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# Macroeconomic and Welfare Effects of Energy Policies in Saudi Arabia: The MEGIR-SA Model

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# About KAPSARC

The King Abdullah Petroleum Studies and Research Center (KAPSARC) is a non-profit global institution dedicated to independent research into energy economics, policy, technology and the environment across all types of energy. KAPSARC's mandate is to advance the understanding of energy challenges and opportunities facing the world today and tomorrow, through unbiased, independent, and high-caliber research for the benefit of society. KAPSARC is located in Riyadh, Saudi Arabia.

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# Executive Summary

MEGIR – Model with Energy, Growth and Intergenerational Redistribution – investigates the long-run implications for growth and equity across generations of different energy policies. It is the first general equilibrium model with overlapping generations to be developed and applied for energy policy analysis in the Arabian Peninsula. The version presented here is parameterized on Saudi data. It is a new and thoroughly revised version of the model developed for western countries by Gonand and Jouvet (2015). It is designed specifically for the economies of the Gulf Cooperation Council (GCC) states, particularly insofar as it incorporates an oil-exporting sector and public finances benefiting massively and directly from oil exports.

Its range of applications goes from modeling the impact on growth and intergenerational equity of higher energy efficiency, to the assessment of the effects of different potential fuel mixes and/or end-use energy prices on long-term growth and welfare distribution by age cohort. The MEGIR-SA model is also well suited to being adapted to include a sovereign wealth fund or for other oil exporting countries. The main advantage of MEGIR-SA is its ability to analyze precisely and simultaneously the effect of energy policies on potential growth and on intergenerational equity. This has some unavoidable cost in terms of modeling other aspects of the economy – e.g., the modeling of the supply side is more simplified than in models incorporating input-output matrix.

This paper provides the detailed technical description of the model that is used in other, companion, policy-oriented, KAPSARC papers. It also gives the characteristics of the baseline, no-reform scenario for the Kingdom of Saudi Arabia (KSA) as assessed by MEGIR-SA.

# Where Does This Model Fit in the Literature?

In the academic literature, the study of the impacts of policies on economic growth usually involves the use of general equilibrium (GE) models. Solow (1978) popularized GE frameworks applied to energy and environmental public policies. Since then energy- and environment-related computable GE models have been commonly used, e.g., Böhringer and Rutherford (1997), Parry and Williams (1999), Böhringer and Löschel (2006), Otto, Löschel and Dellink (2007), Knopf et al. (2010).

However, this literature relies mainly on models that do not aim at accounting precisely 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 overlapping generations (OLG) models.

OLG models simulate the behavior of different cohorts of different age, living in the same economy at the same time. They assess the impacts of policies on private agents depending on their age – old cohorts, working cohorts, young and future generations. Since John and Pecchenino (1994) and John et al. (1995), an important body of literature has been developing within an overlapping generations (OLG) framework. For instance, Bovenberg and Heijdra (1998) develop this approach to conclude that environmental taxes may trigger some pro-youth effects. However, most of the literature here develops theoretical frameworks involving only two generations, an old one and a young one. This points the way to an empirical assessment of the intergenerational redistributive effect of energy policies.

The literature that relies on empirical, dynamic general equilibrium models with overlapping generations in order to analyze the effects on growth and intergenerational equity of environmental policies is scarce (Rasmussen, 2003; Carbone et al., 2012; Carbone et al., 2013; Rausch, 2013; Gonand and Jouvet, 2015). This paper is relatively close to these latter references, notably the final one.

MEGIR-SA is a dynamic general equilibrium model with overlapping generations that is designed to fit with the characteristics of the economies of the Arabian Peninsula, most of which massively export fossil fuels and have predominantly young and rapidly growing populations. It is a new and revised version of Gonand and Jouvet (Gonand F. and P.-A. Jouvet (2015), “The “second dividend” and the demographic structure”, Journal of Environmental Economics and Management). It is designed as a tool for helping decision-makers, aiming to provide material for policy discussions while, in parallel, having received academic approval.

# Potential Applications for GCC Countries

## Effects on growth and equity across generations of higher end-use energy prices and alternative energy mix

One possible empirical application of MEGIR-SA deals with the aggregate effects on growth and equity across generations of higher end-use energy prices and alternative energy mix in GCC countries. Alternative fuel mix and technology scenarios could result in GCC countries, especially KSA, having a lower domestic consumption of oil and thus achieving, at an unchanged level of production, higher oil exports and growth. This may be brought about through higher end-use regulated prices of fossil fuels alongside policies bolstering the rise of alternative sources of energy, especially in the electric power (photovoltaic energy, nuclear power, etc.) sector.

In this policy context, MEGIR-SA can compare the costs of the transition – e.g., higher end-use prices of energy, in the short run at least – with its economic gains, which come from lower domestic oil consumption, thus enabling higher oil exports and public income recycled in the economy. The model can compute the effects of these end-use prices and domestic demand for energy on Saudi public finances, taking account of the fact that lower domestic demand for oil allows for higher oil exports and income. Higher oil income materializes into higher public current and/or capital expenditures, bolstering growth in different ways. The model can compute the dynamic general equilibrium effects of these different future end-use prices and public spending on Saudi GNP over time. Additionally, the model can also look for a possible way of recycling these gains through public finances so that no generation experiences any net intertemporal welfare loss as a consequence of the policy. In any case, the model can display the dynamics of welfare gains/losses each year for each cohort.

These issues will be addressed in a companion, forthcoming, more general discussion paper by Gonand, Hasanov and Hunt.

## Effects on growth and equity across generations of higher energy efficiency

Enhancing energy efficiency is a priority area of policy for the Kingdom and the countries of the GCC. It is particularly challenging, given the region’s great abundance of energy resources and low energy prices, which have encouraged low energy efficiency and energy wastage.

Modeling the interactions between energy efficiency, general equilibrium and energy policy is known to be a difficult task for macroeconomic modelers. Most of the time, GE models consider energy efficiency and its dynamics as exogenous variables. This might result from the fact that many past surges in energy efficiency neither emerged endogenously nor in a decentralized way. Whatever the reason, the literature today gives few insights as to the orders of magnitude involved at the aggregate level by higher energy efficiency gains. Some basic intuition suggests that the influence might be sizeable, though.

As far as GCC countries are concerned, it is reasonable to assume that, in the current situation, to bring about most of the improvement in energy efficiency would not require much public expenditure, and can be taken as exogenous. Indeed, regulatory changes can significantly affect energy efficiency in KSA. It has been estimated that the introduction of measures regulating air conditioners in KSA could reduce power demand by as much as 25 percent or 10GW (Matar, 2015).

In MEGIR-SA, enhancing energy efficiency at the microeconomic level acts at the macroeconomic level on energy productivity, through different channels. First, the direct impact of energy efficiency results in both a substitution effect, which lowers energy consumption for a given level of output, and also a partially offsetting rebound effect which, flowing from higher available income (GNP), leads to higher levels of activity and greater energy consumption. The second possible channel is through the impact of energy efficiency on the fiscal balance of Saudi Arabia due to increased oil revenue from selling otherwise domestically consumed oil onto the export market. The third possible channel involves the recycling of this higher public oil income, either through higher public current expenditures or through public investments in infrastructure -- both affecting, differently, the accumulation of capital in the economy and thus growth and equity across generations.

Scenarios for evaluating the impacts of these policy choices under different macroeconomic assumptions are discussed in the companion KAPSARC discussion paper Macroeconomic Gains from Higher Energy Efficiency in an Oil-Exporting Country: the case of Saudi Arabia using the MEGIR-SA Model. This can be read in conjunction with this methodology paper to provide an illustration of how the model describes the welfare impacts of energy efficiency policy.

## Effects on growth and equity across generations of a Sovereign Wealth Fund

Issues of equity across generations in an oil-exporting country naturally lead to the question of the economic impact of a sovereign wealth fund, as well as of the level of oil production over time, depending on the future price of oil. By its construction, MEGIR-SA can compute the impact of both of these policies on growth and equity across generations in the long run.

# Technical Description of the MEGIR-SA Model on Saudi Data

The dynamics of the model are mainly driven by energy policies, the characteristics of the world oil market, fiscal policies, demographics and optimal responses of economic agents to price signals – i.e., the interest rate, wages and regulated energy prices.

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 dynamics of the variables, 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.

## The energy module

### The oil production sector

The main output of the sub module for the oil production sector is an intertemporal vector of public revenues from oil exports ($\Upsilon_{oil,t}$) expressed in billions of 2005 Saudi Riyals.

$\Upsilon_{\mathrm{oil},\mathrm{t}}$ is computed as $\Upsilon_{\mathrm{oil,t}} = \mathrm{EXP}_{oil,t} * \mathrm{barrel}_{oil,t}$ where $\mathrm{EXP}_{oil,t}$ stands for the national exports of crude oil (in MMbbl) in year $\mathrm{t}$, and $\mathrm{barrel}_{oil,t}$ the price of a barrel of Arabian Light on world markets in year $\mathrm{t}$ (in \$/b). In this version of the model, we neglect the dynamics of the exports of refined products and consider that there will be no exports of natural gas in the future.

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 $\mathrm{t}$ (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 detailed computation of the three latter items is dealt with in more detail below. These are endogenous variables which are, accordingly, influenced by the level of activity, the macroeconomic characteristics of the general equilibrium in the model, demographics, prices and public policies.

The future price of a barrel of Arabian Light on world markets, $\mathrm{barrel}_{oil,t}$, is exogenous:

$$\mathrm{barrel}_{oil,t} = \mathrm{barrel}_{oil,t-1} * \left(1 + trend_{barrel_{oil,t}}\right) *$$
$$\left[1 + \left(-\left[\frac{\mathrm{EXP}_{oil,t}}{\mathrm{EXP}_{oil,t-1}} - 1\right] * \frac{\mathrm{EXP}_{oil,t}}{365 * \mathrm{P}_{oil,world,t}} * \varepsilon_{\mathrm{barrel}/\mathrm{P}_{oil,world,t}}\right)\right]$$

The parameter $trend_{barreloil,t}$ is an exogenous trend in the variation of the price of oil $barrel_{oil,t}$. The bracket on the right of the expression encapsulates, in a simplified manner, the impact of the variation of Saudi oil exports on the annual average price of oil on world markets.

$$\left[\frac{\mathrm{EXP}_{oil,t}}{\mathrm{EXP}_{oil,t-1}} - 1\right] * \frac{\mathrm{EXP}_{oil,t}}{365 * \mathrm{P}_{oil,world,t}}$$

refers to the contribution of the Saudi exports of crude oil to $P_{oil,world,t}$, the world supply of crude oil at year t (in MMbbl/d), which is exogenous for future periods. The parameter $\varepsilon_{barrel\,/Poil,world,t}$ is the elasticity of the price of a barrel of oil to the world supply of oil, as implied by IEA simulations.

Another way of modeling the future price of oil could have been to parameterize a Hotelling type analytical model, as in Fishelson (1983).

In this simplified setting, higher energy efficiency gains in a GCC oil exporting country may influence the price of oil on world markets; a higher energy efficiency in the oil exporting country translates into higher net crude oil exports and a downward effect on the price of oil on world markets, all else being equal. Since the dynamics of KSA exports are smooth over time in the model for future periods, its influence on the world price of oil in the model remains modest. 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).

What remains to be modeled in the energy module is the Saudi retail energy sector, with prices and volumes – and notably $D_{oil,t}$, $D_{elec,crude\ oil,t}$ and $D_{elec,refined\ oil,t}$. This is described in the next sub section.

### The domestic energy sector (end-use prices of energy and demand)

The main outputs of the sub 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 $D_{elec,t}$).

### End-use prices of energy

The end-use price of energy $q_{energy,t}$ is computed as an average of exogenous end-use prices of natural gas, oil products and electricity, weighted by the proportions $D_{i,t-1}/\sum_{iDi,t-1}$ such as

$$q_{energy,t} = \sum\nolimits^{3}_{i=1}(q_{i,t} * D_{i,t-1}/\sum\nolimits_{iDi,t-1})$$

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 ($q_{i,t}$, $i\in\{1;2\}$) are computed as weighted averages of end-use prices of different sub categories of energy products:

$$\forall i\in\{1;2\},\ q_{i,t} = \sum\nolimits^{n}_{j=1} a_{i,j,t}\ q_{i,t}$$

$q_{i,j,t}$ 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 RON ($j=3$) (all expressed in real SAR/l). This structure for energy products covers the major part of the energy demand for fossil fuels.

The $a_{i,j,t}$ weighting coefficients 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.

In MEGIR-SA, the energy module for end-users is simpler than in the model of Gonand and Jouvet (2015), which is designed for western countries. Most particularly, all retail energy prices are set directly by the government and there are no renewables or feed-in tariffs — though these could be introduced in the model, if required, as in Gonand and Jouvet (2015). 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 KSA.

Thus shifts in demand for energy in KSA do not necessarily result in changes in the domestic prices of energy, as observed in 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 $q_{3,t}$ is computed as a weighted average of prices of electricity for households and industry (i=3), $q_{3,t} = \sum^{2}_{j=1} a_{3,j,t}\, q_{3,j,t}$, where $q_{3,j,t}$ stands for the end-use real price, at year $t$, of the product $j$ of electricity.

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 ($j=2$)(in 2005 SAR/MWh). The $a_{3,j,t}$ weighting coefficients are computed using observable data for demand for past periods, and frozen to their level in the latest published data available for future periods.

We checked that the regulated end-use price of electricity broadly covers the costs of production of power in KSA, i.e., that there can be some implicit subsidies but no significant explicit subsidies, though the latter could be computed using MEGIR-SA if needed. In order to do so, we reconstituted data for power prices over past periods and compared these to a simulated production price of electricity. The data was obtained from the annual report of ECRA (2014), the Saudi regulator for power networks, which provides regulated end-use prices for 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).

Empirical parameterization of KSA data suggests that regulated prices of electricity seem to broadly cover the production costs in KSA over time, in line with the data in ECRA, 2014, for instance. The parameters used to model the wholesale average price of electricity come mainly from Matar, Murphy, Pierru and Rioux (2014).

### Energy demand in volume

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 ktep of coal in 2012.

The volume of energy demand over past periods is 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 IEA databases. In this model, they are used mainly to compute the average weighted real energy price for end-users $q_{energy,t}$ over past periods, according to the formula

$$q_{energy,t} = \sum\nolimits^{3}_{i=1}(q_{i,t}*D_{i,t-1}/\sum\nolimits_{i} D_{i,t-1})$$

For future periods, the computation of the energy demands (i.e., $D_{natgas,t}=D_{1,t}$, $D_{oil,t}=D_{2,t}$, $D_{elec,t}=D_{3,t}$) and, hence, the energy mix in the future, relies on a framework commonly used in the literature (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., $D_{oil}$, $D_{natgas,t}$ and $D_{elec,t}$ – to vary over time according to changes in the relative prices of their associated energy vectors, i.e., $q_{1,t}$, $q_{2,t}$ and $q_{3,t}$. We denote domestic final energy demand at year t as $E_t=D_{non\ elec,t}+D_{elec,t}$ with $D_{non\ elec,t}=D_{natgas,t}+D_{oil,t}$ (in ktoe). In the model, $E_t$ is an endogenous item of the production function (see below) that is directly influenced by macroeconomic factors, demographics and the characteristics of the general equilibrium.

Using a CES function and knowing the levels of $D_{non\ elec,t-1}$, $D_{elec,t-1}$, of the endogenous annual variations of $E_t$, provided by the general production function of the economy, along with the retail energy prices $q_{i,t}$'s and the exogenous elasticity of substitution between $D_{non\ elec,t}$ and $D_{elec,t}$, the variables $D_{non\ elec,t}$ and $D_{elec,t}$ can be derived. This operation is iterated for each year over the whole period of simulation of the model to obtain all $D_{non\ elec,t}$'s and $D_{elec,t}$'s for future years. The method is then used to split, at any year in the future, each $D_{non\ elec,t}$ into $D_{oil,}$ and $D_{natgas,t}$.

Formally, one derives the demand for electricity as: $D_{elec,t}=E_t-D_{non\ elec,t}$ with

$$D_{non\ elec,t} = D_{non\ elec,t-1}\left\{\begin{matrix} \left[\frac{E_t}{E_{t-1}}\right] - \\ elast_{subst\ elec,non\ elec}\left(\frac{\Xi_t}{\Xi_{t-1}} - \frac{1+\Xi_t}{1+\Xi_{t-1}}\right)\end{matrix}\right\}$$

with

$$\Xi_t = \frac{D_{elec,t-1}}{D_{non\ elec,t-1}}\frac{q_{non\ elec,t}}{q_{3,t}}$$

where $q_{non\ elec,t}$ is the average weighted price of non electric energy in KSA (i.e., the average weighted price of oil products and natural gas). Then $D_{non\ elec,t}=D_{oil,t}+D_{nat\ gas,t}$ with

$$D_{oil,t} = D_{oil,t-1}\left\{\begin{matrix} \left[\frac{D_{non\ elec,t}}{D_{non\ elec,t-1}}\right] - \\ elast_{subst\ oil,nat\ gas}\left(\frac{X_t}{X_{t-1}} - \frac{1+X_t}{1+X_{t-1}}\right)\end{matrix}\right\}$$

with

$$X_t = \frac{D_{nat\,gas,t-1}}{D_{oil,t-1}} \frac{q_{2,t}}{q_{1,t}}$$

where $q_{2,t}$ is the end-use price of oil products and $q_{1,t}$ is the end-use price of natural gas in 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.

This setting allows us to derive $CONS_{oil,t} = D_{oil,t} + D_{elec,crude\,oil,t} + D_{elec,refined\,oil,t}$, the domestic consumption of oil, where $D_{oil,t}$ stands for the demand for oil, crude or refined, in the non power sectors, $D_{elec,crude\,oil,t}$ is the demand for crude oil in the power sector, and $D_{elec,refined\,oil,t}$, the demand for refined oil products in the power sector. Assuming that the structure of production of electricity from oil, crude or refined products, remains constant in the future,

$$D_{elec,crude\,oil,t} = D_{elec,crude\,oil,t-1} * \frac{D_{elec,t}/D_{elec,t-1}}{Eff_{el,2,t,therm}/Eff_{el,2,t-1,therm}}$$

where $Eff_{el,2,t,therm}$ 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 $D_{elec}$ 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.

## Demographics

The main outputs of the sub module for demographics are a matrix of the population of age a at year $t$, a sub matrix of the Saudi employed population of age a at year $t$, and a sub matrix of the employed population of expatriates of age a at year $t$.

MEGIR-SA encapsulates around 60 cohorts, depending on average life expectancy, that best define its optimal consumption and leisure levels. The model is built on 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 $N_{t,a}$ 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.

Individuals making up a cohort are either nationals or expatriates. The main reason for distinguishing between nationals and expatriates in the model is that the former provide the domestic economy with savings as well as labor, whereas the latter are assumed to 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 and notably its upward influence on the capital per unit of labor in KSA. (See next section, overlapping generations framework.)

The specification breaks up each cohort into working and non-working individuals, Saudis or expatriates. Saudi workers define their optimal consumption and labor supply. 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 or receive any pension during their lifetime. The proportion $\pi_{t,a}$ of pensioners in a cohort is computed as a residual.

## The overlapping generations framework

The main output of the sub module with the overlapping generations (OLG) of Saudi households is an intertemporal vector of private domestic supply of capital per efficient unit of labor at year t.

The OLG framework allows for modeling in detail of the interactions between the consumption/savings and work/leisure arbitrages, fiscal and energy policies and demographics. For instance, the aggregate accumulation of capital is positively linked to the proportion of older employees in the population, and the gross income of private agents is influenced by fiscal policies and the level of public income from oil exports.

The Saudi household sector is 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. This amounts to abstracting from heterogeneity within cohorts. GE-OLG models in general concentrate on intergenerational redistribution, because this is their main focus, and less on intragenerational redistribution – which is better analyzed, for example, using dynamic microsimulations – mainly because the numerical complexity of adding several dimensions of variables would lessen the tractability of the model.

The utility function has two arguments, consumption and leisure. In the model, private agents are assumed to have perfect foresight. The labor supply of the representative individual of a whole cohort ($\ell_{t,a}$) $\in [0;1]$) is such that

$$1 - \ell_{t,a} = \nu_{t,a}\,(1 - \ell^*_{t,a}) + (1 - \nu_{t,a}) = 1 - \nu_{t,a}\ell^*_{t,a})\leq 1,$$

where $\nu$ is the fraction of working individuals in a cohort aged a in year t and $\ell^*_{t,a}$ is the optimal fraction of time devoted to work by the working sub cohort. For instance, if $\nu_{t,a}$=70 percent of a cohort age a at a year t are working and devote $\ell^*_{t,a}$=0.5 of their available time to labor, then the average individual of the same cohort devotes $\ell^*_{t,a}$=35 percent of his/her available time to labor, and 65 percent to leisure.

The objective function over the lifetime of the average working individual of a cohort of age a born in year t is:

$$U^*_{t,0} = \frac{1}{1-\sigma}\sum_{j=0}^{\Psi_{t,0}}\left\{\frac{1}{(1+\rho)^j}\left[\begin{pmatrix}\left(c^*_{t+j,j}\right)^{1-\frac{1}{\xi}} + \\ \chi\left(H_j\left(1-\ell^*_{t+j,j}\right)\right)^{1-1/\xi}\end{pmatrix}^{\frac{1}{1-1/\xi}}\right]^{1-\sigma}\right\}$$

where $c^*_{t+j,j}$ is the consumption level of the average individual of the working sub cohort of age j in year t, $\rho$ is the subjective rate of time preference, $\sigma$ is the relative risk aversion coefficient and, for a CRRA function, this coefficient is equal to the inverse of the intertemporal substitution coefficient.

$$\left(\left(c^*_{t+j,j}\right)^{1-1/\xi} + \chi\left(H_j\left(1-\ell^*_{t+j,j}\right)\right)^{1-1/\xi}\right)^{\frac{1}{1-1/\xi}}$$

$\chi$ is the preference for leisure relative to consumption, $1/\xi$ the elasticity of substitution between consumption and leisure in the instantaneous utility function, and $H_j$ 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).

Introducing this last parameter stabilizes the ratio of the contributions of consumption and leisure to utility when technical progress is strictly positive. The Euler equation (below) suggests that the annual growth rate of consumption is equal, at the steady state, to the difference between the interest rate and the discount rate, which in turn is equal to annual gains of labor augmenting technical change.

Introducing an endogenous labor market in general equilibrium models with OLG poses several challenges. Among other things, many models compute the households' optimal behavior using shadow wages during the retirement period (e.g., Auerbach and Kotlikoff, 1987). The use of numerically computed shadow wages allows for meeting a temporal constraint during the retirement period, i.e., when the fraction of time devoted to leisure is equal to 1. These shadow wages are proxies for Kuhn-Tucker multipliers. While, in principle, mathematically correct, this method may not be very intuitive from an economic point of view, since it assumes that agents keep optimizing between work and leisure even during the retirement period.

One practical issue with the shadow wage approach as implemented in this literature is that the method chosen to derive the shadow wages has an impact on the overall general equilibrium and, therefore, on all variables via the intratemporal first order condition. In addition, this approach makes it practically impossible to derive an analytical solution to the model and complicates its numerical solution.

These problems can be overcome by specifying the model in such a way that the households' maximization problem can be solved in two steps. The specification separates each cohort into working individuals, who decide on their optimal consumption and labor supply, and non working individuals, whose labor supply is zero by definition. Variables in the households' maximization program denoted with a star (*) refer to the sub cohort of working individuals. Variables with no star refer to the whole cohort.

The intertemporal budget constraint for the working sub cohort of age 20 (i.e., a=0) in year t is:

$$\ell^*_{t,0}\omega_{t,0} + \sum_{j=1}^{\Psi_{t,0}}\left[\ell^*_{t+j,j}\omega_{t+j,j}\prod_{i=1}^{j}\frac{1}{(1+r_{t+i})}\right] = c^*_{t,0} + \sum_{j=1}^{\Psi_{t,0}}\left[c^*_{t+j,j}\prod_{i=1}^{j}\frac{1}{(1+r_{t+i})}\right]$$

Parameter $\omega_{t+j,j}$ is the after tax income per hour worked such that $\omega_{t+j,j} = w_t\,\varepsilon_a\,(1 - \tau_{t,NA} - \tau_{t,P})$. $w_t$ stands for the gross wage per efficient unit of labor, which stems from the maximization of the production function, (see below). The parameter $\varepsilon_a$ links the age of a cohort to its productivity. Following Miles (1999), a quadratic function is used: $\varepsilon_a\,(a) = \exp^{0.05(a+20) - 0.0006(a+20)^2}$. Parameter $\tau_{t,P}$ stands for the proportional tax rate financing the PAYG pension regime – see below, public finances module section – paid by households on their income from their labor. $\tau_{t,NA}$ stands for the rate of a proportional tax levied on labor income and pensions to finance public non aging related public expenditure $d_{t,NA}$. (See below, public finances section.)

In a specification like this, the working sub cohort always chooses a strictly positive optimal working time throughout its life. In other words, the representative individual associated with the working sub cohort never retires. This property of the model does not lead to unrealistic results because each entire cohort consists of a working sub cohort and a non working sub cohort, with weights that vary with the age of the cohort. In fact, for the representative individual associated with the whole cohort, the retirement age is defined exogenously through the $\nu_{t,a}$'s which become equal to zero at greater age. Since $1-\ell_{t,a}=1-\nu_{t,a}\,\ell^*_{t,a}$ the representative individual associated with the whole cohort retires in the model when the exogenous parameter $\nu_{t,a}$reaches zero.

In this model, endogenizing the retirement decision with the $\ell^*_{t,a}$ would bring about serious problems. The year when $\ell^*_{t,a}$ becomes equal to zero is closely related to the function $\varepsilon_a$ (a) $= \exp^{0.05(a+20) - 0.0006(a+20)^2}$ linking age and individual productivity and its decline after some threshold years. Indeed, the first order condition suggests that $\ell^*_{t,a} = 0$ only if $\varepsilon_a$ (a) declines sufficiently so that

$$1-\ell^*_{t,a} = (\chi/\omega^*_{t,a})^{\xi} c^*_{t,a} \text{ equals } 1.$$

The associated retirement age can be very high with such a specification (more than 90). Moreover, there is a debate about the form of the function $\varepsilon_a$ *(a)*, which may not decline after some threshold years. For these reasons, endogenizing the retirement decision using the $\ell^*_{t,a}$'s brings about significant problems, at least in this dynamic, general equilibrium context. It is noteworthy that Auerbach and Kotlikoff (1987), for example, impose an exogenous retirement age of 66 in their model.

The first order condition for the intratemporal optimization problem is derived from equalizing the ratio between the marginal utilities of consumption and leisure with the ratio of consumption and leisure prices. In the model, the price of the goods produced is 1. The price of leisure – that is, its opportunity cost – is equal to $\omega_{t,a}$, the net wage per unit of efficient labor for cohort (a,t). Some algebra yields the optimal relation between $c^*_{t,a}$ and $\ell^*_{t,a} > 0$: $1-\ell^*_{t,a} = \left(\frac{\chi}{\omega_{t,a}}\right)^{\xi} \frac{c^*_{t,a}}{H_a} > 0$.

A higher after tax work income per hour worked $\omega_{t,a}$ prompts less leisure ($1-\ell^*_{t,a}$) and more work $\ell^*_{t,a}$. Thus the model captures the distortive effect of a tax on labor supply.

The first order condition for the intertemporal optimization problem derives from maximizing the intertemporal utility function under the budget constraint.

Solving with a Lagrangian, and after some algebra, the following Euler equation is obtained (where $\kappa = 1/\sigma$):

$$\frac{c^*_{t,a}}{c^*_{t-1,a-1}} = \left(\frac{1+r_t}{1+\rho}\right)^{\kappa} \left(\frac{1+\chi^{\xi}\omega_{t,a}^{1-\xi}}{1+\chi^{\xi}\omega_{t-1,a-1}^{1-\xi}}\right)^{\frac{\kappa-\xi}{\xi-1}}.$$

If after tax income per hour worked $\omega_{t,a}$ is steady, and the real rate of return $r_t$ is higher than the psychological discount rate $\rho$, consumption will rise over time for each cohort. If the after tax work income per hour worked $\omega_{t,a}$ rises over time, and the real rate of return $r_t$ is steady and higher than the psychological discount rate $\rho$, consumption $c^*_{t,a}$ will rise over time. Lower risk aversion *($\sigma$)* (hence higher $\sigma$) implies larger intertemporal changes in consumption. That is in the normal case, where the real rate of return $r_t$ is higher than the psychological discount rate $\rho$.

Plugging this Euler equation back into the budget constraint yields the initial level of consumption for the working cohort aged a at year t $c^*_{t,0}$. The optimal consumption path for each working sub cohort is derived from the optimal value of $c^*_{t,0}$ and the

Euler equation. The paths of the labor supplies of the working cohorts $\ell^*_{t,a}$ are then derived from the $c^*_{t,a}$'s using the intratemporal first order condition. Eventually, the optimal labor supply of the average individual of a whole cohort $\ell_{t,a}$, defined as $1-\ell_{t,a}=1-\nu_{t,a}\ell^*_{t,a}$, can be derived. Knowing the optimal paths, $\ell_{t,a}$ simplifies the computation of the optimal level of consumption of the average individual that is representative of a whole cohort.

The values $c^*_{t,a}$ are obtained by maximising the utility function of the average individual of a whole cohort, where the labor supply $1-\ell_{t,a}=1-\nu_{t,a}\ell^*_{t,a} \geq 0$ is already known, i.e.:

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

under the intertemporal budget constraint:

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

where $y_{t+j,j}$ stands for the total income net of taxes of the average individual representative of a whole cohort, such that $y_{t,a}=\ell_{t,a}w_t\varepsilon_a(1-\tau_{t,NA}-\tau_{t,P})+d_{t,NA}-d_{t,energy}+\Phi_{t,a}$.

In this expression, $\Phi_{t,a}$ stands for the pension income received by the retirees of a cohort. (See below, public finances section.) The variable $d_{t,NA}$ stands for the non aging related public current expenditure that Saudi private agents receive in a lump sum fashion, irrespective of age and income.

It is defined as $d_{t,NA}=\Theta_{current,t}/\sum_a N_{t,a,Saudis}$ where $\Theta_t$ is the aggregate current public expenditre (in billion real SAR, see public finances section), and $N_{t,a,Saudis}$ the number of Saudi individuals in the cohort aged a at year t. The variable $d_{t,NA}$ is used as a monetary proxy for goods and services in kind brought by the public sector and consumed by Saudi private agents.

The variable $d_{t,energy}$ stands for the energy expenditures paid by one Saudi individual, such that $d_{t,energy}=C_{en}\frac{\sum_a(w_t\varepsilon_a\nu_{t,a}N_{t,a}+\Phi_{t,a}\pi_{t,a}N_{t,a})}{\sum_a N_{t,a}}\frac{q_{energy,t}E_t}{A_t}$,

where $(w_t\varepsilon_a\nu_{t,a}N_{t,a}+\Phi_{t,a}\pi_{t,a}N_{t,a})$ is the aggregate tax base comprising wages and pensions, $C_{en}$ is a constant of calibration and $\frac{q_{energy,t}E_t}{A_t}$ captures the dynamics of energy expenditures for one efficient unit of labor. Here the formula uses $N_{t,a}$, 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 optimal path for consumption stems from the Euler equation, using a Lagrangian:

$$\frac{c_{t,a}}{c_{t-1,a-1}}=\left(\frac{1+r_t}{1+\rho}\right)^{\kappa}$$

where the intertemporal substitution coefficient is equal to the inverse of the risk aversion ($\kappa=\sigma^{-1}$) parameter. The initial level of consumption $c_{t,0}$ – i.e., the level of consumption of a cohort of age 20 at year t – is obtained by plugging the Euler equation into the budget constraint. Having computed the optimal path of consumption for all the cohorts of the model, average individual saving ($s_{t,a}=y_{t,a}-c_{t,a}$) and individual wealth ($\Omega_{t,a}=(1+r_t)\,\Omega_{t-1,a}-1+s_{t,a}$) can be computed. 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 $W_t=\sum_a(\Omega_{t,a}N_{t,a,Saudis})$ .It is assumed to correspond to the total capital supplied by private agents to the domestic economy. 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 KSA. By dividing the stock of capital supplied by nationals to their domestic economy $\mathrm{W}_t$, by the optimal labor supply, the intertemporal vector of private Saudi supply of capital per efficient unit of labor at year $\mathrm{t}$ can be arrived at.

A notable feature of this OLG is that it allows for taking account of a rebound effect resulting from higher energy efficiency. Indeed, a rise in energy efficiency ($\mathrm{B}_\mathrm{t}$, see below) weighs on $\mathrm{E}_t$ , all else being equal, thus on $\mathrm{d}_{t,energy,}$ and consequently triggers an upward effect on $\mathrm{y}_{t,a}$ and also on GDP, which in turn feeds into a higher $\mathrm{E}_t$. The net effect on $\mathrm{E}_\mathrm{t}$ 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 KSA.

Given this structure, the model computes endogenously the total amount of income received by Saudi agents, net of taxes and energy expenditures, including transfers that recycle public income from oil exports, and taking account of the public stock of infrastructure that contributes to the production function and increases wages per unit of efficient labor – for the latter, see section 2.4. below. This total amount corresponds to a modeled GNP. It is assumed that remittances sent back to KSA by Saudis living in foreign countries are negligible at the aggregate scale.

## The production function

The main outputs of the sub module with the production function are an intertemporal vector of marginal productivity of capital ($\mathrm{r}_t$), of wage per unit of efficient labor ($\mathrm{w}_t$), of total energy demand ($\mathrm{E}_t$), of demand for capital per unit of efficient labor and of GNP, all at year $\mathrm{t}$.

The production function refers here to the private non oil sector of a GCC country. The production function is a 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) here for the method of including the stock of public capital in the production function. We have checked that our results were robust to other, different ways of inserting the stock of public capital in the function.

The K-L module of the nested production function is:

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

The parameter $\alpha$ is a weighting parameter; $\beta$ is the elasticity of substitution between physical capital and labor; $\mathrm{L}_t$ is the total labor force; and $\mathrm{A}_t$ stands for an index of total factor productivity gains which are assumed to be labor augmenting, i.e., Harrod neutral. The parameter

$$\overline{\varepsilon_t} = \sum_a^{\max(a,t)} \varepsilon_a \frac{\nu_{t,a}\mathrm{N}_{t,a}}{\mathrm{L}_t}$$

links the aggregate productivity of the labor force at year $t$ to the average age of active individuals at this year. $N_{t,a}$ is the total number of individuals aged a at year $t$.

It should be noted here that parameter $\nu_{t,a}$ is the fraction of a cohort of age a in t which is employed and receives a wage. $\Delta_t$ corresponds to the average optimal working time in t. Thus $\Delta_t L_t$ corresponds to the total number of hours worked, and $A_t \bar{\varepsilon}_t \Delta_t L_t$ 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 $\Delta_t$ is endogenous.

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 $K_{KSA\,priv,t} = \frac{K_{KSA\,priv,t}}{A_t \bar{\varepsilon}_t \Delta_t L_t}$), yields optimal factor prices, namely, the equilibrium 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 equilibrium 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, these expressions show that a higher level of $K_{KSA\,pub,t}$ also triggers, all else being equal, a higher level of $r_t$ and $w_t$ — where as 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.

In the previous CES production function, $C_t$ stands for an aggregate of production in volume. However, since intermediate consumption does not appear in its expression, it is implicitly disregarded. Introducing energy demand $E_t$ in a CES function, as Solow (1974), yields a more realistic production function $Y_t$, again in volume, associated with the added value which remunerates labor and capital:

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

where a is a weighting parameter, $_{\gamma\text{en}}$ is the elasticity of substitution between factors of production and energy (with $_{\gamma\text{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 $\min\limits_{E_t, C_t} q_t B_t E_t + p_{ct} C_t$ under the constraint $Y_t^{\gamma en} = a(B_t E_t)^{\gamma en} + (1-\alpha)[C_t]^{\gamma en}$.

It is worth noting that in the latter expression, $q_t$ 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: $q_t = B_t\, q_{energy,t}$. Solving with the Lagrangian, and given that the stock of capital, the labor supply, the cost of capital, the wage per unit of efficient labor, the deflator $p_{ct}$ and the real price of energy $q_{energy,t}$ are all known, and that $B_t$ is exogenous, it is possible, after some manipulations, to derive the total energy demand

$$E_t := \frac{q_t^{\frac{1}{\gamma en-1}} a^{\frac{-1}{\gamma en-1}} C_t}{p_{C_t}^{\frac{1}{\gamma en-1}} (1-a)^{\frac{-1}{\gamma en-1}}}.$$

In the model, 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 takes account of the fact that developing public infrastructures $K_{KSA\ pub,t}$ is in itself an energy intensive policy, with an upward effect on domestic demand for energy (since $\partial E_t / \partial K_{KSA\ pub,t} > 0$).

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., $D_{oil,t}$, $D_{natgas,t}$ and $D_{elec,t}$, depending on changes in their relative prices (computing using the $_{qx,t}$'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.

## Public finances

The main outputs of the public finances sub module are the intertemporal vectors of public current expenditure ($\Theta_{current,t}$), public capital expenditure ($\Theta_{capital,t}$) and public net stock of capital ($K_{KSA\ pub}$), all at year t, in billions of 2005 Saudi Riyals.

The public sector is modeled via a central government with non aging related expenditures ($\Theta_{current,t}$ and $\Theta_{capital,t}$) and an autonomous, aging related PAYG pension regime.

For central government, the public income from oil exports ($\Upsilon_{oil,t}$) is set out in the oil production sector sub module (see above). The other public revenues ($\Upsilon_{others,t}$) refer in the model to all the sources of public income that are not directly related with oil exports in Saudi Arabia. These include corporate tax, *zakat*, customs import duties and user fees. Insofar as these public revenues are on average proportional to growth in the long run at unchanged policies, our model simulates them with one aggregate tax on private agents that is proportional to their income.

Current public expenditure $\Theta_{current,t}$ is redistributed in a lump sum fashion in the model, as a proxy of public services. Thus each Saudi private agent receives in cash a non aging related public good $d_{t,NA}$ which does not depend on his/her age and is a proxy for public services.

As noted in the OLG framework section, this verifies $d_{t,NA} = \Theta_{current,t} / \sum_a N_{t,a,Saudis}\ \forall t$. Public capital expenditure $\Theta_{capital,t}$ feeds into a gross stock of public capital $K_{KSA\ pub,t}$, representative of public infrastructure, that is amortized over 40 years. For future periods, the public deficit is assumed to be nil and thus $\Upsilon_{oil,t} + \Upsilon_{others,t} = \Theta_{current,t} + \Theta_{capital,t}$.

In the baseline, no reform, scenario, the proportions of current expenditure and capital expenditure as a fraction of total central government expenditure are assumed to remain constant at their latest level, thus:

$$\Theta_{current,t} = \frac{\Upsilon_{oil,t} + \Upsilon_{others,t}}{\Upsilon_{oil,t-1} + \Upsilon_{others,t-1}} \Theta_{current,t-1}.$$

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 $\tau_{t,P}$.

## Example of a parameterization on Saudi data

*Oil and energy sector*: the domestic production of crude oil $\mathrm{P}_{oil,KSA,t}$ is set exogenously in the model by public authorities at 10.6 MMbbl/d in the future. For this paper, the price of a barrel of oil on world markets is taken from Oxford Economics' latest forecast and, after 2050, increases in real terms by +0.5 percent per year. The parameter $\varepsilon_{barrel/Poil,world,t}$ is the elasticity of the price of a barrel of oil to the world supply of oil, as suggested by simulations from the IEA (2014). 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 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 percent every five years — i.e., close to +0.4 percent per year after 2050, slightly above demographic growth rates currently experienced by most western countries.

*OLG framework/households'* program: the households' psychological discount rate $\rho$ is set at 2 percent per annum, in line with much of the empirical literature (Gourinchas and Parker, 2002). Parameter $\chi$ — 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 et Kotlikoff, 1987, p.35). The risk aversion parameter σ in the CRRA utility function is assumed to be 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 1 (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 1.

The elasticity of substitution between energy and capital ($y_{en}$) 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 nowadays 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 ($a$) 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 percent 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 percent per year from 1990 until 2010, in line with IMF (2013) and Espinoza (2012). From 2010 onwards, we assume a value of +1.0 percent 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 KSA was close to 0 (IMF, 2013). The parameter $\varsigma$ 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 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 percent on Saudi data (OECD, 2015).

*Calibration and numerical convergence*: 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 $p_{Ct}$ 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 $(\Xi_t)_d = K_{KSA\,priv,t} / [A_t \bar{\varepsilon}_t \Delta_t L_t]$ – the demand for capital per unit of efficient labor – and $(\Xi_t)_s = W_t / [A_t \bar{\varepsilon}_t \Delta_t L_t]$ — the supply of capital per unit of efficient labor. The numerical convergence is such that $\forall t \in [2000;2079];\ |(\Xi_t)d - (\Xi_t)_s| < 1$ percent.

Any modification of the informational set of private agents – e.g., the announcement of a reform during the 2010s – involves a reoptimization process and defines new intertemporal paths for consumption, savings and capital supply. Before any informational surprise, the informational set corresponds to the baseline scenario. From the announcement onwards, a new intertemporal path of consumption is defined over its remaining lifetime by each living cohort, with assumed perfect foresight.

Gonand and Jouvet (2015) provide a robustness check on the sensitivity of the EG-OLG model of which MEGIR-SA is a new, profoundly revised and GCC oriented version. They find that the dynamics of the model is reasonably robust for a whole set of parameters. The dynamics of the model is, as anticipated, more impacted by different values for parameters directly linked with the dynamics of the accumulation of physical capital, i.e., the share of physical capital in the value added and the intertemporal elasticity of substitution. However, significant differences also appear for rather non consensual values relating to these two parameters.

# Baseline Scenario With Unchanged Energy Policies: An Application to KSA

This section summarizes the results obtained in a no reform, baseline scenario, with no new energy policy implemented in the future, parameterized on Saudi data.

## Saudi demographic assumptions

The MEGIR-SA model assumes three key trends in the future dynamics of the Saudi population: a deceleration in the population, with a shift from a very young population towards an aging population (Figure 1), and a progressive Saudization of the labor force. Aging in KSA may be significantly observed from the middle of the 2020s onwards, with a rapid increase in the proportion of the population aged more than 60, from 4 percent today to 22 percent in 2050. Some UN forecasts consider that the proportion of Saudis in the employed population may rise from around 45 percent today to around 76 percent by the middle of the century.

Demographic aging and Saudization both reinforce capital deepening, the former because savings increase for older working households and the latter because Saudis, by contrast with expatriates, are assumed to invest their savings in the domestic economy. Our MEGIR-SA model suggests that the capital intensity of the Saudi economy would indeed increase slightly in future decades. It indicates that the stock of private non oil capital per unit of efficient labor is broadly stable during the 1990s and 2000s on average, a result in line with Espinoza (2012).

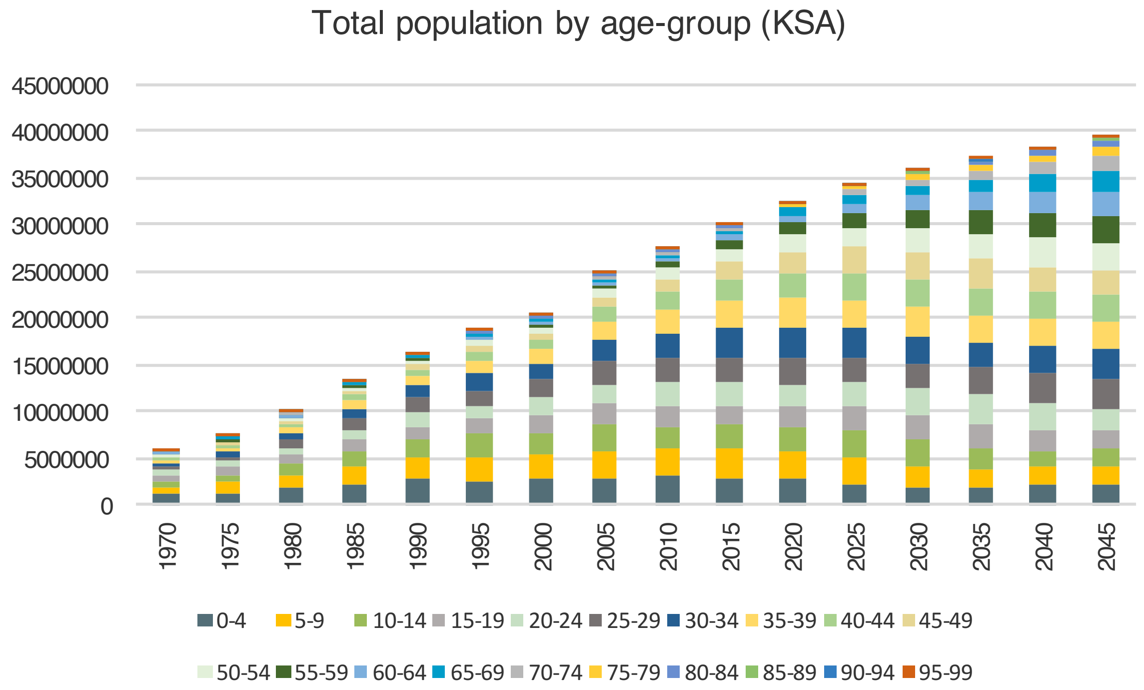


**Figure 1**. Demographic structure in the model on Saudi data.

Source: KAPSARC.

## Energy module assumptions

The baseline scenario for KSA assumes that the regulated end-use prices of natural gas, oil products and electricity remain unchanged in the future, and that the future energy mix does not change sizably. The policy implications of the results obtained in MEGIR-SA are not significantly sensitive to this assumption, however, since results are computed as the difference between a policy scenario and a 'no reform' scenario, where both assume the same end-user domestic prices of energy.

We consider two possible, admittedly extreme, simulations for the assumed future world price of oil and the assumed future level of Saudi oil production, both jointly influencing the development of future oil income in Saudi Arabia. These two cases are defined so that the future, observed oil income of Saudi Arabia will most probably lie between these two extreme simulations:

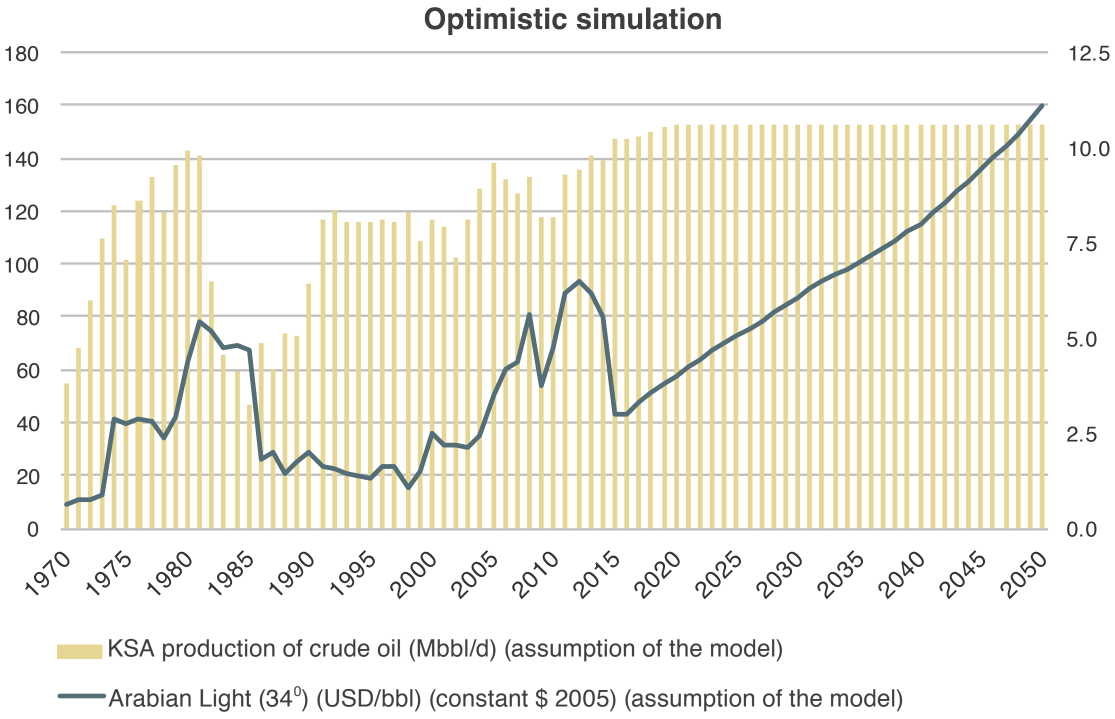
> Optimistic simulation: ever increasing future prices of oil and a high, stable level of oil production. We use Oxford Economics forecasts, according to which future crude oil prices will keep increasing up to U.S. $154/bbl in 2050 in constant terms. Such a level of oil price in constant terms is two times higher than the peak oil price level observed, in real terms, in 2008. After 2050, the price of oil is assumed in our model still to increase at a moderate pace by +0.5 percent per year in real terms.

> We also assume a high, stable level of production after 2020, around 11 MMbbl/d. Before 2020, we follow Oxford Economics, which forecasts an increase in the level of Saudi production of crude oil.

> (Relatively) pessimistic simulation: future real price of oil remaining at its 2016 level and slightly decreasing level of production (-1 percent per year from 2020 onwards). In fact, an even more pessimistic assumption could have been chosen in the long run, the marginal cost of production of a barrel of Arabian light. The academic literature tends to consider that the price of oil in the long run may be more related to shifts in the world demand for oil than to supply shocks (Kilian, 2009). Recent developments on the oil markets tend to confirm that an ever increasing trend in the price of oil is not a foregone conclusion. (See figure 2).

In both cases, we implicitly consider that the price of oil on the world market remains weakly correlated with the level of Saudi oil production, implying a relatively low market power of KSA on the oil markets. This is coherent with Huppmann and Holz (2012), and also with most data over the last 20 years. The model introduces some linkage between the oil price and Saudi exports of oil (see technical description above).

The baseline scenario on Saudi data assumes that the index of energy efficiency remains stable in the future, as it has been on average over the past two decades. Precisely assessing an average energy efficiency index in an entire economy is not always easy since energy efficiency is observed only at the microeconomic level. Energy productivity is directly measured at the aggregate level as the ratio of GDP/energy demand, but it does not change in a strictly parallel manner with energy efficiency because of the rebound effect and other general equilibrium feedback effects. However, aggregate data suggest that energy productivity in KSA has on average been stable over the last two decades (Galeotti, Howarth and Lanza, 2016), which points



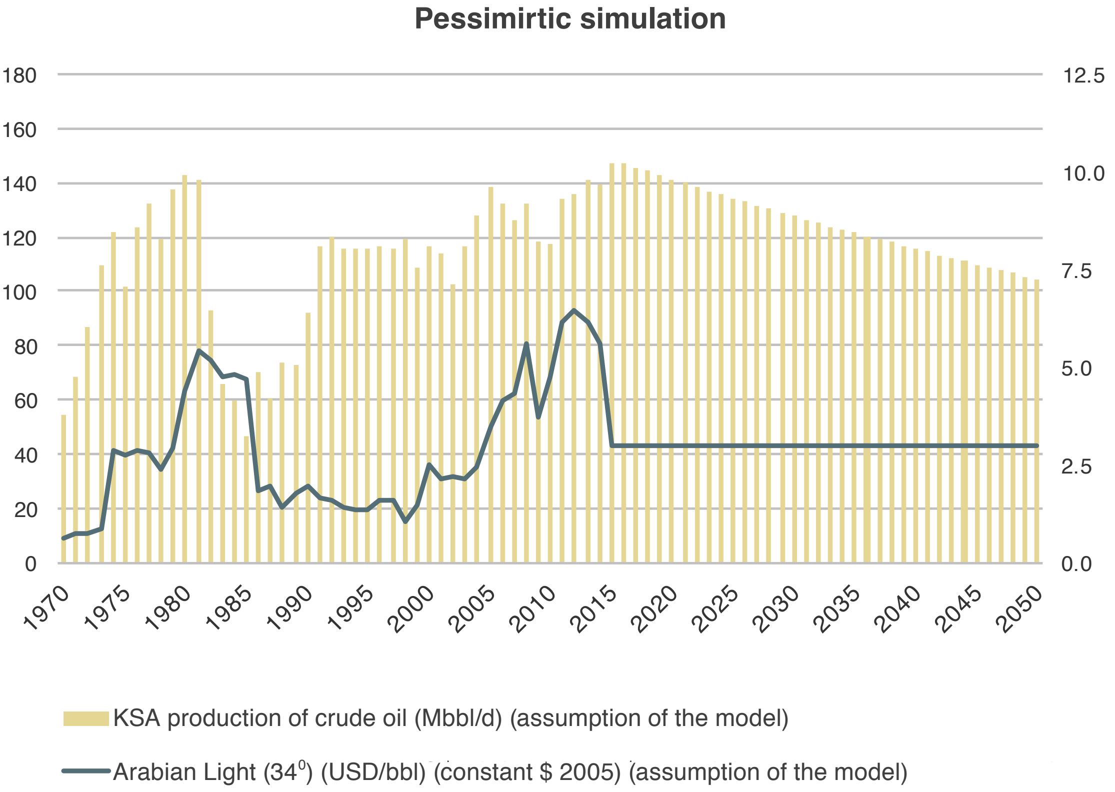


**Figure 2**. Two possible extreme cases for the future price of oil and KSA production.

Source:KAPSARC.

to a non-increasing average energy efficiency index at the microeconomic level. Thus in this scenario we assume no energy efficiency gains, on average, in the KSA for the last two decades.

Assuming annual gains of labor augmenting technical change of 1 percent over the next few decades and with no energy efficiency improvement, KSA oil exports would decline progressively over the next few decades (Fig.3), unless future production keeps continually increasing. This estimate might be conservative. If future KSA gains from labor augmenting technical change were to be higher, then exports of oil would disappear sooner into the future — an alternative simulation that MEGIR-SA could easily deliver.

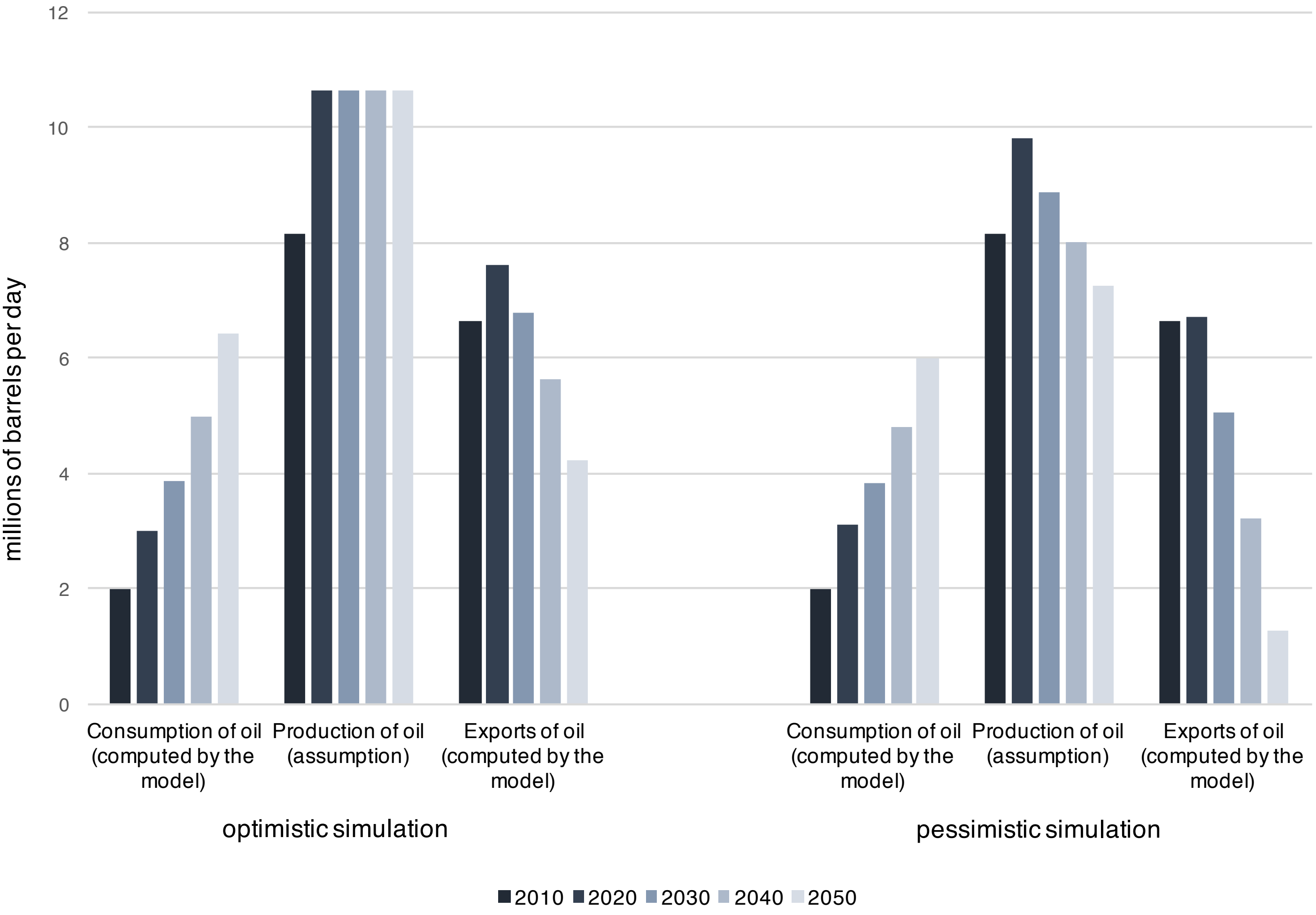


**Figure 3**. Simulation of crude oil consumption, production and exports.

Source: KAPSARC.

Indeed, KSA oil consumption would mainly be bolstered by the effects of demographics and of progressive labor augmenting technical change. In the optimistic simulation, KSA oil revenues would rise up to the 2050s. This result mirrors the influence of a decline in the volume of exports that is not offset by the impact of rising prices from the 2040s onward. In the pessimistic simulation, exports would decline from now on and vanish in the 2050s (Fig.4).

## Fiscal assumptions

All scenarios assume that the Saudi Government budget remains balanced over the next decades. Possible future developments of MEGIR-SA might include a sovereign wealth fund and simulating its changing size over time.

In the optimistic simulation, public revenues, oil and/or nonoil, would keep rising until the 2050s and allow for increasing public expenditures, current and/or capital. In the pessimistic simulation, the declining trend in oil income weighs on Saudi public finances in the future. That is, if no tax increase is decided and no debt issued (Fig.5), bringing about a looming problem of sustainability for KSA public finances over the next decades, at least in this simulation which has no future energy efficiency gains.

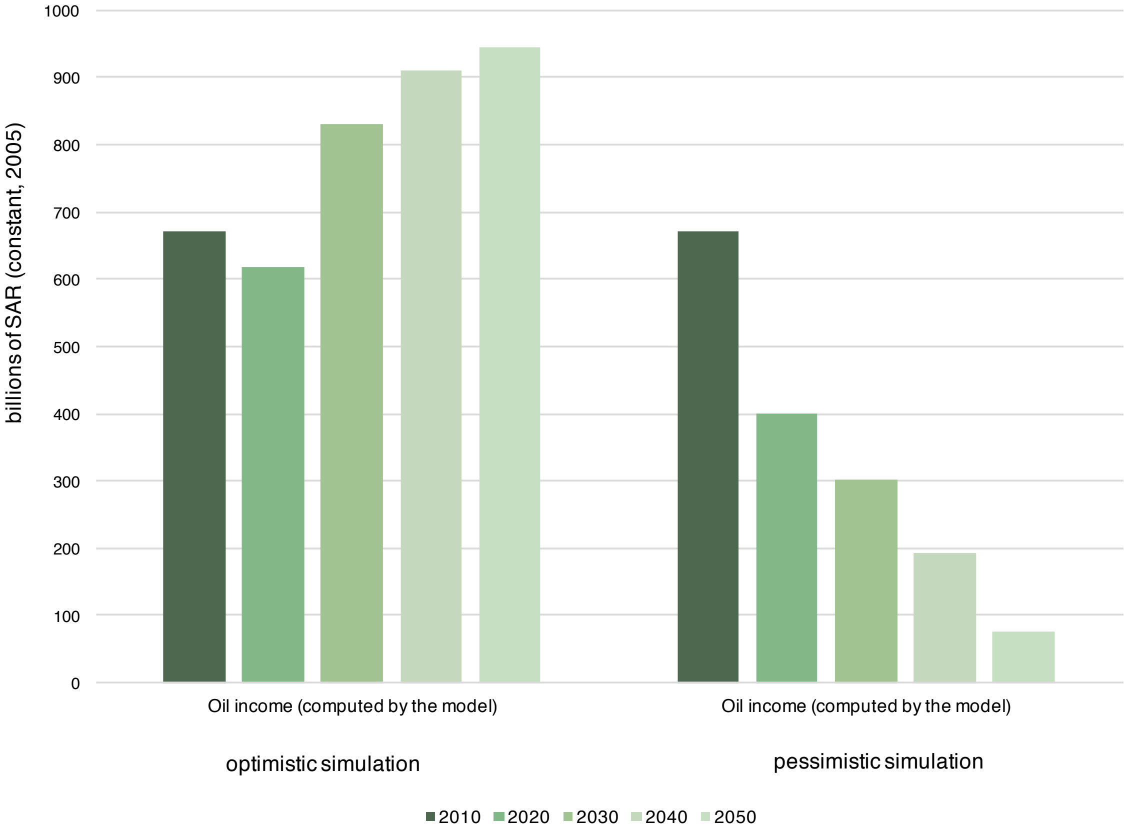


**Figure 4**. Simulation of future KSA oil revenues.

Source: KAPSARC.

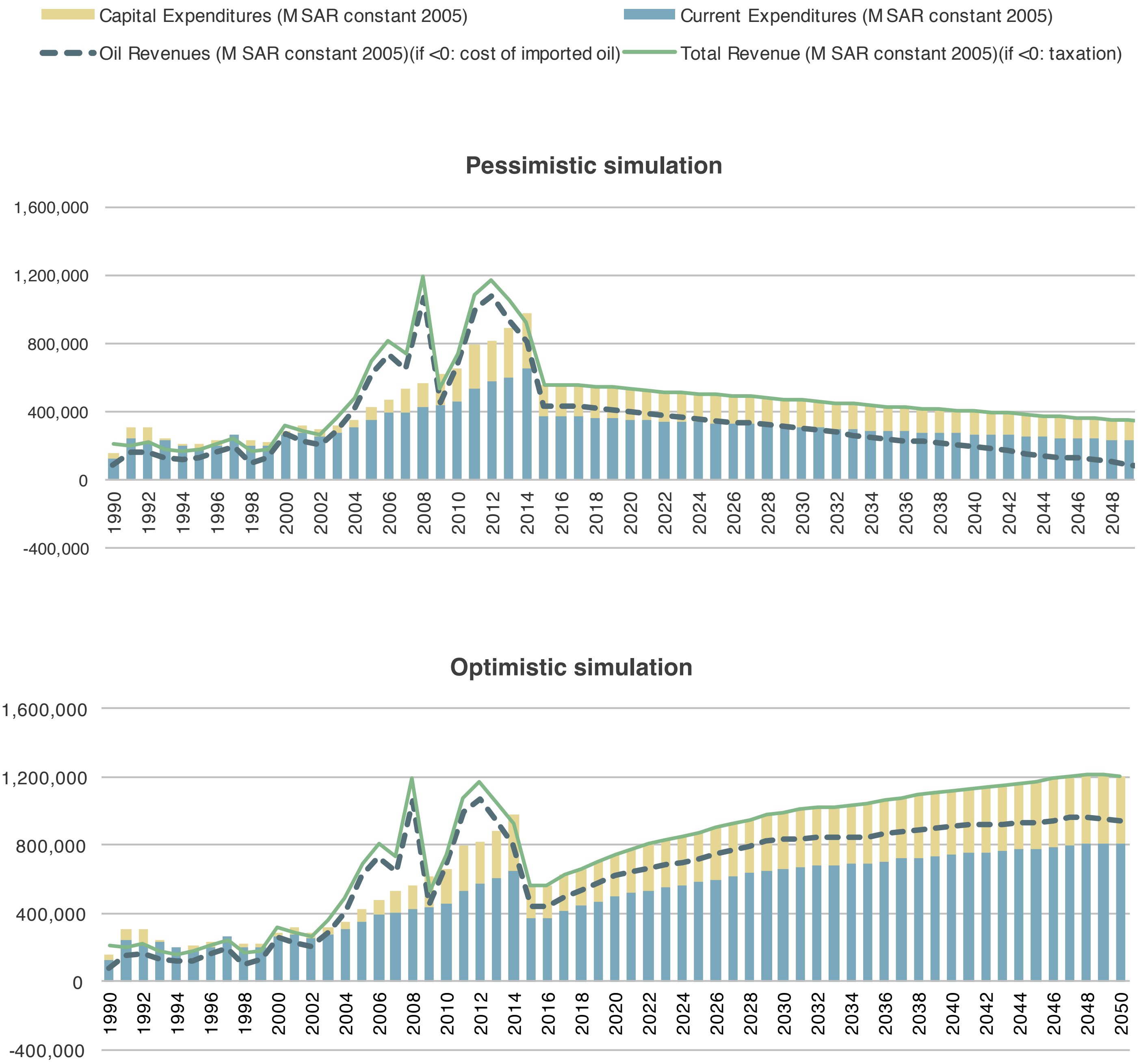


**Figure 5**. Simulation of Saudi public finances in the long-run.

Note: All these variables are computed by the model for futrue periods (they are endogenous).

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## About the Project

Increasing energy productivity holds some of the greatest possibilities for enhancing the welfare countries get out of their energy systems. It also recasts energy efficiency in terms of boosting competitiveness and wealth, more powerfully conveying its profound benefits to society.

KAPSARC and UNESCWA have initiated this project to explore the energy productivity potential of the Arab region, starting with the six GCC countries and later extending to other countries.

Aimed at policymakers, this project highlights the social gains from energy productivity investments, where countries are currently at, and pathways to achieving improved performance in this area.

# Notes

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