The model is built exclusively on real data: the price of the good produced out of physical capital and labor p_{C_t} is constant and normalized to 1. The intertemporal equilibrium of the model is dynamic: modifying one variable -- i.e., the endogenous productivity of capital or the optimal wage, or energy retail prices, or oil exports, etc. -- in a given year modifies the supply and demand of capital in that year and in any other year in the model, after as well as before the change. Numerical convergence applies to $(\Xi_t)_d = K_{KSA\,priv,t}/[A_t\overline{\varepsilon_t}\Delta_t L_t]$ -- the demand for capital per unit of efficient labor -- and $(\Xi_t)_s = \mathrm{W}_t/[A_t\overline{\varepsilon_t}\Delta_t L_t]$ -- the supply of capital per unit of efficient labor. The numerical convergence is such that ∀t∈[2000;2079]; $|(\Xi_t)_d - (\Xi_t)_s| < 1\%$.