ON-LINE APPENDIX TO

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

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ANNEX 1: ADDITIONAL TECHNICAL MATERIAL ABOUT THE MEGIR-SA MODEL

OLG framework

A feature of our OLG framework is that it allows for 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 its citizens 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.

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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 context 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 seven ktoe of coal in 2012.

The $a_{i,j,t}$ weighting coefficients used to compute the weighted energy prices ($q_{i,t}$) are computed using observable data of consumption 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 $D_{non\ elec,t-1}$, $D_{elec,t-1}$, 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 $D_{oil,t}$ and $D_{natgas,t}$.

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

with $D_{non\ elec,t} = D_{non\ elec,t-1}\left\{\left[\frac{E_t}{E_{t-1}}\right] - elast_{subst\ elec,non\ elec}\left(\frac{\Xi_t}{\Xi_{t-1}} - \frac{1+\Xi_t}{1+\Xi_{t-1}}\right)\right\}$ 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 the KSA (i.e., the average weighted price of oil products and natural gas). Then $D_{non\ elec,t} = D_{oil,t} +$

$\mathrm{D}_{nat\ gas,t}$ 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 $\mathrm{Eff}_{el,2,t,therm}$ 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 $\mathrm{D}_{elec,t}$ 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) 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: $\begin{cases} \forall t > 2016;\ \Upsilon_{others,t} = \Upsilon_{others,t-1}\frac{A_t\overline{\varepsilon_t}\Delta_t L_t}{A_{t-1}\overline{\varepsilon_{t-1}}\Delta_{t-1}L_{t-1}} \\ \Upsilon_{others,2016} = \Upsilon_{others,2015}\frac{A_{2016}\overline{\varepsilon_{2016}}\Delta_{2016}L_{2016}}{A_{2015}\overline{\varepsilon_{2015}}\Delta_{2015}L_{2015}} + \sum_{i=1}^{3}([(\mathrm{q}_{i,2016}-\mathrm{q}_{i,2015}) * \mathrm{D}_{i,2016}]) \end{cases}$ 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” ($\Upsilon_{others,t}$) 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 considers this phenomenon 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 and by gender 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 and gender 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/ ξ) is equal to unity 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. In models on Saudi data, Blazquez et al. (2017) use an intertemporal substitution elasticity of 0.5; while Nakov and Nuno (2013) rely on a log function, thus with an intertemporal substitution elasticity tending asymptotically to 1. Our assumption is the mean between the values used by these two latter papers.

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. Blazquez et al. (2017), studying Saudi Arabia, use 0.4. Our assumption is the mean between the values used by these two latter papers.

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 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 the 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%.

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 zero (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).

As concerns the parameterization of the households' program and of the production function presented above, much of the values of the exogenous parameters are set according to studies carried out for other countries than Saudi Arabia, as in Nakov and Nuno (2013) and Blazquez et al. (2017) who both analyze Saudi Arabia. Like these authors, we are not aware of studies assessing these parameters in the specific Saudi context.

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). We checked that our parameterization and calibration allowed for our MEGIR model to fit well with the KSA data relating to the stock of private non-oil capital in the 1990's and the 2000's in Saudi Arabia. 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 unity. 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]; $|(\Xi_t)_d - (\Xi_t)_s| < 1\%$.

ANNEX 2: IMPACT OF A CHANGE IN SAUDI OIL EXPORTS ON THE INTERNATIONAL OIL PRICE AND ASSOCIATED SIMULATIONS.

Background

As explained in the main text, given the very long-run analysis undertaken for this research we assume that a change in Saudi oil exports would not impact on the international oil price; in other words, we assume that the elasticity of the international price with respect to Saudi oil exports is zero. However, there are several reasons to question the zero-elasticity assumption, at least in the short run.[4] Many theoretical models of the world oil market view OPEC and/or Saudi Arabia as a dominant firm leader facing a downward-sloping excess demand curve (*i.e.,* world demand minus fringe supply) of oil (cf. Huppmann and Holz, 2012). Moreover, events suggest that in the past OPEC managed to raise (lower) oil prices by limiting (increasing) its production and lowered the price of oil by increasing its production (Yergin, 2012). Furthermore, several studies have concluded when OPEC's spare capacity is low (high) oil prices tend to be more (less) volatile (Pierru et al., 2018) suggesting that OPEC face a downward sloping demand curve so that any decrease (increase) in oil exports by Saudi Arabia/OPEC would increase (decrease) the international oil price. In which case, a change in Saudi oil exports would impact the international price. That said, there is some evidence to suggest otherwise such as Killian (2009) and Killian and Hicks (2013), which suggests that an oil supply shock does not necessarily trigger a sizeable and long-lasting impact on the international price of oil.

Therefore, although we assume that the elasticity of the international price with respect to Saudi oil exports is zero, given our focus on the very long-run, we felt it would be prudent to check the sensitivity of this assumption given the discussion above. The following sections of Annex 1 details the estimation of the key elasticity and the impact of using this has on the model simulation results.

Conceptual model

Oil prices, like any other prices, can be analyzed using a supply-demand framework (see, Kilian, 2008; Aastveity et al., 2012). Several previous studies modeled oil prices using an augmented supply-demand framework, in which other variables of interest are included in the analysis. For example, in addition to oil supply and demand fundamentals, Wang and Sun (2017) included wars and political tensions, economic policy uncertainty, Kilian and Lee (2014) and Kaufmann (2011)

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[4] We are grateful for an anonymous referee for urging us to consider these issues more than we did initially.

added oil inventories, Liu et al. (2016) considered derivative market speculation, Chen et al. (2016) used political risk and speculation. Additionally, Fan and Xu (2011) assess the impact of the price of gold, among other explanatory variables, on the price of oil. The idea being that gold and oil can be alternatives for each other in international commodity markets. Bataa and Park (2017) examined the separate effect of the USA shale oil production, their variable of interest, alongside global oil production and aggregate demand on the oil price. Our framework, outlined below, is similar to theirs but our variable of interest is Saudi oil exports rather than Saudi oil production. Additionally, we include the prices of natural gas and coal into the analysis inspired by Brown and Yucel (2008), Bachmeir and Griffin (2006), Zamani (2016), Zellou and Cuddington (2012), Villar and Joutz (2006), Asche et al. (2006), and Hartley et al. (2007), who show that the prices of oil and natural gas move together in the long-run.

Therefore, to estimate the key elasticity we used the following specification in the empirical testing and estimation.

$$opar_t = \gamma_0 + \gamma_1 oxs_t + \gamma_2 ocw_t + \gamma_3 opw_t + \gamma_4 npwr_t + \gamma_5 cpwr_t + \psi_t \qquad \text{(A2.1)}$$

Definitions of the variables are given Table A2.1 with all variables entered in Equation (A2.1) in natural logarithm form and hence expressed in lower case. Given this, the coefficients γ_i represent the elasticities to be estimated econometrically, in particular γ_1 is the elasticity of the real international oil price with respect to Saudi oil exports. ψ_t is the error term. Equation (A2.1) expresses the real price of Arabian light (*opar*) as a function of Saudi crude oil exports (*oxs*), world oil demand (*ocw*), world oil supply excluding Saudi exports (*opw*) and the real price of the substitutive goods, i.e., natural gas (*npwr*) and coal (*cpwr*).

We also estimate and test Equation (A2.2), in which both the demand- and supply-sides are represented by the world GDP (also defined in Table A2.1).

$$opar_t = \delta_0 + \delta_1 oxs_t + \delta_2 gdpw_t + \delta_3 npwr_t + \delta_4 cpwr_t + \omega_t \qquad \text{(A2.2)}$$

Where again all variables are in natural logarithms so the coefficients δ_i represent the elasticities to be estimated econometrically, with in particular intercept δ_0 and ω_t is the error term. Thus Equation (A2.2) is used as a robustness check of estimated elasticity δ_1 to the estimate from Equation (A2.1), γ_1.

Data and methodology

We use annual time series data over the period 1980-2017 in the empirical analysis. Table A2.1 documents the variables, their notation, description and sources.

Table A2.1: Notation, Description and Source of the Variables

Notation	Description	Source
OPAR	World Real Crude Oil Spot Price: Arabian Light, US$ per barrel, deflated by US CPI	SAMA and BLS
OXS	Saudi Exports of Crude Oil, million Barrels.	SAMA
OCW	World Petroleum Consumption, million barrel	EIA*
OPW	World Production of Crude Oil including Lease Condensate, million barrel	EIA
OPW	World Production of Crude Oil including Lease Condensate less KSA Crude Oil Export, million barrel	Authors' own calculation**
GDPW	World Gross Domestic Product, Billion $2010 PPP	EIA
NPWR	World Real Gas Price, deflated by US CPI, 2010=100	WB/HA and BLS
CPWR	World Real Coal Price, deflated by US CPI, 2010=100	WB/HA and BLS

Note: SAMA=Saudi Arabian Monetary Authority; BLS=Bureau of Labor Statistics; EIA= U.S. Energy Information Administration; WB=World Bank; HA=Havier Analytics; * Since the EIA data ends in 2015, we applied the same growth rate of 2015 to calculate the values for 2016 and 2017. The calculated values are very close to those from the Oxford Economics Global Economic Model Database.** We exclude Saudi crude export from the world production of crude oil to avoid double accounting and potential econometric issues that this can cause;

Cointegration and error correction modeling methodology is employed for the empirical testing and estimation. We first check integration properties of the data, applying the Augmented Dickey-Fuller (ADF, Dickey and Fuller, 1981) unit root test to check stationarity of our variables. As a robustness check, we also use ADF test with structural breaks developed by Perron (1989), Perron and Vogelsang (1992a, 1992b), and Vogelsang and Perron (1998). The Autoregressive Distributed Lags Bounds Testing (ARDLBT) method is employed to test for the existence of the cointegration and estimate the long-run relationship between our variables. The ARDLBT method is selected because it outperforms its counterparts and yields more consistent results in small samples (Pesaran and Shin, 1999; Pesaran et al., 2001). To have robust interferences about the cointegration properties of the variables, we use small sample bias correction in the ARDLBT by applying Narayan (2005) critical values.

Results of the Empirical Analysis.

All the variables are found to be non-stationary in their log-level and stationary in the first difference of their log-level. In other words, the variables follow the integrated order of one, I(1) process. The unit root test results are not reported here and the details are available from the authors under request.

The maximum lag order is set to three and the Schwarz information criterion is preferred to pick up the optimal lag length (see Pesaran and Shin, 1999; Pesaran et al., 2001) in the ARDLBT analysis. To make sure that estimated long-run coefficients are accurate and can be used for analysis, both estimated specifications are tested for the residual diagnostics (serial correlation, autoregressive conditioned heteroscedasticity, ARCH, heteroscedasticity, and normality tests) as well as functional mis-specification. Then the bounds test for cointegration is conducted and if the test results indicate that there is a cointegrating relationship between the variables, finally, long-run elasticities are estimated. Table A2.2 below documents the results of the post-estimation tests, the cointegration test as well as the estimated long-run coefficients for equations (1) and (2).

Table A2.2. ARDL estimation and test results.

Equation:	*(1)*		*(2)*	
Selected specification:	*ARDL(2,2,0,0,0,3)*		*ARDL(1,2,0,1,2)*	
Test results of the Residual diagnostics, Mis-specification and Cointegration				
$\chi^2_{SC}(2)$	0.49	0.62	0.54	0.59
$\chi^2_{ARCH}(2)$	2.07	0.16	1.25	0.30
$\chi^2_{HETR}(15)$	0.93	0.54	0.75	0.66
JB_N	1.78	0.41	0.78	0.68
F_{FF}	0.43	0.52	0.26	0.61
F_W	14.56^{*A}		4.74^{*B}	
Estimated long-run elasticities				
Regressor	***Coef.***	***Prob.***	***Coef.***	***Prob.***
oxs	**-0.47**	**0.00**	**-0.43**	**0.02**
ocw	4.56	0.02	-	-
opw	-3.54	0.04	-	-
npwr	0.79	0.10	0.85	0.00
cpwr	0.79	0.02	0.86	0.00
gdpw	-	-	0.65	0.00

Notes: *opar* is the dependent variable in the estimations; F_{SC}, F_{ARCH}, F_{HETR}, F_{FF} *and* F_W denote F statistics to test the null hypotheses of no serial correlation, no autoregressive conditioned heteroscedasticity, no heteroscedasticity in the residuals and no functional form mis-specification and no cointegration in the Wald test, respectively; JB_N indicates the Jarque–Bera statistic to test the null hypotheses of normal distribution of the residuals. α denotes SoA coefficient; * indicates that sample statistic is greater than upper bound of the critical value of Pesaran et al. (2001) at the 1% significance level in the given combination of the regressors and Intercept is included in the long-run equation. ^{A} and ^{B} indicate that sample statistic is greater than upper bound of the critical value of Narayan (2005) at the 1% and 5% significance levels, respectively in the given combination of the regressors, number of observations and Intercept is included in the long-run equation. ***Coef.*** and ***Prob.*** mean coefficient and its probability. Constant is omitted for simplicity; Estimation period: 1983–2017.

Discussion of the Results

We find a cointegrated relationship between the Arabian light oil price and its determinants in both specifications even after applying the small sample bias correction, which is consistent with our *a-priori* expectations that the relationship between the real oil price and its determinants is in line with the supply-demand framework. The numerical results of the relationships are given in Table A2.2. and, *ceteris paribus*, suggest that a 1% increase (decrease) in the Saudi oil export leads to a 0.43-0.47% decrease (increase) in the real price of the Arabian light. Hasanov et al. (2017), *inter alia*, discuss that Saudi Arabia's share in the world's proven oil reserves with the amount of 16.2% is higher than that of the North American region (13.3%) and the combined total of Africa, Asia & Oceania, and Europe

(11.2%) in 2014. They further discuss that Saudi was the number one oil exporter in the world by holding 17% of the total world crude oil exports in 2015 and produced 12.7% of the total world crude oil including lease condensate during 2010-2014.

Given our main interest in this indicative econometric analysis is to ascertain what the impact of a change on Saudi crude oil exports might have on the real price, we do not discuss in detail the impacts of the other explanatory variables here. However, it is worth mentioning that they also have economically expected, and statistically significant effects and findings are consistent with those of the earlier studies mentioned above.

Our estimates of the elasticity of the real oil price to Saudi oil exports of somewhere between -0.43% and -0.47% stems from an econometric analysis using data over the relatively recent past. The very long run elasticity however might well be lower. For example, Blazquez et al. (2018), using an analytical relationship parametrized on real Saudi data, suggest a value of -0.3. Thus we feel it is prudent to assume a value -0.5 as an alternative to that in the main text, which assumes that this key elasticity is to zero. The results of the alternative model simulations are therefore discussed below.

Alternative results for the MEGIR-SA model

Formally, the price of the barrel of oil in the simulations of the model is defined as $\text{barrel}_{oil,t} = \left[\text{barrel}_{oil,t-1}(1 + trend_{barrel})\right]\left(1 - \varepsilon_{barrel/oilexp}\left[\frac{\text{EXP}_{oil,t}}{\text{EXP}_{oil,t-1}}\right]\right)$ where $\varepsilon_{barrel/oilexp}$ is the long-run elasticity of the price of a barrel of Saudi exports. For reasons explained in the main text, the baseline value is set at 0. Here, we examine the consequences of setting $\varepsilon_{barrel/oilexp} = -0.5$. The quantitative impact of the hypothesis about the elasticity of the price of a barrel to Saudi exports remains relatively contained in our model as far as households' intertemporal welfare is concerned.

Compared to the scenarios with a zero elasticity of the price of oil to Saudi exports, the declining profile of the price of oil over time in all scenarios entails an upward impact on the price of oil when this elasticity is set at -0.5. In scenarios B, the intertemporal profile of Saudi oil exports declines relatively slowly at least up to the 2040s: thus the effect of endogenizing the price of oil builds up progressively and begins to materialize significantly in the 2040s. In scenarios C, the decline of future Saudi oil exports is steeper, and so the upward effect on oil prices is stronger. This effect accounts for the fact that the impact of the reform on the households' intertemporal welfare is slightly higher when the elasticity is -0.5 rather than 0.

Compared to the no-reform, baseline scenario A, the upward impact of the Saudi oil exports stemming from higher administered energy prices on the domestic market (scenarios B and C) triggers a downward influence on the price of oil when the elasticity is assumed to be -0.5. This impact kicks in from the implementation of the reform onwards. For scenarios B, this effect accounts for the fact that the impact of the reform on the households' intertemporal welfare is slightly lower when the elasticity is -0,5 rather than 0.

Figures A2.1 to A2.4 compare the results when the elasticity of the price of oil to the Saudi oil exports is 0 (left panel, identical to the graphs in the main text) and when it is -0,5 (right panel).

Figure A2.1 *(with no reaction of the price of oil to Saudi export (left panel, see main text) or an elasticity of -0.5 (right panel))*

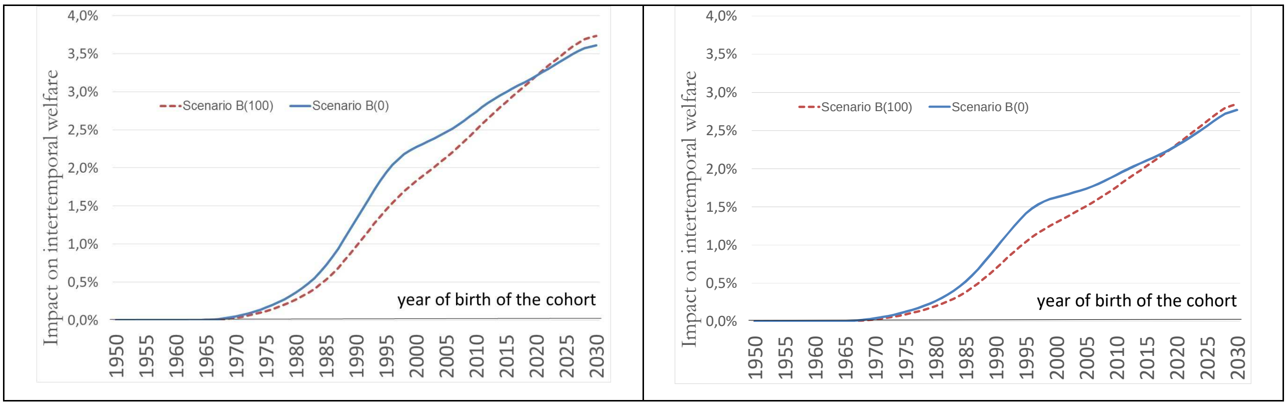


Figure A2.2 *(with no reaction of the price of oil to Saudi export (left panel, see main text) or an elasticity of -0.5 (right panel))*

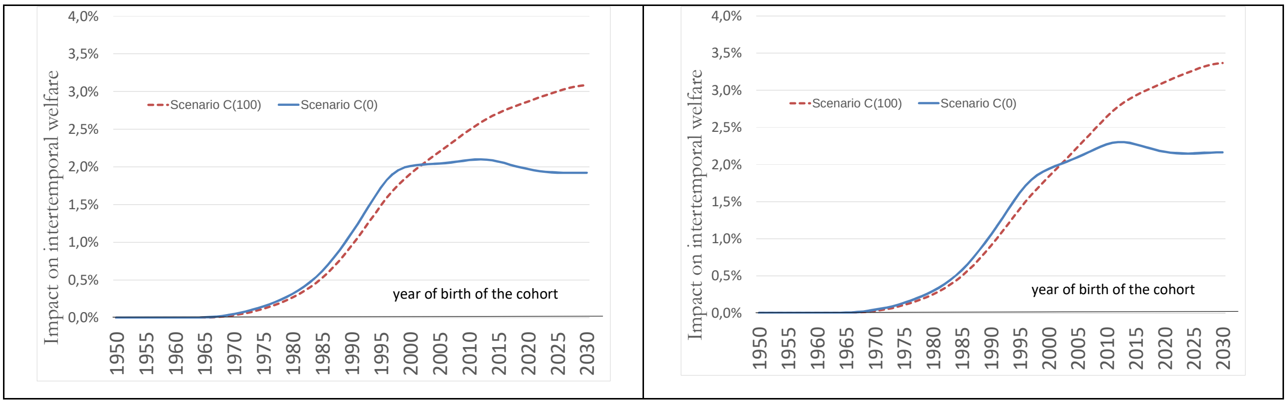


Figure A2.3 *(with no reaction of the price of oil to Saudi export (left panel, see main text) or an elasticity of -0.5 (right panel))*

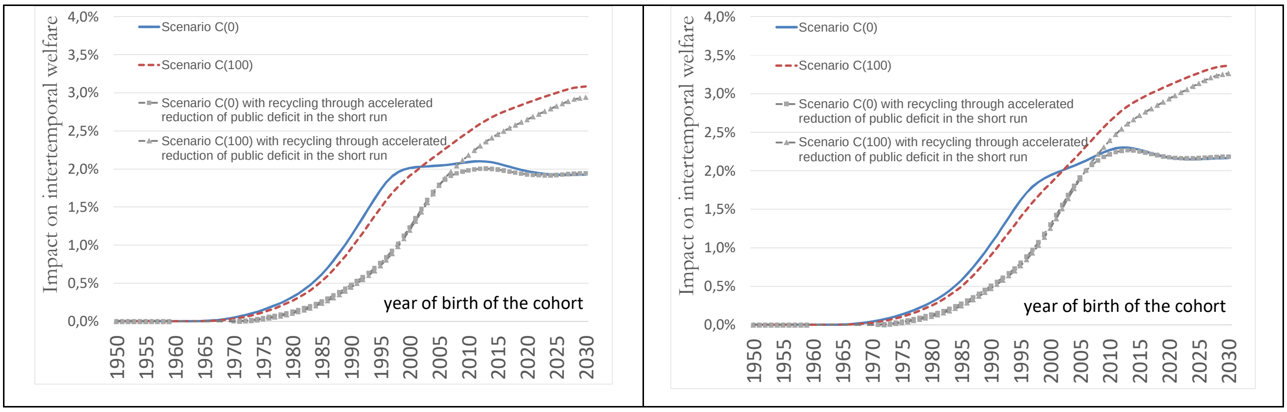


Figure A2.4 *(with no reaction of the price of oil to Saudi export (left panel, see main text) or an elasticity of -0.5 (right panel))*

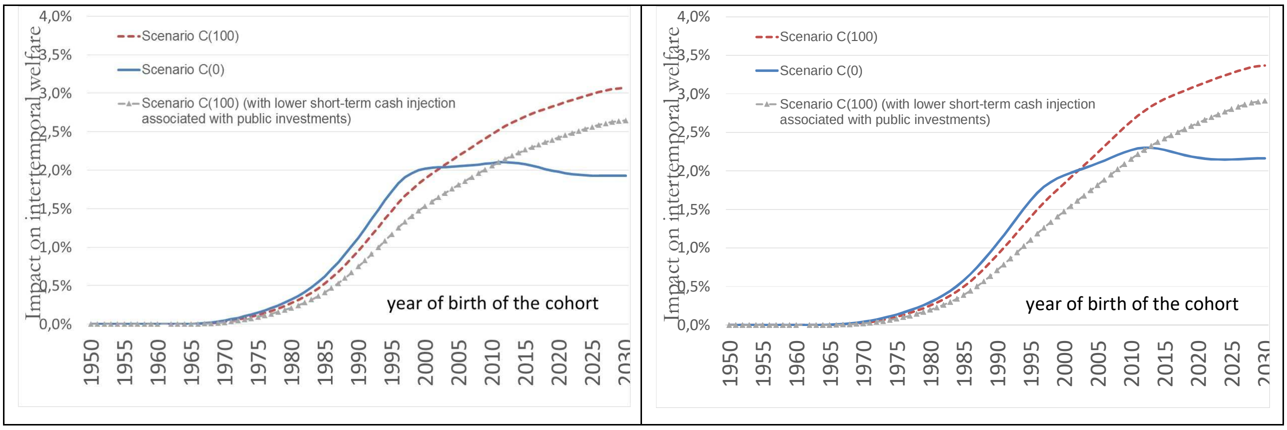
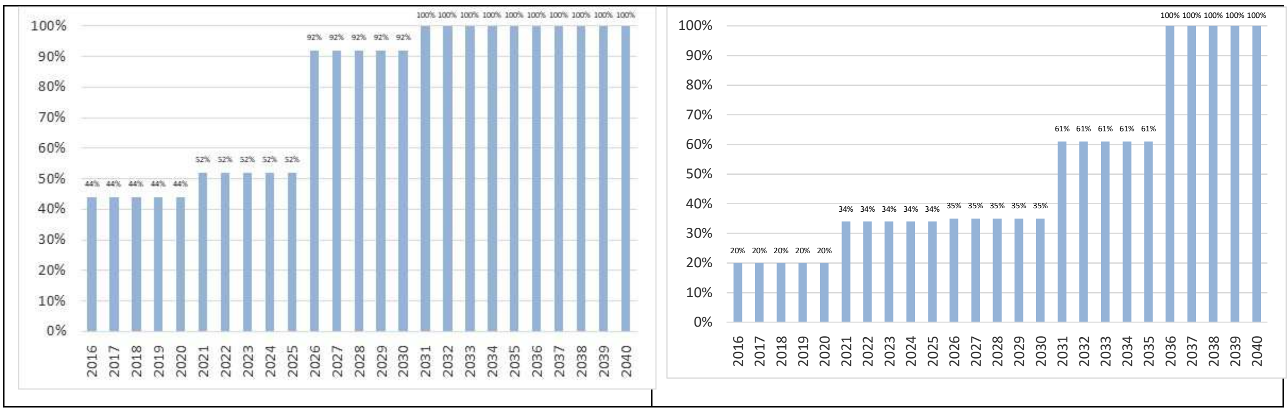


Figure A2.5 *(with no reaction of the price of oil to Saudi export (left panel, see main text) or an elasticity of -0.5 (right panel))*



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Note: this list of references only includes the additional references quoted in this On-Line Appendix. The references quoted in the main article are presented at the end of this main article.

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