Sectoral and Economy-Wide Effects of Domestic Energy Price Reforms in Saudi Arabia

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Key Points

This paper simulates the sectoral and economy-wide consequences of deregulating energy prices in Saudi Arabia. Our analysis is based on KAPSARC's general equilibrium energy model (KEMGE), a new hybrid computable general equilibrium model (CGE). The model examines the effects of full price deregulation, starting in 2019, on economic activity and revenues in the year 2030. KEMGE extends a previous KAPSARC energy model to simulate various domestic pricing policies as part of broader fiscal reforms. It then can be used to assess the consequences of price reforms on energy sector activity, economic growth, energy-related CO₂ emissions, and households' consumption. The bottom-up part of the model represents in detail the effects of policies across the energy-intensive sectors. The CGE modeling framework takes into account the effects of energy price reforms on sectors outside the energy-intensive sectors, not least through the government's budget and domestic investments. It also captures the feedback effect of changes in Saudi exports on oil prices. When comparing the simulation of deregulation scenarios with a baseline of current policies and an Arab Light oil price of around US\$70 per barrel (in 2018 US\$), in the long run, we obtain the following conclusions:

- Full price deregulation increases gross domestic product (GDP) by 3%-6%, compared with a baseline, with administered prices at their 2018 levels. The GDP gains come mainly from an increase in oil export revenues.
- The price reforms are beneficial to the non-energy-intensive sectors if the revenue the reforms generates is used for additional domestic investment instead of being saved overseas.
- Price reforms without additional investments in the non-energy sector may not be beneficial to households unless they receive cash transfers or some other monetary compensation.
- There is a trade-off between revenue-recycling policies that directly support household income (i.e., cash transfers), and policies that contribute to increased activity in the non-energy sector as a result of higher investment.
- Full price-deregulation would reduce Saudi Arabia's energy-related carbon dioxide (CO₂) emissions by around one third by 2030, compared with our baseline.

Summary

Administered energy prices have played a key role in Saudi Arabia's socio-economic development. However, they have numerous adverse effects because they induce a wasteful use of energy resources. Over recent years, Saudi Arabia has reformed its administered energy pricing, as part of its broader objective to reform its economy in accordance with Saudi Vision 2030, its blueprint for economic diversification. In 2016, the first wave of Saudi Arabia's fuel price reform increased domestic gasoline, diesel and electricity prices by up to 80%. In 2018, the second wave of fuel price reform once again raised domestic gasoline and electricity prices significantly. Targeted cash transfers through the Citizen's Account Program have helped to mitigate the adverse impacts of these reforms on the livelihoods of low-income households. The reforms have contributed to a reduction in electricity and transportation fuel consumption, and have reduced the costs to the government of administered prices.

In this paper, we assess the economic consequences in 2030 of administered fuel price reforms. We use KAPSARC's general equilibrium energy model (KEMGE), a new modeling framework that integrates the KAPSARC Energy Model (KEM) of energy-intensive sectors, with a computable general equilibrium model (CGE) that represents the rest of the economy. KEM shows how administered prices influence energy flows among the energy and energy-intensive sectors. The CGE model stages transactions among firms, households, the government and the rest of the world.

KEMGE captures the direct effect of fuel price reforms on energy consumers. It also represents the indirect feedback effects of these reforms through public finance, current account and investment. These feedbacks are particularly important because they represent how 'revenue effects' combined with

consumer price increases can determine the overall impact of the reforms.

KEMGE fully integrates the KEM and the CGE with a 'hard link.' The formulation and numerical solution of the models pose several difficulties. We manage to solve KEMGE by implementing a dedicated solution algorithm that consists of a Jacobi iteration between the KEM and the CGE model.

Our policy scenarios represent the full deregulation of administered prices, where they align with international benchmarks. Each policy scenario corresponds to a specific scheme for recycling the revenue obtained from the reforms: the consolidation of public finance, transfers to households, and investment in the non-energy sector.

Our simulations show that full fuel price deregulation would increase Saudi gross domestic product (GDP) by 3%-6% in 2030, compared with our baseline case where domestic energy prices remain at their 2018 level and where the Arab Light oil price remains around US\$70 per barrel in the long run. Higher energy prices trigger fuel switching and investments in energy efficiency. Crude oil exports rise and generate additional fiscal revenue, despite increased exports lowering world oil prices. Solar photovoltaic generation becomes the most competitive electricity technology and is deployed at scale. This is because thermal generation is no longer supported by low administered fuel prices. Fuel price deregulation reduces Saudi Arabia's energy-related carbon dioxide (CO₂) emissions by around one third at horizon 2030 compared with the baseline. Energy price reforms, where the additional revenue generated is assigned to budget consolidation, reduces households' real income. However, fuel price reforms combined with transfers and/or investment increase households' revenue.

The greatest positive impact on GDP is when the additional revenue is channeled to investments in the non-energy sector. In this case, the increase in

aggregate demand stimulates activity in the short run and capital deepening increases GDP in the long run.

Introduction

In Saudi Arabia, as in the other Gulf Cooperation Council (GCC) countries, domestic energy prices are administered and remain below international benchmarks. However, Saudi Arabia has started increasing fuel prices. In 2016, Saudi Arabia initiated its first fuel price reform. As a result, domestic gasoline, diesel and electricity prices increased by up to 80%. A second wave of fuel price reform was implemented in 2018, with domestic gasoline and electricity prices once again rising significantly. The same year, the government's Citizen's Account Program targeted cash transfers to low-income households to mitigate the adverse impacts of higher energy prices on their livelihoods. The reforms have contributed to lower electricity and transportation fuel consumption and have reduced the costs to the government of administered prices, freeing up a portion of the government's budget.

The reforms are in line with the standard tax policy analysis where administered prices are distortions that cause a deadweight loss of total welfare compared with fully deregulated prices. Fixed prices create incentives that do not reflect the benefits of consuming domestically available energy commodities and the opportunity cost of not selling them on international markets. Hence, low administered energy prices often lead to wasteful energy consumption, high energy-related carbon dioxide (CO₂) and air pollutant emissions. Administered prices also have a cost to governments, which have to spend significant portions of their budgets to supporting domestic utilities, instead of investing to increase long-term growth or focusing on growth-enhancing tax reforms. Lastly, the redistributive performance of price controls is poor in that higher income groups consume significantly more energy than lower income groups. Administered prices are, if not simply regressive, less progressive than other social policies.

However, administered prices have played a key role in Saudi Arabia's economic development and diversification efforts. Therefore, we still need to evaluate the overall cost of price regulation and the trade-offs associated with it. Saudi Arabia has based its economic diversification strategy on export-oriented energy-intensive industrial sectors whose competitiveness depends on low energy and feedstock prices. Therefore, policies that increase domestic energy prices, if they are not accompanied by other offsetting measures, may reduce the role of these industries in economic development.

Household transportation fuel consumption is high due to the specific features of the country: the urban sprawl, the lack of public transportation, and habits forged in years of very low fuel prices. Electricity demand is high because of the need for air conditioning and desalinated water. Hence, compensation mechanisms are important to make price reforms beneficial to the households.

This paper simulates the sectoral and economy-wide consequences of deregulating energy prices in Saudi Arabia. Our analysis is based on KAPSARC's general equilibrium energy model (KEMGE), a new hybrid computable general equilibrium model (CGE). The model examines the effects of full price deregulation, starting in 2019, on economic activity and revenue in the year 2030. KEMGE extends the KAPSARC energy model (KEM) to simulate various domestic pricing policies as part of broader fiscal reforms. It then can be used to assess the consequences of the country's price reforms on its economic growth, economic diversification and social objectives. The bottom-up part of the model represents in detail the effects of policies across the energy-intensive sectors. The CGE modeling framework takes into account the effects of energy price reforms that are channeled outside the energy-intensive sectors, not

least through the government's budget and domestic investments. When comparing the simulation of deregulation scenarios with a baseline that assumes a continuation of current policies and an Arab Light oil price of around US\$70 per barrel (in 2018 US\$) in the long run, we obtain the following conclusions:

Full price deregulation increases gross domestic product (GDP) by 3%-6%, compared with a baseline where administered prices remain at their 2018 level. The GDP gains come mainly from an increase in oil export revenues.

The price reforms are beneficial outside of the energy-intensive sectors if the revenue the reforms generate is translated into additional domestic investment instead of being saved overseas.

Price reform without additional investments in the non-energy sector may not be beneficial to households unless they receive cash transfers or some other monetary compensation.

There is a trade-off between revenue-recycling policies that directly support household revenue (i.e., cash transfers), and budget consolidation policies that contribute to increased activity in the non-energy sector thanks to higher investment.

Full price deregulation would reduce Saudi Arabia's energy-related CO₂ emissions by around one third by 2030, compared with our baseline.

The rest of the paper is organized as follows. Section 2 highlights the gaps between the industry-level and the macro-level analyses of price reforms, and explains how an integrated hybrid modeling framework combines the respective merits of these types of analyses. Section 3 describes our hybrid modeling framework. In section 4, we detail the key transmission channels from the energy price reforms to the rest of the economy and represent them in our policy scenarios. Section 5 gives our simulation results. Section 6 concludes.

Top-Down and Bottom-Up Modeling of Energy Price Reforms

Bottom-up modeling analysis of Saudi Arabia's energy price reforms

The KEM model of Matar et al. (2013) is the only bottom-up model of Saudi Arabia's energy-intensive sectors. It represents, as a mixed complementarity problem (MCP), the various energy-intensive sectors and how they interact to serve fixed demand under an administered prices regime.¹ Matar et al. (2015) determine the administered prices and investment credits that considerably reduce energy system costs while sheltering end-consumers from price increases. The reduction in system costs is a result of higher inter-industry transfer pricing for oil that induces fuel switching and investment in fuel-efficient technologies in the power and the water sectors. Matar et al. (2017) extend the analysis to a multi-period setting and stress the benefits of policy packages that combine price reforms, investment credits and feed-in tariffs. Matar (2017) studies households' electricity pricing policies and finds that 'time of use' electricity pricing would curb electricity consumption and increase the efficiency of the electricity sector by reducing oil-fired power generation and phasing out low-efficiency gas turbines in favor of combined-cycle units and non-fossil technologies. Matar and Anwer (2017) stress that households' electricity price reforms induce larger gains for the energy system when they are combined with transfer price reforms. This policy mix increases the availability of natural gas, thus improving the competitiveness of energy-intensive export-oriented sectors. Finally, Wogan et al. (2019) use KEM to explore how various policies can contribute to CO₂ emissions mitigation in the power sector. They highlight the greater benefit of price deregulation over portfolio and clean

energy standards in terms of mitigation and energy system costs.

One of the limitations of the analyses with the bottom-up models is that they do not include the feedback effects of the pricing policies outside the energy sector. These feedbacks are particularly important in Saudi Arabia where oil represents around a third of GDP and 70% of the government's revenue.² Pricing policies influence the government's budget, household real income and the current account balance. The government can use the revenue generated by fuel price reform to finance transfers to households or to fund investments aimed at offsetting some of the unintended effects of the reform. Top-down macroeconomic models extend the scope of the bottom-up analysis and examine how price policies interact with other governmental interventions, not least with public spending, to reach a desirable outcome.

Top-down modeling analysis of energy policies in Saudi Arabia

The top-down models are especially suited to analyzing the consequences of energy policies or energy price reform. They represent how economic agents are impacted directly or indirectly by such policies. Some studies have used general equilibrium models for Saudi Arabia to study energy policy issues. Nakov and Nuno (2013) use a stylized general equilibrium model for Saudi Arabia, with a representative fringe oil producer and a representative oil-importing economy. They show that Saudi Arabia's decisions on oil production and spare capacity can be explained by its dominant firm behavior and its low production costs. Blazquez et al. (2017) use a stylized dynamic general equilibrium model to assess the benefits of large-scale solar

deployment in Saudi Arabia. They determine the welfare-maximizing rate of solar penetration and find that it depends on integration costs. They stress that more solar generation makes the country more vulnerable to oil price fluctuations. Gonand et al. (2019) study energy price reforms using a dynamic overlapping-generations model. It contains a representation of the country's budget balance and the possibility of the government using the revenue generated by the price reform to finance public investment spending. They highlight the overall beneficial impact of increasing retail energy prices and show how this can benefit future generations more when the revenue generated by the price increases finances public investment.

Two studies on price reform use multi-sector CGE models. They combine broad insights from macroeconomic models with a detailed description of the sectoral consequences of the policy. This type of approach helps to assess policies that stimulate the economy, or some sectors in particular, while meeting some budget consolidation objectives. Soummane et al. (2019) use a recursive CGE model calibrated on a 2013 social accounting matrix (SAM) and exogenous energy trajectories drawn from the KEM model. They show that reforms aimed at improving energy efficiency, when combined with directing additional oil export revenues into supporting selected industries, can partially offset the detrimental impacts of an exogenous drop in international oil prices. Roos and Adam (2019) use a multi-period recursive CGE model of Saudi Arabia with 57 sectors. They stress that removing subsidies improves the efficiency of resource use, and that budget-neutral compensation payments for Saudi nationals offset the negative effect of increases in energy prices on their real incomes. They also stress that removing subsidies without targeted sectoral support leads to negative outcomes for energy-intensive industries.

One problem with 'top-down' models is that they provide over-simplistic representations of price controls, which makes them particularly unfit for analyzing the energy policies of Middle East and North Africa (MENA) countries. In top-down models, price controls are approximated by an exogenous price wedge between the cost of delivering commodities and their market prices. The price wedges are calibrated on aggregated inventories of energy subsidies, such as IEA (2020). This approach has serious limitations when it comes to representing very specific policy packages, in particular when domestic prices are fixed.

Top-down models also lack technological detail. They are built from aggregated macroeconomic production functions that miss key technological constraints. The bottom-up approach is more appropriate than top-down models for studying the deployment of new technologies and their complex interactions. For example, Matar et al. (2015) show that in Saudi Arabia, at low penetration levels of solar photovoltaic (PV) generation, solar PV and natural gas are substitutes in electricity generation. They also stress that, at higher levels of solar PV penetration, solar and natural gas become complements, substituting for baseload nuclear generation. None of the standard production functions can allow for this shifting relationship, which results from having a load curve that captures the amount of capacity needed at different time segments throughout the day.

No study on price reforms in Saudi Arabia, or in any other GCC or MENA country, has used a hybrid modeling framework that is able to combine both the detail of a bottom-up model and the high-level analysis of a top-down approach. However, hybrid models have been used for energy and environmental policy analysis in other regions of the world.

Hybrid models for energy policies

There are several examples of applied general equilibrium modeling frameworks that combine a top-down representation of economics activities with a detailed, bottom-up representation of specific sectors. These approaches belong to three categories: i) the top-down oriented approach where a standalone top-down model (in general a CGE) is calibrated on bottom-up information; ii) soft-linking, where a few variables link a bottom-up model with a top-down model; and iii) hard-linking, integrating a bottom-up model and a top-down model within a single general equilibrium model.

In the top-down approach, the technology costs determined in a bottom-up model are used to calibrate the macroeconomic functions of the top-down model (McFarland et al. 2004; Wing 2006). The same approach was followed by Peters (2016), who expanded the power sector representation of the Global Trade Analysis Project (GTAP) model (Corong et al. 2017). Nevertheless, the top-down-oriented methods use a very small portion of the information available in bottom-up models. Therefore, the responses to policy shocks in the top-down models do not incorporate the physical constraints that characterize energy systems.

In the soft-link approaches, top-down and bottom-up sub-models are solved iteratively and exchange information at each iteration until a fixed point is found (Hoffman and Jorgenson 1977; Messner and Schrattenholzer 2000; Martinsen 2011; Andersen et al. 2019). The models that are linked together may be of different types and based on different behavioral assumptions. Authors argue that soft-linking has the advantage of keeping the respective merits of both sub-models (Hartwig et al. 2017). In addition, since the sub-models are

not tightly connected, it is possible to adjust for inconsistencies in data and model definitions by modifying the solutions that flow from one model to the other during the iterative process. However, soft-linking methods suffer from the lack of a solution concept that can anchor the search for a fixed point. Simulations from soft-linking models are more difficult to interpret since responses to shocks may result from fundamentally different adjustment mechanisms within each of the two models.

In the hard-link approach, the top-down and the bottom-up sub-models are integrated into a single model. This approach is appealing since it captures sectoral details and economy-wide feedbacks in a fully consistent framework with a well-defined solution concept. The responses it produces to exogenous shocks are driven by the optimization behavior of the economic agents. Hence, the results are easier to interpret using the concepts of neoclassical economic theory. ETA-Macro (Manne 1977), MARKAL-MACRO (Manne 1992), and TIMES-MACRO (Remme and Blesl 2006) are examples of hard-linking where a large-scale energy model is coupled with an aggregate one-sector model of the rest of the economy.

When there are price controls, as in Saudi Arabia, the integrated model underlying the hard-link approach has to be formulated as an MCP. The formulation of the MCPs for such models is presented in Böhringer (1998) and illustrated in Böhringer and Löschel (2006). In practice, the formulation of the integrated MCP model may be difficult to implement, especially if there are many primal and dual variables shared between the bottom-up and the top-down models.

Böhringer and Rutherford (2009) present a method to solve the hard-link equilibrium using a decomposition technique. They introduce a solution algorithm based on a Jacobi iterative procedure

between two sub-models. They solve the top-down model as an MCP, while the bottom-up model is solved as a quadratically constrained program (QCP) that portrays a partial equilibrium problem, with a linear demand response calibrated on the prices and quantities from the top-down model. The quantities from the QCP are then passed to the top-down model, which determines the corresponding

prices. The prices and quantities are then used as new reference points for the calibration of the linear demand function used in the QCP. This decomposition method has been successfully implemented by Tuladhar et al. (2009), Rausch and Mowers (2014) and de Maere d'Aertryck et al. (2014) in hybrid energy-economy models.

The KEMGE Modeling Framework

KEMGE is a hybrid computable general equilibrium model that represents Saudi Arabia as an open economy. The bottom-up part of the model corresponds to KEM and represents six energy-intensive industries using linear models, and whose input and output prices can be either administered or deregulated. If the prices are deregulated, KEM is a linear programming representation of competitive industries, or, equivalently of large businesses without pricing power. The top-down part of KEMGE represents the rest of the economy in a CGE.

The KEM model for the bottom-up representation of industries

KEM represents energy-intensive industries: oil upstream; oil refining; petrochemicals and fertilizers; electricity, water and cement. N denotes the set of industries ($\text{card}(N)=n=6$). Each industry produces, imports and exports multiple products.³ O denotes the set of these products ($\text{and } \text{card}(O)=o$). The set of products produced by industry i is denoted by O_i ($\text{and } \text{card}(O_i)=o_i$). Each product is produced by only one industry,⁴ i.e. $O_i \cap O_j = \emptyset, i \neq j$.

Each industry i produces, imports, exports and sells domestically o_i different products in order to maximize profits Π_{e_i} , hence, for each $i \in N$,

$$\Pi_{e_i} = \max \left\{ \begin{array}{l} p'_{f_i} e_{f_i} + \sum_{j \neq i} p'_{q_{j,i}} e_{q_{j,i}} + p'_{int_i} e_{x_i} \\ - \sum_{j \neq i} p'_{q_{i,j}} e_{q_{i,j}} - (1 + tc) p'_{int_i} e_{m_i} - p'_x x_{e_i} \end{array} \right\} \quad (1)$$

Where:

p_{f_i} and e_{f_i} are vectors of dimension o_i of prices and quantities of sector i products sold to other sectors (i.e., non-industry sectors).

$p_{q_{j,i}}$ and $e_{q_{j,i}}$ are vectors of dimension o_i and are transfer prices and quantities of products of sector i that are inputs to sector j .

p_{int_i} , e_{x_i} and e_{m_i} are vectors of dimension o_i of international prices, export and import quantities; tc is a transportation cost.

p_x and x_{e_i} are vectors of dimension o_i of the prices and quantities of Armington goods required to produce each output of sector i . There is a single price for the Armington good, hence all the columns of p_x contain the same value.

The linear activity system of each sector $i \in N$ can be described as:

$$e_{f_i} + \sum_{j \neq i} e_{q_{j,i}} + e_{x_i} \leq e_{p_i} + e_{m_i} \quad (\lambda_{e_i}) \quad (2)$$

$$\sum_{j \neq i} A_{i,j} e_{q_{i,j}} + C_i x_{e_i} + u_i \leq B_i e_{p_i} \quad (\mu_i) \quad (3)$$

Equation (2) is the product balance at the sectoral level: the total sale of products (to final consumers, other sectors and foreign customers) is not greater than domestic production (e_{p_i}) and imports. The dual variable λ_{e_i} is a vector of dimension o_i . Equation (2) is also the market-clearing condition for the products of sector i , and the dual variable (λ_{e_i}) is the market-clearing price.⁵

Equation (3) represents the technical constraints on production as a linear system. The $A_{i,j}$ are matrices with o_j columns and as many rows as there are constraints in the linear systems. They represent the contribution of inputs from industry j ($j \neq i$) to the production process.⁶ The matrices C_i represent the demand of Armington goods corresponding to the various production processes. B_i is a matrix with o_i columns and as many rows as $A_{i,j}$.

When the prices are regulated, the government sets the domestic prices of industry products, i.e.,

$$\begin{aligned} p_{f,i} &= \bar{p}_{f,i} \\ p_{q,j,i} &= \bar{p}_{q,j,i} \end{aligned}$$

If the domestic prices are different from the international prices,⁷ the maximization problem of sector i is unbounded and the dual problem represented in the first-order conditions is infeasible. It reflects the fact that there are persistent opportunities to make profits by arbitraging between domestic and foreign prices or between the prices available to the different domestic consumers. The regulated price case requires additional constraints to allocate quantities: imports and exports are capped, and domestic consumers are rationed through a system of quotas.

In the deregulated price case, the domestic prices are equal to the market-clearing prices λ_{ei} . At equilibrium, the flexible domestic prices adjust until no arbitrage is possible; hence they eventually align to international prices. The caps and the quotas are no longer needed to allocate quantities.

The CGE model for the top-down representation of the rest of the economy

The top-down part of KEMGE represents the remaining industries, the households, the government, and the investment savings balance.

The products of the KEM model have to be aggregated to make the model communicate with the CGE.⁸ The energy-intensive products from KEM are aggregated into six representative goods that are consumed in the rest of the economy. Each sector $i \in N$, maximizes profits Π_{z_i} .

$$\Pi_{z_i} = \max\{p_{z_i}z_i - p_{f,i}'e_{f,i} \mid z_i \leq F_{v_i}^{CES}(e_{f,i})\}$$

Where p_{z_i} and z_i are the scalars of prices and quantities of the industry good i . The nested constant elasticity of substitution (CES) production functions $F_{v_i}^{CES}$ represent the degree of substitutability between the KEM products of sector i . We assume no substitutability between load segments for the power and water sectors. We also assume no substitutability between demand for cement and petrochemical products. Hence F^{CES} is a Leontief function for each of these four sectors. We allow for a limited substitution between oil and natural gas in the upstream fuel sector (with an elasticity of substitution of 0.1). We use a more complex CES function to match the substitution between refined products with observed price elasticities (see Table 1 for the price elasticities and Figure 7 for the structure of the production function).

The “other,” or “non-energy” sector, represents all the activities outside the KEM sectors. It produces a composite non-energy product using capital, labor, energy-intensive goods and Armington goods. The composite products are differentiated, depending on whether they are sold domestically or exported. The sector maximizes its profits so that:

$$\Pi_p = \max \left\{ \begin{aligned} &p_d y_d + p_x y_x - w \cdot l - (r + \delta) \cdot k_T \\ &- p_z' z_q - p \cdot x_y \mid F^{CET}(y_d, y_x) \\ &\leq F_y^{CES}(k_T, l, z_q, x_y) \end{aligned} \right\}$$

Where:

p_d and y_d are the scalars of the prices and quantities of composite products sold domestically.

p_x and y_x are the scalars of the prices and quantities of composite products that are exported.

w and l represent the wage rate and employment, respectively.

The KEMGE Modeling Framework

r , δ and k_T are the net rental rate, the decay rate, and the stock of capital, respectively.

p_z and z_q are the vectors of dimension n that contain the prices p_{z_i} and the quantities z_{qi} of industry goods i used in the non-energy sector.

p and x_y are the scalars of the prices and quantities of Armington goods used in the non-energy sector.

F^{CET} and F_y^{CES} are a constant elasticity of transformation (CET) and a CES production function, respectively (see Figure 7).

The “Armington good sector” is a sector that aggregates domestic and imported non-energy products into a single good. This sector is a computational artifact representing imperfect substitutability between domestic and foreign goods. The supplier of Armington goods maximizes profits Π_x :

$$\Pi_x = \max \left\{ \begin{array}{l} p \cdot x - p_d y_d - p_m y_m \\ | \quad x \leq F_{armin}^{CES}(y_d, y_m) \end{array} \right\}$$

Where, p and x are the scalars of the prices and quantities of Armington goods, p_m and y_m are the scalars of the import prices and quantities of “other products,” and F_{armin}^{CES} is a CES production function.

The “investment good” sector aggregates industry goods and Armington goods into goods used for investment and government consumption. The profit maximization problem of the investment good producer is:

$$\Pi_v = \max \left\{ \begin{array}{l} p_v inv - p_z' z_v - p \cdot x_v \\ | \quad v \leq F_v^{CES}(z_v, x_v) \end{array} \right\}$$

Where the scalars p_v and investments (inv) represent the price of a quantity of investment goods, z_v is the dimension- n vector of industry goods embedded in

the investment goods, x_v is the quantity of Armington goods embedded in the investment goods. F_v^{CES} is a CES production function.

Likewise, the profit maximization problem of the “government goods” producer is:

$$\Pi_g = \max \left\{ \begin{array}{l} p_g g - p_z' z_g - p \cdot x_g \\ | \quad g \leq F_g^{CES}(z_g, x_g) \end{array} \right\}$$

Where the scalar p_g is the price of government goods, g is the quantity of government goods, z_g is the dimension- n vector of industry goods embedded in the government goods, x_g is the scalar of Armington goods embedded in the government goods. F_g^{CES} is a CES production function.

The initial capital stock k_0 is exogenous. It decays at rate δ and increases with new investment (inv). When considering a time horizon T , the dynamics of capital in the non energy-intensive industries becomes:

$$k_T = (1 - \delta)^T \cdot k_0 + \sum_{t=1, \dots, T} (1 - \delta)^{T-t} inv$$

The CGE explicitly represents the capital stock and investment flows, whereas KEM represents capital and investment only implicitly through annuities that are part of the production cost (C_i in equation [3]). The annuities are a claim on non-energy products. Hence, the circular flow of the economy is preserved. However, the investments of KEM are intermediate consumptions from the KEMGE accounting perspective, and they are not influenced directly by the interest rate of the CGE part of the model.

The representative household consumes composite goods x_c , aggregated energy-intensive goods z_{c_i} ($i \in N$), and saves s_h , so as to maximize a utility function U (see Figure 7) under a budget constraint

$$\max \left\{ U \left(x_c, z_{c1}, \dots, z_{cn}, \frac{s_h}{p} \right) \mid p_c x_c \right. \\ \left. + \sum_{i \in N} p_{z_i} z_{c_i} + s_h \leq m_h \right\}$$

With

$$m_h = w \cdot l + r \cdot k + \theta_{\pi_h} \Pi + tr$$

The household's revenue m_h includes labor and capital income. It also includes a share, θ_{π_h} , of total profits, Π , received from various economic sectors. The share reflects the households' ownership of the industries. Lastly, households received transfers, tr , from the government.

The market equilibrium for aggregated energy goods is

$$z_i \geq z_{c_i} + z_{g_i} + z_{v_i} + z_{q_i} \perp p_{z_i} \geq 0$$

The equilibrium for the Armington goods market is

$$x \geq \sum_{i \in I} x_{e_i} + x_c + x_g + x_v \perp p_x \geq 0$$

All activities with CES technologies have zero profits at equilibrium. Hence, their total profits are equal to the profits in the KEM industries

$$\Pi = \sum_i \Pi_{e_i}$$

The foreign saving, which corresponds to the change in net foreign investment is, by definition, the opposite of the current account balance

$$s_f = -b = -(p_x y_x - p_m y_m + \sum_{i \in I} p'_{int_i} (e_{x_i} - e_{m_i}))$$

Total investment is equal to total domestic saving

$$inv = s_h + s_g + er \cdot s_f \quad (8)$$

Where s_g is the government's savings and er is the exchange rate ⁹

The government's consumption spending is a proportion, g_p , of nominal GDP:

$$p_g \cdot g / gdp = g_p$$

Where nominal GDP is computed from the revenue side

$$gdp = w \cdot l + r \cdot k_T + \Pi$$

The government's budget constraint is

$$(1 - \theta_{\pi_h}) \Pi + \tau_h m_h = p_g \cdot g + tr + s_g \quad (9)$$

The foreign sector

Saudi Arabia is a large oil exporter, and an increase in its oil exports reduces global oil prices. We represent the feedback effect of Saudi Arabia's oil exports on oil prices using the function:

$$p_{int_j} = d_j \cdot (e_{x_j})^{-\eta_j} \quad (10)$$

Where d_j is a scaling parameter, and η_j is the elasticity of international oil prices to Saudi oil exports, calculated based on Saudi Arabia's share of the global oil market, the elasticity of other producers' supply, and the elasticity of global demand.

We assume that Saudi Arabia's imports and exports of non-oil commodities have no influence on their foreign prices. Therefore, the international price, p'_{int} , of other industrial products, and the import and export prices (p_m, p_x) of the non-energy composite good are exogenous.

Model calibration

The base year of the model is 2018. We have approximated a simple 2015 SAM of Saudi Arabia using 2015 input-output tables (IO) from Saudi Arabia's General Authority of Statistics (GaStat 2019c) and from the OECD (2018). We then updated the IO tables to 2018 using various ancillary datasets, in particular from the Saudi Arabian Monetary Authority (SAMA 2019). We have modified the oil production and oil revenue data to reflect the OPEC+ production cuts from 2016 to 2018 and the fact that oil prices were 40% higher in 2018 than in 2015.¹⁰ We have incorporated the changes in the activity of energy-intensive sectors in our SAM. Changes in the output of refined products, petrochemicals and cement are based on SAMA (2019). Electricity and cement consumption are drawn from SAMA (2019). Diesel and gasoline consumption come from the International Energy Agency (IEA 2019), and the data was completed by the Joint Organisations Data Initiative (JODI 2019). The demand for desalinated water is calibrated according to data from the Electricity and Cogeneration Regulatory Authority (ECRA 2018). The import and export prices for petrochemical and refined products are calculated based on GaStat's foreign trade statistics.¹¹

We have used SAMA (2019) to calibrate the governments' revenue and spending, its domestic investment and current account balance.

We used the detailed technology-by-technology information embedded in KEM over the aggregated accounting information from the SAM for the supply side of the energy-intensive sectors. The data on the energy-intensive sectors are drawn from a baseline simulation done with KEM between 2015 and 2018. This simulation incorporated the planned investment in production capacity, with demand adjusted to the

activity levels of the SAM. The simulation produced detailed monetary transactions and product flows, consistent with physical processes and a complete set of products and industry-specific administered prices. There are discrepancies between the SAM and the corresponding flows from KEM because they use different data definitions. We resolved these discrepancies by running the integrated model, which produced a reconciled data set with bottom-up outcomes, consistent with a balanced SAM.

We have adjusted the monetary flows relating to energy-intensive sectors and products in the SAM, so as to (i) produce value share coefficients that sum up to one and (ii) to produce a relevant target current account balance, i.e., a trade balance consistent with import and export values taken from KEM. Based on these shared coefficients that incorporate the CGE and the KEM flows, we ran the CGE model. Our 2018 base-year SAM is consistent with the bottom-up representation of activities in KEM models. This SAM is balanced because it is the output of a CGE model.

We have produced a baseline projection from 2018 to 2030, assuming that the administered prices and the international commodity prices remain at their 2018 levels. We have adjusted the number of hours worked, the labor productivity and the investment rate, in order to obtain, in our baseline, a 2.5% annual growth of non-energy GDP.¹² This growth rate is in line with the projections made by the International Monetary Fund (IMF 2019) up to 2024.

Note that the baseline does not aim to represent what is most likely to happen in Saudi Arabia's economy. It serves as a reference point in order to single out the potential effects of price deregulation policies if all other policies remain the same. This is why the baseline assumes a policy status quo from 2018. It does not, therefore, include Saudi Vision

Table 1. Own-price elasticities of substitution in KEMGE.

	Value in KEMGE	Empirical estimates for Saudi Arabia	Sources
Gasoline	-0.18	-0.15 -0.2 -0.15	Atalla et al. (2018) Huntington et al. (2017) Hasanov et al. (Forthcoming)
Diesel	-0.18	-	
Jet-fuel	-0.20	-	
Electricity	-0.24	-0.16 -0.35	Atalla and Hunt (2016) Hasanov et al. (Forthcoming)
Cement	-0.20	-	
Water	-0.20	-	
Petrochemicals	-0.20	-	

Note: "-" means that there was no estimate available in the literature.

2030 policies¹³ and their expected beneficial impacts on the country's economic growth.

The elasticity parameters in the production and utility functions were chosen so as to replicate the empirical estimates for the price elasticity of demand for gasoline and electricity (Table 1). We have used the same price elasticities for energy and energy-intensive commodities. These price elasticities were adjusted by setting appropriated parameters in the nested production functions presented in Figure 7.

Computation of the integrated model

We compute the solution of the model using a decomposition algorithm based on Böhringer and Rutherford (2009). We formulate the KEM and CGE sub-models separately. The KEM sub-model, which has around 51,000 equations and variables,

is formulated as a mixed complementarity problem (MCP) and is solved using the PATH solver (Ferris and Munson 2000). The CGE sub-model, which has 90 variables and equations, is formulated as a constrained nonlinear system (CNS) and solved using the CONOPT solver (Drud 1994). We include linear demand functions in KEM. At each iteration of the solution algorithm, the coefficients of these functions are recalibrated on the results of the CGE model. Likewise, in each iteration, we update the commodity prices, the energy-related revenue and the fiscal variables in the CGE sub-model, in order to transmit the effect of the policies from the energy sector to the rest of the economy. We continue the iterations until the energy prices and consumption vary by less than a convergence criterion. Appendix B provides a detailed description of the solution algorithm. The algorithm has converged in no more than 12 iterations for all the scenarios we have simulated.

Deregulation Scenarios That Illustrate the Role of Revenue Recycling

The importance of a revenue recycling scheme

Energy price reforms propagate from the energy sector to the rest of the economy through multiple channels (Figure 1). The reforms result in higher energy prices, which directly reduces household energy consumption. Household budgets for non-energy goods are reduced by their increased expenditure on energy. At the same time, non-energy goods cost more as a result of higher-priced energy inputs. Thus, household consumption of non-energy goods also falls. As higher prices propagate through the economy, the non-energy sector loses its trade

competitiveness, exports decrease, and imports substitute for domestic production to meet domestic demand. Lower household consumption, reduced exports and increased imports further depress the output of the non-energy sectors. The lower output generates less primary income (labor and capital revenue) and less consumption, which, in turn, further negatively impacts economic activity.

Consequently, there are complex feedback loops throughout the economy as it adjusts to higher energy prices. Not all impacts are negative. More oil is available for export and government revenues increase.

Figure 1. Key transmission channels of energy price reforms to the non-energy sector in KEMGE.

The energy export channel can offset the negative effects of price reform on household consumption and the non-energy sector's output. Lower domestic energy consumption increases energy exports and, consequently, the profits of the energy sector, even though adding supply to world markets lowers prices. The increased profits increase the ability of the government to leverage growth using indirect transmission channels for household consumption and non-energy sector output.

The revenues from energy exports can be re-injected in the economy in many different ways. It can be invested outside the country to generate income. It can also be invested domestically in the non-energy sector to increase economic activity and diversification. In this case, the revenue contributes to increasing the capital stock and potential output. The government's increased revenue from higher exports can increase government savings. Alternatively, the additional revenue could be transferred to households to stimulate consumption.

Price deregulation scenarios under alternative recycling schemes

The baseline scenario represents a projection of Saudi Arabia's economy in 2030, assuming that domestic administered prices and international energy prices remain at their 2018 levels.

All our policy scenarios assume all energy and energy-intensive commodity prices are fully deregulated, with domestic fuel prices adjusted to international levels.

Each policy scenario corresponds to a particular scheme for recycling the additional fiscal revenue generated by the energy sector to the rest of the

economy (Table 2). Each recycling scheme is implemented using an alternative closure rule. A closure rule determines which variables can adjust to price deregulation, and which variables remain fixed, in the equations representing the investment-saving balance (equation 8) and the government's budget balance (equation 9).

Under the consolidation scheme (CN), the additional revenues from the reform serve to improve the government's savings, not to increase its domestic investments. We fix the transfers to households to their baseline level and let the government's savings adjust accordingly. To neutralize the effects of the reform through investment, we fix the domestic investment-to-GDP ratio at its baseline level and we let the current account adjust to absorb the additional savings. The savings are therefore not invested in the domestic economy. The adjustment of the current account corresponds to an increase in net foreign investment.

Under the transfer scheme (TR), the additional revenue from the reform is used to increase cash transfers to households. These transfers are endogenous, and the government's saving-to-GDP ratio is exogenous and set at the baseline level. In other words, the transfers are budget neutral for the government. As in scenario CN, we neutralize the investment channel by keeping the domestic investment-to-GDP ratio fixed and the current account flexible.

Under the investment scheme (IV), the additional revenue from the reform is directed to domestic investment. The household transfers are fixed, hence the additional oil revenue increases the government's savings. The increase in savings at the national level is invested in the domestic economy because the net foreign investment positions are fixed.

Deregulation Scenarios That Illustrate the Role of Revenue Recycling

Under the investment and transfer scheme (IVT), the additional revenue from the reform is split between transfers to households and domestic investments. The government uses the additional fiscal revenue to increase transfers to households in a budget-neutral way. The net government saving is therefore fixed. Households have more revenue, not least because they received additional transfers,

and increased domestic savings. As we fix the net investment position, the increase in domestic savings is invested in the domestic economy. In the end, in the IVT scenario, the increase in domestic investment is lower than in the IV scenario because the government uses its additional revenue to support households instead of increasing the savings available to finance investment.

Table 2. The recycling schemes in each price reform scenario.

Scenario	Government budget closure (equation 9)		Investment-saving closure (equation 8)	
	Transfers to households (tr)	Government savings (s_g)	Domestic investment (inv)	Net foreign investment position (sf)
Consolidation (CN)	Fixed	Free	Fixed	Free
Transfer (TR)	Free	Fixed	Fixed	Free
Investment (IV)	Fixed	Free	Free	Fixed
Investment and transfer (IVT)	Free	Fixed	Free	Fixed

Illustration: Simulating the Effects of Energy Price Reforms

Effect of the reforms on energy prices

The effect of the reforms on domestic fuel prices depends on the fuel considered (Table 3). The deregulation scenarios significantly increase the prices of those fuels that had been spared by the price reforms of 2016 and 2018, and hence remained well below international benchmarks.

The methane price almost quadruple, the diesel prices for transport more than double, and the domestic Arab Light oil price and the heavy fuel oil (HFO) price increase by a factor of 10.

The effect on gasoline prices is mixed. The price of gasoline 91 increases by around 36%. The price of gasoline 95, which has already been reasonably aligned with international prices since

Table 3. Consumer energy prices^a in the various scenarios.

	History			Scenarios	
				Baseline	Deregulation scenarios ^b
	2015	2016	2018	2030	2030
Gasoline 91 (\$/l)	0.12	0.2	0.36	0.36	0.67
Gasoline 95 (\$/l)	0.16	0.24	0.55	0.55	0.72
Methane (\$/MMbtu)	0.75	1.25	1.25	1.25	5.66
Arab Light (\$/bl)	4.24	6.36	6.36	6.36	63
Arab Heavy (\$/bl)	2.67	4.41	4.41	4.41	63
Diesel (\$/bl)					
- Transport	10.6	19.9	19.9	19.9	103
- Utilities	3.8	14	14	14	103
- Industries	9.12	14	14	14	103
HFO 380 (\$/t)	14	27.5	27.5	27.5	251
Electricity ^c (\$/MWh)					
- Household	34.6	38.4	80	80	57
- Government	69.3	84.8	84.8	84.8	57
- Industries	34.6	42.3	42.3	42.3	57
Oil export price ^d (\$/bl)	49.2	40.2	70.5	70.5	62.7

Note: ^a Prices are in 2013 US\$. ^b The prices correspond to the CN scenario. The prices in the deregulation scenarios are endogenous, driven by international prices, transportation costs, congestion, and export restrictions. ^c average electricity prices; ^d free on board (FOB) price of Arab Light; l= liter; MMBtu= Million British thermal units; b= barrel; GWh = gigawatthours; t= tonnes.

2018, decreases slightly. If international prices had remained constant in the deregulation scenario, gasoline 95 prices would have, too. But price deregulation adds Saudi exports to international oil markets (see section 5.3) and therefore reduces international oil prices, pulling the domestic gasoline 95 price down. Overall, the average price of gasoline for consumers increases: The price increase of the 91 grade, representing 70% of gasoline demand, more than offsets the slight price decrease of the 95 grade.

The domestic electricity price decreases under the deregulation scenario. This may seem counterintuitive. The sharp increase in the prices of fossil fuels for power generation raises the cost of supplying electricity, especially given the low fuel efficiency of existing power generators. Hence, deregulated electricity prices, reflecting the cost of generation,¹⁴ should be higher than the regulated price.

However, the administered price of electricity resulting from the 2016 and 2018 price hikes is above the generation cost, as assessed in KEMGE. In other words, in the baseline scenario, the electricity sector benefits from a rent that corresponds to the wedge between the average revenue above average cost.¹⁵ The deregulation of the electricity price suppresses rent and helps reduce the electricity price. On the other hand, the deregulation of the prices of other fuels increases the electricity generation costs and contributes to increasing the price of electricity. However, this second effect is limited and is dominated by the first effect, as the availability of cheap solar technologies largely contributes to mitigating the effect of rising fuel prices in lowering the power generation cost.

Domestic price reforms stimulate crude oil exports

Under full price deregulation, the volume of crude oil exports increases by around 25% (Figure 2, Panel A), mostly as a result of lower domestic consumption of oil and oil products. The additional exports come entirely from oil savings in various sectors of the economy. The demand for crude from domestic refineries shrinks and shifts toward Arab Heavy only. Methane consumption increases as a result of the withdrawal of quotas that restricted some sectors' use of methane. The power sector substitutes methane for crude oil. The direct use of oil in the other sectors of the economy also decreases.

Activity in the refining sector declines (Figure 2, Panel B) as a result of the fall in domestic demand for fuel induced by the price deregulation. The refining sector is no longer required to serve the large domestic demand at low administered prices. With a surge in domestic fuel prices, power generation, which was a key consumer of oil products, switches entirely from heavy fuel oil and diesel to methane and renewables. At the same time, the water sector, which faces increasing fuel costs, phases out steam-based desalination and adopts reverse osmosis technologies, which are more fuel efficient and run on electricity instead of fossil fuels. The increase in diesel and gasoline prices reduces the demand for transportation fuel compared with the baseline scenario. Meanwhile, the increases in diesel and gasoline exports are too modest to compensate for the reduction in domestic demand. However, the results pertaining to the refining sector need to be taken with particular precautions. The KEMGE model does not explicitly represent refiners outside Saudi Arabia and their margins. Hence the model ignores the adjustment of Saudi Arabia's refining market share due to changes in price competitiveness with overseas refiners.

Figure 2. Lower domestic consumption of refined products boosts oil exports.

Sources: Authors' calculation based on KEMG. Note: Other includes propane, ethane and gas condensates; 'Other products' include petroleum coke, asphalt, liquefied petroleum gas (LPG) and naphtha; Mtoe = million tonnes of oil equivalent.

Further investigation would require a very detailed global refining model.

Price deregulation downsizes the energy-intensive sectors and makes them more profitable

Price deregulation generates additional profits (over US\$24 billion) for energy-intensive sectors, equivalent to 3% of the baseline GDP (Figure 3). This illustrates the extent of the distortions with current regulated prices and allocation mechanisms.

Price deregulation reduces the size of the refining sector but improves its profitability compared with the baseline (Figure 3). In the baseline scenario (price regulation), the refining sector is the only sector that does not purchase inputs at regulated

prices and has to buy crude oil at market prices. However, the sector is obliged to sell its products to domestic consumers at regulated prices. Hence, in the baseline scenario, refineries serve the country's large domestic demand at a loss and receive compensation from the government budget or other utilities. Refining activity decreases with the price reforms because the higher fuel prices shave domestic demand. The refining sector is no longer loss making and becomes a source of revenue that can flow to the government budget or to households.

The output and profits for crude oil are only slightly affected by price deregulation (Figure 3). Saudi Arabia's production quota restricts additional oil output. Our natural gas production projections are fairly conservative. They do not include the contribution of new large gas fields. In the

Illustration: Simulating the Effects of Energy Price Reforms

deregulation scenario, the upstream sector also slightly increases its revenue thanks to natural gas sales, since the sector sells natural gas at market prices, which are higher than administered prices.

In the baseline scenario, the upstream sector sells oil to the domestic market, mostly to refiners, at a deregulated price. Thus, in the deregulation scenarios, the upstream sector does not gain any additional revenue from redirecting its oil sales to foreign markets. The major revenue gains for the upstream sector come from the phase-out of the delivery of crude oil at low administered prices to the power and water sectors, among others. However, this beneficial impact on the sector's profits is

partially offset by the decrease in international oil prices induced by the additional quantities of Saudi crude exported.

The petrochemical sector remains competitive internationally, even once feedstock prices are fully deregulated. At the same time, higher feedstock prices reduce the sector's margins, resulting in lower profits than under the administered prices. However, the result on margins and activity on the refining sector would deserve further robustness checks. KEMGE, as with KEM, does not explicitly represent the export market for petrochemical products. Hence, it may miss changes in export market shares implied by the demand response and by the cost

Figure 3. Changes in the prices and profits of energy-intensive sectors.

Sources: Authors' calculation based on KEMGE.

Note: ^aThe category "All energy-intensive sectors" is the total of the six sectors represented in this graph. The model does not take into account the cost of connecting every cement plant to the natural gas network. Therefore, for some regions, the model is underestimating the costs of switching from liquids fuels to methane in the cement sector.

structure of the other petrochemical exporters. The regulated cement prices were relatively high compared with their deregulation prices; the output of the cement sector grows only slightly under deregulation. Despite the higher energy costs, deregulation brings cement prices down and stimulates consumption slightly, as cement exports are capped in the model.

Activity in the electricity sector increases with deregulation. The deregulated price is below the administered price, which brings electricity demand slightly above the baseline. At the same time, fossil fuel prices for power generation increase to international levels. In other words, in the deregulation scenario, the electricity sector has lower revenues and higher costs per kilowatthour (KWh). With the deregulation scenario's average cost pricing, the electricity sector's profits fade away.

In the power sector, full price deregulation gives way to a massive penetration of solar PV, with 56 gigawatts (GW) of capacity installed by 2030 (Figure 4). Solar PV is the least costly option, because its levelized costs are very low in the MENA region, and because power generation no longer benefits from low administered fossil fuel prices.

Another investment in power generation capacity is retrofitting existing gas turbines into more efficient combined-cycle units. Deregulation also leads to significant fuel switching from oil products to methane and to investments in energy efficiency improvements (Figure 4). Thermal generation using crude oil, heavy fuel oil (HFO) or diesel is no longer competitive because of the high prices of these fuels. Hence, the power sector switches entirely to gas for thermal generation. There is also a need for

Figure 4. Price deregulation stimulates solar PV penetration.

Source: Authors' calculations based on KEMGE.

Note: In panel A, open cycle includes both gas- and oil-fired generation. Hence, this figure does not show the gas-to-oil substitution.

Illustration: Simulating the Effects of Energy Price Reforms

additional capacity because price regulation tends to increase power demand.

In all of the deregulation scenarios, the water sector no longer uses fossil fuels and becomes a large electricity consumer, despite a reduction in water output. Because of high HFO prices, thermal desalination is no longer competitive. Reverse osmosis is adopted and creates a sizeable claim for grid electricity. In the deregulation scenarios, the electricity demand from the water sector is around 15 terawatt-hours (TWh), and desalination represents around 3% of electricity consumption.

Deregulation leads to a 35% reduction in energy-related CO₂ emissions in 2030 compared with the baseline (Figure 5). This drop corresponds to around 240 million tonnes of CO₂ (MtCO₂), which is close to Saudi Arabia's nationally determined

contribution to reduce its emissions by 230 MtCO₂ per year under the Paris Agreement.¹⁶ The electricity and water sectors abate by around 135 MtCO₂ per year. This is roughly in line with the 1.2 gigatonnes (Gt) of cumulative abatement for these sectors in a price deregulation scenario up to 2030, as found by Wogan et al. (2019). But the similarity in the results of this paper and that of Wogan et al. is due to different mechanisms. The abatement in Wogan et al. (2019) is largely because they start from a base year of 2013, when there was a considerable gap between administered and deregulated prices. In 2013, international oil prices were extremely high, and domestic oil prices in Saudi Arabia were extremely low. Hence, the deregulation scenario induces a dramatic rise in Saudi Arabia's domestic energy price. Wogan et al. (2019) also assumed a steady increase in electricity demand. Our baseline scenario includes the 2016 and 2018

Figure 5. Energy price deregulation reduces energy-related CO₂ emissions by a third. Energy-related CO₂ emissions in 2030 (million tonnes of CO₂).

Source: Authors' calculations based on KEMGE.

Note: The numbers do not include emissions from cement production.

fuel price reforms, and the consequent reduction in CO₂ emissions. The oil price used in our base year, 2018, is 33% lower than in 2013. However, in our deregulation scenario, the cost of solar PV is lower than in Wogan et al. (2019), as our scenario reflects more recent information on solar PV costs.¹⁷ We obtain more abatement than Wogan et al. in the power and water sectors, due to the greater penetration of solar PV in power generation.

By 2030, the power and water sectors reduce their emissions by 44% and 50%, respectively, compared with our baseline scenario. Increased final fuel prices makes energy conservation gains important to the rest of the economy.

The price reforms boost non-energy GDP through capital deepening

Energy price deregulation boosts GDP significantly,

by between 3%-6%, depending on the policy for recycling oil revenue (Figure 6). Energy price reforms can have positive spillover effects on the non-energy sector and can also have large effects on GDP, due to capital deepening. The role of capital deepening is illustrated in scenarios where domestic investment is endogenous and absorbs total domestic and foreign savings (scenario IV). In these cases, the revenue generated by the price reform is invested in non-energy-intensive sectors instead of being saved abroad. Capital deepening increases the potential growth of the economy. If the revenue generated by the reforms is not reinjected into the domestic economy (scenarios CN, TR), foreign assets increase in value, but domestic investment only increases at the same rate as the economy expands. Hence, the potential growth of the non-energy sector is far more limited in the latter scenarios. If the revenues generated from the fuel price reforms are not fed back to the economy through domestic investment, they lead to a slight contraction of the non-energy sector.

Figure 6. Channeling energy sector revenue into domestic investments boosts domestic GDP growth.

Source: Authors' calculations based on KEMGE.

Illustration: Simulating the Effects of Energy Price Reforms

The fall in international oil prices due to increases in Saudi Arabia's oil exports tends to mitigate some of the beneficial effects of the domestic price reforms on Saudi GDP. However, they still produce a net-beneficial impact. Falling international oil prices lower the boost to GDP from the fuel price reforms from 4.2 to 3.5% in the budget consolidation scenario.

The effects on households depends on the recycling scheme

Fuel price reform with no investment in the non-energy sector may not benefit households that do not receive transfers or do not benefit indirectly from any revenue-recycling scheme (scenario CN in Table 4). The price reforms weigh on household consumption because of the higher prices of energy and other goods. In addition, primary revenue decreases since lower energy consumption reduces the marginal productivity of capital, lowering labor and rental revenues. Households receive a fraction of the profits from energy-intensive sectors that are not collected by the government. This fraction, less than 20%, may be insufficient to compensate households for fuel price increases and the decrease in primary revenue. If the revenue from the reforms is consolidated in the government's budget and not reinvested in non-energy-intensive sectors, household consumption contracts.

However, various indirect effects can make fuel price reforms beneficial for households. First, transfers help to reverse the negative effects on households' real income and consumption (scenario TR). The transfers stimulate domestic consumption but have a negligible influence on GDP because most of the increase in domestic consumption is spent on imported goods. Note, however, that the

scenario's price reforms improve the current account position of Saudi Arabia, which can have beneficial effects on economic activity through improving financial conditions in the country. However, the beneficial impact of the reforms through current account stabilization is not explicitly represented in the model, as the CGE includes real, not monetary variables.

When revenues generated by the reforms are invested in the domestic economy, they deepen capital, increase potential output, and generate, in the end, more revenue for households (scenario IV). Transfers from the government are a more direct means of supporting household income. They can also be implemented in the short run. However, they also move some of the additional oil revenue away from investment and limit capital deepening as a source of growth induced by the price reform (scenario IVT). In the end, transfers to households do not lift household consumption compared with investment-led growth that stimulates capital deepening (scenario IV).

There is a trade-off between policies that directly support household revenue with transfers and budget consolidation policies that aim to improve consumption through increased investment. Whenever the revenue generated by the reforms is recycled through investments in the non-energy sector, the reforms are less detrimental to households (scenarios IV and IVT in Table 4). With the additional crude exports due to reduced domestic consumption, the terms of trade improve. As in the case of the Dutch disease, the prices of imported goods decrease, which helps lift domestic consumption but reduces non-oil exports and encourages import substitution. In addition, increased investment becomes the key driver of economic growth. However, when the real exchange rate adjusts to balance the current

account, government intervention with transfers to households is less efficient than with a fixed current account. This is because additional household consumption tends to place pressure on the current account and results in negative adjustments to the terms of trade. These adjustments lead to import price increases that offset some of the real income gains from the transfers. This highlights a key economic policy trade-off. On the one hand, disinflationary policies directed at improving the

current account performance can stimulate some sectors, giving them strong competitive advantages. This can also improve the country's financial sustainability, thanks to increased net investment and accrued foreign exchange reserves. On the other hand, these policies have a detrimental impact on domestic demand and the development of the non-energy sector, which depends largely on the domestic market.

Table 4. Fuel price reforms boost GDP but not necessarily consumption. GDP expenditure decomposition in 2030 (% compared with the baseline).

	Consolidation (CN)	Illustration: Consolidation (CN) with fixed intl. oil prices	Transfer (TR)	Investment (IV)	Investment and Transfer (IVT)
<i>Variation</i>					
Households	-2.7%	-1.2%	2.2%	2.1%	2.0%
Government	-0.4%	0.5%	1.7%	5.1%	1.3%
Investments	4.6%	7.6%	4.2%	17.6%	3.0%
Imports	0.5%	3.0%	9.0%	13.6%	8.3%
Exports	14.1%	13.6%	12.5%	13.4%	12.5%
<i>Total GDP</i>	3.5%	4.2%	3.4%	6.1%	3.1%
<i>Contribution to GDP growth rate</i>					
Households	-1.3%	-0.6%	1.0%	1.0%	1.0%
Government	-0.1%	0.2%	0.6%	1.7%	0.4%
Investments	1.0%	1.6%	0.9%	3.7%	0.6%
Imports	-0.1%	-0.9%	-2.8%	-4.2%	-2.6%
Exports	4.1%	4.0%	3.7%	3.9%	3.7%
Total	3.5%	4.2%	3.4%	6.1%	3.1%

Sources: Authors' calculation based on KEMGE.

Conclusions and Further Research

We show in this paper how to design and implement a hybrid general equilibrium model that combines a top-down model of the economy with a bottom-up model that represents the energy-intensive sectors in detail.

Our simulations show that, in the context of existing administered prices and international 2018 prices, full price deregulation would increase GDP by 3%-6% in 2030 above that of our baseline no-reform scenario. Energy-efficiency gains in industry, price-induced changes in transportation fuel demand, large-scale penetration of solar PV, and electrification of water desalination would help to increase the volume of oil exports by around 25% without increasing production. Activity in the refining sector may decline because of lower domestic demand, but its net revenue would increase.

Energy price reforms can support the non-energy sector only when the energy sector's revenues are channeled into domestic investment instead of being invested abroad. The price reforms with no investment in the non-energy sector may not be beneficial to households without transfers or other compensation policies. When the government redistributes the fiscal revenue generated by the reforms to households via cash transfers, this

directly benefits real household income. However, this redistribution partially offsets the indirect beneficial impacts of increased investment. Price deregulation would also reduce Saudi Arabia's energy-related CO₂ emissions by around one third.

Further research is needed to assess how pricing policies can influence non-energy sector growth and diversification. The impact of pricing policies on export-oriented diversification depends on the global demand for goods exported by Saudi Arabia. Key factors that will influence the resilience of the energy-intensive sectors to price hikes are the level of product differentiation, competitors' cost structures, and the global demand outlook. More flexible and consistent modeling of the effects of price reforms on trade and diversification require an explicit representation of the global energy-intensive goods market, with a dedicated trade sub-model.

The modeling framework still has a very stylized representation of the non-energy-intensive sectors. Further developments in the CGE part of the model could help to refine the representation of structural policies, including labor, investment, and fiscal policies. Such a feature could help further integrate the energy policies into broader economic policy objectives.

Endnotes

¹ See Murphy et al. (2019) for a detailed presentation of the MCP formulation of partial equilibrium models with price controls.

² This observation is derived from 2018 data; GDP at producer price and current prices; share of oil revenue in total government revenue. Source: <http://www.sama.gov.sa/>.

³ The products are differentiated by region and, for electricity, by season and load segment. For simplicity, we ignore this differentiation in our notations.

⁴ This is a simplification that avoids further complexity in notations. However, in KEMGE, different industries can produce the same product. For instance, the electricity and the water sectors both produce on-grid electricity.

⁵ In our case, the supply and the market clearing constraints are the same because the goods are supplied by one sector only. Hence the product balance within a sector represents the product balance of the market.

⁶ In case of Leontief technologies, A_{ij} would have o_i rows and contain input-output coefficients, and B_i would be an identity matrix of dimension o_i .

⁷ If the domestic prices are not set within a narrow band between p_{int_i} and $(1 + tc)p'_{int_i}$.

⁸ Because KEM has a detailed representation of products in each sector. In addition, the demands of KEM products are determined for each of the four regions of KEM. For instance, there are nine different products from the refinery sector, hence there are $4 \times 9 = 36$ different demands. In the electricity sector, which has eight load periods, two daily load profiles and three seasons, there are $4 \times 8 \times 2 \times 3 = 192$ different demands.

⁹ The exchange rate serves as a numeraire in the models and is set to 1.

¹⁰ Based on the spot prices of Arabian Light published by SAMA (2019).

¹¹ (Gastat 2019a, b) and previous issues back to 2016.

¹² “Non-energy GDP” includes all the sectors of the economy except the oil and gas extraction, refining, petrochemicals, power generation, water and cement sectors. Note that our ‘non-energy’ GDP is slightly different from GaStat’s and the IMF’s ‘non-oil GDP.’ The former excludes only oil and gas extraction and refining.

¹³ See <https://vision2030.gov.sa/en>

¹⁴ We use average cost pricing for electricity in the deregulation scenarios.

¹⁵ In the baseline, the rent of the electricity sector is redistributed to Saudi households through the Citizen’s Account Program.

¹⁶ Compared with a business-as-usual scenario at horizon 2030 (UNFCCC 2015).

¹⁷ The cost of PV in the model is assumed to be \$1436/kWe (IEA/NEA 2015).

¹⁸ We do not necessarily need a proxy of the CGE model elasticities; we can obtain the convergence of the algorithm with various levels of elasticity. In our case we use $\psi_i = -0.3, \forall i \in N$.

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Appendix

A. The macroeconomic functions used in the model

Figure 7. Structures of other sectors' production functions and households' utility function.

B. The solution algorithm

Figure 8. Structures of other sectors' production functions and households' utility function.

Note: MCP = mixed complementarity problem; CNS = constrained nonlinear system.

Initialization (k=0):

We solve KEM with fixed demands $z_i^{(0)}$ ($i \in N$) of aggregated KEM goods. We obtain:

- Prices $p_{z_i}^{(0)}$ of the aggregated KEM goods.
- The demands $x_{e_i}^{(0)}$ of Armington goods for intermediate consumption in the KEM sectors.
- The total profit $\Pi_{kem}^{(0)} = \sum_{i \in N} \Pi_i^{(0)}$ of the KEM sectors.
- The net exports $NXK^{(0)} = \sum_{i \in I} p_{int_i}^{(0)'} (e_{x_i}^{(0)} - e_{m_i}^{(0)})$ of the KEM commodities.

Iteration (k):

1. We update the CGE sub-model by:
 - Setting the production costs of the KEM goods equal to their price $p_{z_i}^{(k-1)}$ computed from KEM.
 - Setting as exogenous the total demand $x_{e_i}^{(k-1)}$ of non-energy-intensive goods for intermediate consumption in the KEM sectors.
 - Assigning shares of the profit $\Pi_{kem}^{(k-1)}$ of the KEM sectors to households and to the government's revenue.
 - Including the net exports $NXK^{(k-1)}$ of KEM commodities in the current account.
2. We solve the CGE sub-model and obtain:
 - Demands for the aggregated KEM goods, $z_i^{(k-1)}, i \in N$
 - The price of the Armington good $p^{(k-1)}, i \in N$
3. We update the KEM sub-model by:
 - Recalibrating the sectoral linear demand curves on prices and quantities $(z_i^{(k-1)}, p_{z_i}^{(k-1)})$ assuming a given price elasticity ψ_i .¹⁸
 - $z_i = a_i^{(k)} + b_i^{(k)} p_{z_i}, i \in N$, with $b_i^{(k)} = \psi_i \cdot \frac{z_i^{(k-1)}}{p_{z_i}^{(k-1)}}$ and $a_i^{(k)} = z_i^{(k-1)} - b_i^{(k)} p_{z_i}^{(k-1)}$
 - Adjusting the KEM non-energy costs to changes in the Armington good price $p^{(k-1)}$.
4. We solve the KEM model and we obtain:
 - Equilibrium prices and quantities $(z_i^{(k)}, p_{z_i}^{(k)})$.
 - The demands of $x_{e_i}^{(k-1)}$ of non-energy-intensive goods for intermediate consumption in the KEM sectors.
 - Profit $\Pi_{kem}^{(k)}$ of the KEM sectors.
 - The net exports $NXK^{(k)}$ of KEM commodities.

Convergence criterium

We repeat the iterations until convergence, i.e., until the variation of price and quantities (P_i, Q_i) between two iterations is lower than the given threshold ϵ that we set to 0.01%.

$$\left(\sum_{i \in I} \left(\frac{P_{z_i}^{(k)}}{P_{z_i}^{(k-1)}} - 1 \right)^2 + \left(\frac{z_i^{(k)}}{z_i^{(k-1)}} - 1 \right)^2 \right)^{\frac{1}{2}} \leq \epsilon (= 0.01\%)$$

The KEM sub-model is formulated through the Extended Mathematical Programming (EMP) extension of GAMS and solved as an MCP using the PATH solver. The CGE sub-model is formulated as a constrained nonlinear system (CNS) and solved with the CONOPT solver.

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About the Project

Given the large size of Saudi Arabia's energy and energy-intensive sectors, and the structural changes that these sectors will experience over the coming years, it is essential to capture the feedbacks between the energy and non-energy components of the economy with sufficient veracity.

The KAPSARC General Equilibrium Energy Model (KEMGE) is a novel hybrid model that combines the KAPSARC Energy Model (KEM) with a representation of the rest of the Saudi economy. It will provide an open-source technology-rich tool to assess the impacts of energy policies on the Saudi economy and the impacts of non-energy policies on its energy sector.

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