ONLINE APPENDIX TO

Structural Transformation Options of the Saudi Economy Under Constraint of Depressed World Oil Prices

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Annex A IMACLIM-SAU FORMULARY

IMACLIM-SAU operates in a dynamic recursive framework where yearly economy-wide equilibria are connected by accumulation of the capital stock, financial debts and chained price indexes. From a mathematical point of view, each yearly equilibrium results from the solving of a system of simultaneous non-linear equations:

$$\begin{cases} f_1(x_1, x_2 \dots, x_n, y_1, y_2 \dots, y_m) = 0 \\ f_2(x_1, x_2 \dots, x_n, y_1, y_2 \dots, y_m) = 0 \\ \dots \\ f_n(x_1, x_2 \dots, x_n, y_1, y_2 \dots, y_m) = 0 \end{cases}$$

With x_i a set of n variables, y_i a set of m parameters and f_i a set of n functions, for some of them linear, for some of them non-linear, in x_i. The f_i functions embody constraints of either an accounting nature or a behavioral nature. The accounting constraints impose themselves on the modeler for the sake of consistency. The behavioral constraints, quite distinctively, convey the modeler's views on economic causalities and correlations.

The count of equations and variables depends on whether IMACLIM-SAU models regulated energy prices or not. Regulated versus reformed energy prices affect equations (32), (57) and (58), which shift from (a) to (b) variants.

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Because of indexed notation, each equation covers up to 169 constraints (the intermediate prices of 13 products into 13 productions). The detail is as follows:

- Equations (4), (7), (8), (10), (11), (12), (14), (15), (16), (17), (18), (19), (20), (21), (23), (24), (25), (26), (27), (28), (31), (32) (a or b), (33), (34), (37), (40), (42), (43), (45), (47), (60), and (61) cover one constraint each: 32 constraints.
- Equation (58b) covers 2 constraints.
- Equations (9), (50), (58a) and (59) cover 4 constraints each: 16 constraints in the regulated (a) variant, 12 constraints in the reformed (b) variant.
- Equation (13) covers 8 constraints.
- Equations (1), (2), (3), (29), (30), (48) cover 9 constraints each (for 9 non-energy goods): 54 constraints.
- Equations (5), (6), (22), (35), (36), (38), (39), (41), (44), (46), (49), (51), (53), (54), (55) and (56), cover 13 constraints each (one equation per sector): 208 constraints.
- Equation (57b) covers 26 constraints.
- Equation (57a) covers 52 constraints.
- Equation (52) covers 169 constraints (input-output prices).

The version considering regulated energy prices (a variants) thus counts 539 constraints, while that considering reformed prices (b variants) counts 511 constraints. The following table identifies the 539/511 variables (Var. count of last-but-one column) matching these numbers of constraints with, when differentiated, the count of the regulated model on the left side and that of the reformed model on the right side of a slash sign. The table also lists all parameters of the model, which for most of them are calibrated at base-year level on our hybrid dataset, for some others stem from other external sources.

Table A.1: IMACLIM-SAU notations

Notation	Description	Var.	Par.
C_i	Final consumption of good i by households. Consumptions of energy goods are exogenous (see Annex C.2). Consumption of AGR is exogenous as well (follows population dynamics).	8	5
D_j	Net debt of agent $j \in \{H, F, G, ROW\}$ (households, firms, public administrations, foreign agents).	4	0
$GFCF_j$	Gross fixed capital formation of agent $j \in \{H, F, G\}$ (households, firms, public administrations).	3	0
G_i	Final public consumption of good i.	13	0
I_i	Final consumption of good i in investment.	13	0
K_i	Total capital stock in sector i.	13	0
L_i	Total labor demand from sector i	13	0
KL_i	Value-added KL intensity of the production of non-energy good i.	9	0

M_i	Imports of good i. Imports of REF are exogenous (Annex C.4), imports of OIL, GAS and ELE are exogenously set to 0.	9	4
NLB_j	Net lending or borrowing of agent $j \in \{H, F, G, ROW\}$ (households, firms, public administrations, foreign agents).	4	0
N_P	Pensioned population	0	1
N_T	Total population	0	1
N_U	Unemployed population	1	0
R_C	Consumption budget of households	1	0
R_j	Gross disposable income of agent $j \in \{H, F, G\}$ (households, firms, public administrations).	3	0
S_i	Total supply of good i.	13	0
X_i	Export of good i. Exports of GAS and ELE are exogenously set to 0 in both scenarios. Additionally, exports of OIL are exogenous in the *Transformation* scenario (Annex C.4).	11/10	2/3
Y_i	Domestic output of good i. Outputs of OIL and REF are exogenous in the *Continuity* scenario. Output of REF alone is exogenous in the *Transformation* scenario (Annex C.4).	11/12	2/1
a_{KLi}	Parameter of substitution of K to L in good i production.	0	13
b_{KLi}	Parameter of substitution of K to L in good i production.	0	13
i_j	Effective interest rate on the net debt of agent $j \in \{H, F, G\}$.	0	3
p_{Ci}	Price of good i for households. See Annex C.1 for the specific assumptions regarding energy prices.	13	0
p_{Gi}	Public price of good i.	13	0
p_{Ii}	Investment price of good i.	13	0
p_{Li}	Cost of labor input in the production of good i.	13	0
p_{Mi}	Import price of good i. The import prices of non-energy goods are constant (non-energy imports are the model's numéraire). See Annex C.3 for the specific assumptions regarding the import prices of energy.	4	9
p_{KL_i}	Price of value-added good KL in non-energy sector i.	9	0
p_{Si}	Average price of good i supply (output and imports).	13	0
p_{Xi}	Export price of good i. See Annex C.3 for the specific assumptions regarding the export prices of energy.	13	0
p_{Yi}	Output price of good i.	13	0
p_{ij}	Price of good i for the production of good j. See Annex C.1 for the specific assumptions regarding intermediate energy prices.	169	0
s_I	Investment effort as a share of GDP. 2013 to 2017 efforts are indexed on The World Bank statistics. From 2018 on, the ratio linearly converges to its 2013-2017 average in 2030.	0	1
t_{ETCi}	Net energy tax per unit of household consumption of good i.	0	13
t_{ETGi}	Net energy tax per unit of public consumption of good i.	0	13
t_{ETIi}	Net energy tax per unit of good i immobilization.	0	13
t_{ETij}	Net energy tax per good i consumption in good j production.	0	169
t_{OTCi}	Net other excise tax per unit of household consumption of good i.	0	13
t_{OTGi}	Net other excise tax per unit of public consumption of good i.	0	13
t_{OTIi}	Net other excise tax per unit of good i immobilization.	0	13
t_{OTij}	Net other excise tax per good i consumption in good j production.	0	169
α_{ij}	Technical coefficient, good i intensity of good j.	0	169
δ_{TM}	Scaling factor on transport margins of transport-providing sectors.	1	0
δ_{Xi}	Scaling factor on good i exports accounting for the growth trend of Saudi export markets.	0	1
κ_i	Technical coefficient, capital (write-off) intensity of good i. Exogenous for energy goods.	9	4
λ_i	Technical coefficient, labor intensity of good i. Exogenous for energy goods.	9	4
π_i	Rate of net operating surplus (mark-up) in the production of good i.	0	13
ρ_{KLi}	Parameter of substitution of K to L in good i production.	0	13
ρ_P	Average *per capita* pensions benefitting the retired population.	1	0
ρ_T	Average *per capita* transfers benefitting households outside unemployment benefits and pensions.	1	0
ρ_U	Average *per capita* unemployment benefits.	1	0

σ_{KLi}	Elasticity of substitution of K to L in non-energy good i production.	0	9
σ_{Mpi}	Elasticity of the contribution of imports into total good i supply to the ratio of output to import prices.	0	9
σ_{Xpi}	Elasticity of the share of exports into total good i uses to the ratio of import to export prices (does not apply to exports of GAS and ELE, exogenously equal to zero).	0	11
σ_{wu}	Elasticity of the purchasing power of wages to the unemployment rate.	0	1
τ_{CT}	Corporate tax rate.	0	1
τ_{MI}	Average annual monetary inflation rate between the calibration year and all projected years.	0	1
τ_{IT}	Income tax rate on households' gross disposable income.	0	1
τ_{LTi}	Social contribution (labor tax) rate applicable to wages in sector i.	0	13
τ_{S}	Saving rate of households.	1	0
τ_{SMCi}	Specific margin on households' consumption of good i. In the *Continuity* scenario, the four margins on energy sales adjust to warrant administered energy prices. In the *Transformation* scenario, the margins on GAS and OIL adjust to align domestic prices on international prices while the margins on ELE and REF are constant parameters (prices are liberalized).	4/2	9/11
τ_{SMXi}	Specific margin on good i exports. Margins on energy exports adjust to accommodate exogenous export prices of energy goods.	4	9
τ_{SMij}	Specific margin on good i consumption in good j production. In the *Continuity* scenario, the margins on sales of all energy goods to all sectors adjust to warrant administered prices. In the *Transformation* scenario, the margins on GAS and OIL adjust to align domestic prices on international prices while the margins on ELE and REF are constant parameters (prices are liberalized).	52/ 26	117/ 143
τ_{TMi}	Transport margin on the sales of good i.	4	9
τ_{CMi}	Trade margin on the sales of good i.	1	12
τ_{VATi}	Value-added tax rate applying to the consumption of good i.	0	13
τ_{Yi}	Output tax rate on the production of good i.	0	13
ω_{KGi}	Share of capital income of sector i accruing to public administrations.	0	13
ω_{KH}	Share of total capital income accruing to households.	0	1
ω_{OTj}	Ratio to GDP of not-elsewhere accounted for transfers accruing to agent $j \in \{H, F, G\}$ (households, firms, public administrations).	0	3
β_{I}	Scaling factor of immobilizations from calibration year.	1	0
β_{G}	Scaling factor of public consumptions from calibration year.	1	0
ϕ_{L}	Scaling factor of labor productivity (technical progress) from calibration year.	0	1
Ω_{B}	Adjustment factor inversely affecting imports and exports of the non-energy good (see Annex B.2).	0	1
Ω_{L}	Adjustment factor affecting labor productivity (see Annex B.2).	0	1
Ω_{K}	Adjustment factor affecting capital productivity (see Annex B.2).	0	1
Ω_{w}	Adjustment factor affecting real wage correlated to unemployment via the wage curve (see Annex B.2).	0	1
B	Trade balance at current prices.	1	0
CPI	Consumer price index evolution from calibration year.	1	0
MPI	Import price index evolution from calibration year.	1	0
GDP	Gross domestic product.	1	0
GOS_{i}	Gross operating surplus of sector i.	13	0
L	Total active population (labor endowment) in full-time equivalents.	0	1
SM_{i}	Specific margin in sector i.	13	0
T	Total taxes and social contributions.	1	0
u	Unemployment rate.	1	0
p_{K}	Rental price of capital	1	0
w	Average net wage across all sectors.	1	0
w_{i}	Net wage in sector i.	13	0

A.1 Firms

Producers' trade-offs

Trade-offs in the production of energy goods $E = \{OIL, GAS, REF, ELE\}$ are exogenous assumptions based on KEM and IEA data (see Annex C).

Non-energy productions follow a standard nested production tree. At the bottom of the tree, capital and labor trade off with a constant σ_{KLi} elasticity of substitution to form the value-added aggregate KL_i. The mobilized quantity of labor L_i is however augmented by a productivity factor ϕ, while both the labor and capital inputs are also adjusted by dynamic calibration factors Ω (see Annex B.2). Therefore $KL_i = \left(\alpha_{KLi}(\Omega_K K_i)^{\rho_{KLi}} + \beta_{KLi}(\Omega_L \phi L_i)^{\rho_{KLi}}\right)^{\frac{1}{\rho_{KLi}}}$, with here and elsewhere, for convenience, $\rho_i = \frac{\sigma_i - 1}{\sigma_i}$. Facing prices p_K and p_{Li}, cost minimization induces:

$$\forall\, i \notin E \quad L_i = \frac{1}{\Omega_L \phi}\left(\frac{\Omega_L \phi \beta_{KL_i}}{p_{L_i}}\right)^{\sigma_{KL_i}} \left(\alpha_{KL_i}^{\sigma_{KL_i}} \left(\frac{p_K}{\Omega_K}\right)^{1-\sigma_{KL_i}} + \beta_{KL_i}^{\sigma_{KL_i}} \left(\frac{p_{L_i}}{\Omega_L \phi}\right)^{1-\sigma_{KL_i}}\right)^{-\frac{1}{\rho_{KL_i}}} KL_i \qquad \text{(A-1)}$$

$$\forall\, i \notin E \quad K_i = \frac{1}{\Omega_K}\left(\frac{\Omega_K \alpha_{KL_i}}{p_K}\right)^{\sigma_{KLi}} \left(\alpha_{KL_i}^{\sigma_{KL_i}} \left(\frac{p_K}{\Omega_K}\right)^{1-\sigma_{KL_i}} + \beta_{KL_i}^{\sigma_{KL_i}} \left(\frac{p_{L_i}}{\Omega_L \phi}\right)^{1-\sigma_{KL_i}}\right)^{-\frac{1}{\rho_{KL_i}}} KL_i \qquad \text{(A-2)}$$

All secondary factor intensities are exogenous, taken from either KEM (energy intensities) or constant at calibration-year value (non-energy intensities). The value-added intensity of non-energy productions is constant (Leontief assumption):

$$\forall\, i \notin E \quad \frac{KL_i}{Y_i} = \frac{KL_{i0}}{Y_{i0}} \qquad \text{(A-3)}$$

The absence of proper estimates for Saudi substitution elasticities led to borrow these parameters from the literature (Okagawa and Ban, 2008).

Table A.2: Elasticities of substitution of capital and labor

Sector	σ_{KL}
OIL	0.139
GAS	0.139
REF	0.046
ELE	0.46
AGR	0.023
MIN	0.139
CHM	0.33
NMM	0.358
MAN	0.046
WTP	0.31
ATP	0.31
OTP	0.31
C&S	0.31

Net lending and borrowing and net financial debt

The firms' gross disposable income R_F consists of the remainder of the Gross Operating Surpluses (GOS) of sectors, taking account of the shares accruing to households and public administrations, and a share ω_{OTF} of GDP as residual transfers, minus interest payments on their net financial debt D_F, at rate i_F, and corporate taxes at rate τ_{CT} on their net operating surplus $\sum_i \pi_i p_i Y_i$:

$$R_F = \sum_i GOS_i - \sum_i \omega_{KGi} GOS_i - \omega_{KH} \sum_i GOS_i$$

$$+ \omega_{OTF}\, GDP - i_F D_F - \tau_{CT} \sum_i \pi_i p_i Y_i \qquad \text{(A-4)}$$

The share ω_{OTF}, the interest rate i_F and the corporate tax rate τ_{CT} are constant over time at their 2013 calibration values.

The GOS of sector *i* is the sum of the consumption of fixed capital $p_K\, K_i$, the net operating surplus $\pi_i\, p_i\, Y_i$ and the specific margins SM_i (which do not sum to 0 after the calibration year):

$$GOS_i = p_K\, K_i + \pi_i\, p_{Y_i}\, Y_i + SM_i \qquad \text{(A-5)}$$

The sum of specific margins on sector i sales is:

$$SM_i = \sum_j \tau_{SMij}\, p_{Si}\, \alpha_{ij}\, Y_j + \tau_{SMC_i}\, p_{Si}\, C_i + \tau_{SMX_i}\, p_{Si}\, X_i \quad \text{(A-6)}$$

The margins on non-hybrid sales (the sales of those goods without satellite accounts on physical flows, in the case of IMACLIM-SAU all non-energy goods) are equal to zero. Additionally, for each hybrid good, the sum of margins on all sales is equal to zero at calibration year, by construction of the IOT.

At projection years, all positive trade and transport margins remain at their calibration values while the negative margins, which correspond to those sectors providing the underlying trade and transport services (in the case of IMACLIM-SAU the C&S sector for trade and the C&S, WTP, ATP and OTP sectors for transport), adjust to warrant accounting balances:

$$\sum_i \tau_{CMi}\, p_{Si} \Big(\sum_j \alpha_{ij}\, Y_j + C_i + G_i + I_i + X_i \Big) = 0 \quad \text{(A-7)}$$

$$\sum_i \tau_{TMi}\, p_{Si} \Big(\sum_j \alpha_{ij}\, Y_j + C_i + G_i + I_i + X_i \Big) = 0 \quad \text{(A-8)}$$

$$\forall i \in \{CPS, WTP, ATP, OTP\} \quad \tau_{TMi} = (1 + \delta_{TM})\, \tau_{TMi0} \quad \text{(A-9)}$$

The firms' investment effort $GFCF_F$ is equal to total investment net of the investment of households and public administrations:

$$GFCF_F = \sum_i p_{I_i}\, I_i - GFCF_G - GFCF_H \quad \text{(A-10)}$$

The net lending or borrowing (NLB) of firms NLB_F is the difference between the firms' disposable income and investments:

$$NLB_F = R_F - GFCF_F \quad \text{(A-11)}$$

The firms' net financial debt D_F evolves according to the accumulated NLBs—the net financial debts of domestic agents are the only dynamic variables other than the capital stock and the chained price indexes. Monetary inflation at annual rate τ_{MI} degrades the real value of the debt. At date *t*:

$$D_{F,t} = (1 - \tau_{MI})\, D_{F,t-1} - NLB_{F,t} \quad \text{(A-12)}$$

A.2 Households

Consumer trade-offs

Households' final consumption C_i are exogenous for energy goods as well as for agricultural goods AGR. For lack of analysis in the available literature, the remainder of the consumption budget allocates according to the Cobb-Douglas assumption of constant budget shares:

$$\forall i \in A = \{MIN, CHM, NMM, MAN, CPS, WTP, ATP, OTP\}$$

$$\frac{p_{Ci} C_i}{R_C - \sum_{j \notin A} p_{Cj} C_j} = \frac{p_{Ci0} C_{i0}}{R_{C0} - \sum_{j \notin A} p_{Cj0} C_{j0}} \quad \text{(A-13)}$$

Income, savings, investment, NLB and net debt

The after-tax gross disposable income of households R_H proceeds from primary factor income, social transfers, property income and an aggregate of other secondary transfers.

$$R_H = \sum_i w_i\, \lambda_i\, Y_i + \omega_{KH} \sum_i GOS_i + \sum_{i=P,U,T} \rho_i\, N_i$$

$$+ \omega_{OTH}\, GDP - i_H\, D_H - \tau_{IT}\, R_H \quad \text{(A-14)}$$

Primary factor income comprises the sum of net wages from all economic sectors $\sum_i w_i\, \lambda_i\, Y_i$ and an ω_{KH} share of gross operating surpluses GOS_i, directly accruing to households in the form of, mainly, housing rents (imputed or real). Social transfers involve pensions $\rho_P\, N_P$, unemployment transfers $\rho_U\, N_U$ and other social transfers $\rho_T\, N_T$. ρ_i stands for per capita transfers and N_i for a target population: exogenous pensioned population N_P, endogenous unemployed population N_U or exogenous total population N_T. Other transfers form a constant ω_{OTH} share of GDP calibrated at base year. They include international remittances, which reach 4.7% of GDP in the case of Saudi Arabia at our 2013 calibration year (Al Kaabi, 2016). Property income is the interest payment on the net debt D_H

at rate i_H resulting from the balance of income from financial assets and interest payments on liabilities. Income taxes are paid at rate τ_{IT} on disposable income R_H.

Following on our choice of a Johansen closure (see Section 2), Households' savings at rate τ_S adjust to balance investments and savings. The consumption budget of households is equal to the disposable income net of savings:

$$R_C = (1 - \tau_S)\, R_H \tag{A-15}$$

The investment effort of households $GFCF_H$ is indexed on both disposable income R_H and the aggregate investment effort s_I:

$$GFCF_H = A_{GFCFH}\, R_H\, s_I \tag{A-16}$$

With A_{GFCFH} a constant calibrated on base-year values. The net lending or borrowing of households NLB_H is the difference between their disposable income and their consumption and investment:

$$NLB_H = R_H - R_C - GFCF_H \tag{A-17}$$

Similar to firms, the net household debt at date t resulting from the accumulation of NLBs is:

$$D_{H,t} = (1 - \tau_{MI})\, D_{H,t-1} - NLB_{H,t} \tag{A-18}$$

A.3 Public administrations

Public income

The gross disposable income of public administrations R_G derives from taxes and social security contributions T, exogenous ω_{KGi} and ω_{OTG} shares of the GOS of sectors (reflecting public participations) and GDP, corrected from transfers to households $\sum_j \rho_j\, N_j$ and interest payments at rate i_G on the net public debt D_G:

$$R_G = T + \sum_i \omega_{KGi}\, GOS_i + \omega_{OTG}\, GDP - \sum_{i=U,P,T} \rho_i\, N_i - i_G\, D_G \tag{A-19}$$

Tax revenue T comprises primary factor and output taxes, value-added and excise taxes, the income tax and other direct taxes, and the corporate tax:

$$T = \sum_{i=1}^{n} \tau_{LTi}\, w_i\, \lambda_i\, Y_i + \tau_{Yi}\, p_{Yi}\, Y_i + \frac{\tau_{VAT_i}}{1+\tau_{VAT_i}} \left(p_{C_i}\, C_i + p_{G_i}\, G_i + p_{I_i}\, I_i\right)$$

$$+ \sum_i \sum_j (t_{ETij} + t_{OTij})\, \alpha_{ij}\, Y_j + (t_{ETCi} + t_{OTCi})\, C_i + (t_{ETGi} + t_{OTGi})\, G_i + (t_{ETIi} + t_{OTIi})\, I_i$$

$$+\tau_{IT}\, R_H + t_H\, CPI\, N_T + \tau_{CT} \sum_i \pi_i\, p_{Yi}\, Y_i \qquad \text{(A-20)}$$

Public expenditures and budget balance

The value of total public consumption is a constant s_G ratio to GDP:

$$\sum_i \; p_{G_i}\, G_i = \; s_G\, GDP \qquad \text{(A-21)}$$

Sectoral public expenses grow homothetically from calibration year:

$$G_i = \beta_G\, A_{Gi} \qquad \text{(A-22)}$$

With A_{Gi} a set of constants calibrated at base year.

Social transfers per capita, ρ_U, ρ_P and ρ_T, are indexed on the average wage:

$$\rho_P = \; A_{\rho P}\, w \qquad \text{(A-23)}$$

$$\rho_U = \; A_{\rho U}\, w \qquad \text{(A-24)}$$

$$\rho_T = \; A_{\rho T}\, w \qquad \text{(A-25)}$$

With $A_{\rho P}$, $A_{\rho U}$ and $A_{\rho T}$ three constants calibrated at base year.

Public investment is indexed on total investment. This effectively maintains the public contribution to investment at calibration-year level (37.7%), which is close to the observed average between 2010 and 2016 (SAMA, 2018) at 36.2% of total investment.

$$GFCF_G \; == \; A_{GFCFG} \sum_i \; p_{Ii} \, I_i \tag{A-26}$$

With A_{GFCFG} a constant calibrated at base year. Similar to firms or households, the NLB of public administrations is the difference between disposable income and investment:

$$NLB_G = \; R_G - GFCF_G \tag{A-27}$$

The public debt accumulates as:

$$D_{G,t} = \left(1 - \tau_{MI}\right) D_{G,t-1} - NLB_{G,t} \tag{A-28}$$

A.4 International trade and the foreign agent

For all energy goods, imports are exogenous, and exports are either exogenous as well, or flow from market clearing (see below). For the non-energy goods, the share of imports M_i in total resource S_i has a σ_{Mp_i} elasticity to terms-of-trade and is corrected by the inverse of the export dynamic calibration factor Ω_B (see Annex B.2):

$$\forall \; i \; \notin \; \{OIL, GAS, REF, ELE\} \qquad \frac{M_i}{S_i} = \frac{1}{\Omega_B} A_{M_i} \left(\frac{p_{Y_i}}{p_{M_i}}\right)^{\sigma_{Mp}} \tag{A-29}$$

with A_{M_i} constants calibrated on 2013 data. We follow IMF (2016) using elasticities from Hakura and Billmeier (2008) to set σ_{Mp} at -0.09 for all non-energy sectors indistinctly. We regard this elasticity as compatible with the import structure of the Kingdom, composed of goods with very few domestic substitution opportunities.

Non-energy exports X_i are elastic to terms of trade around exogenous trends δ_{Xi} reflecting the growths of Saudi export markets as well as diversification strategies (see Section 3). Like import elasticities, we derive σ_{X_p} from IMF (2016) based on Hakura and Billmeier (2008) estimating the elasticity of non-oil exports at 0.69:

$$\forall \; i \; \notin \; \{OIL, GAS, REF, ELE\} \qquad X_i = \; \Omega_B \; (1 + \; \delta_{Xi}) \, A_{X_i} \left(\frac{p_{X_i}}{p_{M_i}}\right)^{\sigma_{X_p}} \tag{A-30}$$

They are adjusted by Ω_B following dynamic calibration from 2014 to 2017 (see Section 2.2). A_{X_i} are another set of constants calibrated in 2013. The trade balance B is:

$$B = \sum_i \; p_{X_i} X_i - p_{M_i} M_i \tag{A-31}$$

Both the long-lasting peg of the Saudi riyal to the US dollar and the sensitivity of Saudi exports to the world oil price forbid considering that real effective exchange rate (REER) variations balance Saudi trade (see Section 2). Our *Continuity* scenario rather constrains the REER to reflect the significant statistical relationship between the REER and the trade balance contribution to GDP detected and explained by Soummane et al. (2019). To specify the relationship, we tested several functional forms including a linear link (with an R^2 of 0.622), with little impact on model results. We settle on an exponential form, which exhibits an R^2 of 0.674. This relationship defines the REER as an exponential function of the trade-balance-to-GDP ratio:

$$\frac{CPI}{MPI} = A_{REER} + B_{REER} \; e^{C_{REER}\frac{B}{GDP}} \tag{A-32a}$$

with B_{REER} and C_{REER} calibrated on 1986 to 2015 statistical observation of the two variables (see Figure 1 of Soummane et al., 2019), and A_{REER} the adjustment that allows fitting 2013 data.

In our *Transformation* scenario we drop the constant REER assumption to rather acknowledge the impact of the massive increase of regulated energy prices on the REER by constraining the price of value-added (KL) in the C&S sector on the same $\delta_{p_{KL}}$ trajectory that it follows in our *Continuity* scenario (implicitly, relative to the numéraire of IMACLIM-SAU i.e. the basket of non-energy foreign goods):

$$p_{KL\_CPS} = \left(1 + \delta_{p_{KL}}\right) D_{REER}, \tag{A-32b}$$

with D_{REER} the value of p_{KL} at calibration year.

The Rest of the world (ROW) agent balances out trade (by selling imports $\sum_i p_{Mi} M_i$ and buying exports $\sum_i p_{Xi} X_i$), property income and interest payments. Its net lending or borrowing capacity NLB_{ROW} is thus:

$$NLB_{ROW} = \sum_i p_{Mi} M_i - \sum_i p_{Xi} X_i - \sum_{j=H,F,G} i_j D_j - \sum_{j=H,F,G} \omega_{OTj} GDP \quad \text{(A-33)}$$

The net debt of foreign agents D_{ROW} balances out domestic assets and liabilities:

$$D_{ROW} = -\sum_{j=H,F,G} D_j \quad \text{(A-34)}$$

A.5 Market clearings

Goods markets

The balance of goods markets is between resources, which comprise domestic production Y_i and imports M_i, and uses, which consist of the consumptions of all sectors $\sum_j \alpha_{ij} Y_j$, households' and public consumptions C_i and G_i, immobilizations I_i and exports X_i. For energy goods, the data hybridization process results in this equation being expressed in thousand tons-of-oil-equivalent (ktoe), in consistency with the 2013 Saudi energy balance of the IEA. The public consumptions and immobilizations of all energy goods are equal to zero at calibration year and remain so up to projection horizons by national accounting convention for the former and by definition for the latter.

$$S_i = \sum_j \alpha_{ij} Y_j + C_i + G_i + I_i + X_i \quad \text{(A-35)}$$

$$Y_i = S_i - M_i \quad \text{(A-36)}$$

Labor market

On the labor market, a 'wage curve' describes the elasticity of real wage (the purchasing power of wage w) to unemployment u. The real wage w/CPI attached to unemployment at 2013 level (5.6%) is defined as the 2013 average real wage multiplied by labor productivity increase ϕ and a wage moderation factor Ω_w (see Annex B.2) via the calibration of one constant A_u:

$$\frac{w}{CPI} = \phi \, \Omega_w \, A_u \, u^{\sigma_{wu}} \quad \text{(A-37)}$$

The net wages in all sectors evolve in parallel to w:

$$w_i = A_{wi}\, w \qquad \text{(A-38)}$$

The cost of labor is equal to the wage increased by labor tax contributions:

$$p_{L_i} = \left(1 + \tau_{LT_i}\right) w_i \qquad \text{(A-39)}$$

Labor demands of all sectors and unemployment balance out labor endowment L:

$$\sum_i L_i = (1 - u)\, L \qquad \text{(A-40)}$$

For each sector, labor consumption and output are conventionally related via labor intensity:

$$L_i = \lambda_i\, Y_i \qquad \text{(A-41)}$$

The unemployed population N_U is:

$$N_U = u\, L \qquad \text{(A-42)}$$

Capital markets

On the capital market, sectoral demands balance out capital endowment K:

$$\sum_i K_i = K \qquad \text{(A-43)}$$

With for each sector, similarly to labor:

$$K_i = \kappa_i\, Y_i \qquad \text{(A-44)}$$

Investment

Investment expenses $\sum_i p_{I_i} I_i$ form an exogenous share s_I of GDP (investment in energy goods is equal to zero except for stock variations that are cancelled out in the data-hybridization process).

$$\sum_i \; p_{I_i} I_i = \; s_I \, GDP \tag{A-45}$$

The sectoral structure of investment remains unchanged from the base year to projected horizons:

$$I_i = \beta_I \, A_{Ii} \tag{A-46}$$

with A_{Ii} constants calibrated on 2013 data.

GDP

GDP is defined on the expenditure side as:

$$GDP = \sum_i \; p_{C_i} C_i + p_{G_i} G_i + p_{I_i} I_i + p_{X_i} X_i - p_{M_i} M_i \tag{A-47}$$

A.6 Producer and consumer prices

For non-energy goods, the price of the value-added aggregate p_{KL_i} is a canonical function (KL_i being a CES product of K_i and L_i) of prices p_{K_i} and p_{L_i} and of the elasticity of substitution of the two inputs σ_{KL_i}:

$$\forall \; i \; \notin \; \{OIL, GAS, REF, ELE\}$$

$$p_{KL_i} = \left(\alpha_{KL_i}^{\sigma_{KL_i}} \left(\frac{p_{K_i}}{\Omega_{K_i}} \right)^{1-\sigma_{KL_i}} + \beta_{KL_i}^{\sigma_{KL_i}} \left(\frac{w_i}{\Omega_{L_i} \phi_i} \right)^{1-\sigma_{KL_i}} \right)^{\frac{1}{1-\sigma_{KL_i}}} \tag{A-48}$$

The output or producer price of goods i p_{Y_i} is the sum of input costs, output taxes at a τ_{Yi} rate, and is subject to a mark-up rate π_i corresponding to the rent on natural resources and/or the net operating surplus:

$$p_{Y_i} = \sum_j p_{ji} \, \alpha_{ji} + p_{L_i} \, \lambda_i + p_K \, \kappa_i + \pi_{\text{i}} \, p_{Y_i} + \tau_{Y_i} \, p_{Y_i} \tag{A-49}$$

The import prices of non-energy goods are exogenous and constant (these goods act as the collective numéraire of the model). The import prices of energy goods follow exogenous trajectories that are indexed on the price of value-added in the C&S sector, to account for the differentiated impact of oil-price variations on the Saudi and foreign economies (see Annex C.3):

$$\forall\, i \in \{OIL, GAS, REF, ELE\} \quad p_{Mi} = A_{pMi}\, p_{KL\_CPS} \tag{A-50}$$

With A_{pMi} the ratios of the (year-specific) exogenous international energy prices and the price of value-added in the C&S sector at base year.

The price p_{S_i} of the total resource in good i, S_i, is inferred from:

$$p_{S_i}\, S_i = p_{Y_i}\, Y_i + p_{M_i}\, M_i \tag{A-51}$$

Turning to purchasers' prices, the price of good i for the production of good j, p_{ij}, is equal to the resource price of good i augmented from commercial margins τ_{CM_i}, transport margins τ_{TM_i}, agent-specific margins $\tau_{SM_{ij}}$, energy taxes t_{ETij} and other excise taxes t_{OTij}:

$$p_{ij} = p_{S_i}\left(1 + \tau_{CM_i} + \tau_{TM_i} + \tau_{SM_{ij}}\right) + t_{ETij} + t_{OTij} \tag{A-52}$$

The consumer prices of households, public administrations, the investment good and exports are constructed similarly with additional value-added taxes (except exports) but drop the unnecessary specific margins when energy is not concerned (public consumption, investment):

$$p_{C_i} = \left(p_{Si}\left(1 + \tau_{CM_i} + \tau_{TM_i} + \tau_{SMC_i}\right) + t_{ETCi} + t_{OTCi}\right)(1 + \tau_{VATi}) \tag{A-53}$$

$$p_{G_i} = \left(p_{Si}\left(1 + \tau_{CM_i} + \tau_{TM_i}\right) + t_{ETGi} + t_{OTGi}\right)(1 + \tau_{VATi}) \tag{A-54}$$

$$p_{I_i} = \left(p_{Si}\left(1 + \tau_{CM_i} + \tau_{TM_i}\right) + t_{ETIi} + t_{OTIi}\right)(1 + \tau_{VATi}) \tag{A-55}$$

$$p_{X_i} = p_{Si}\left(1 + \tau_{CM_i} + \tau_{TM_i} + \tau_{SMX_i}\right) \tag{A-56}$$

Additionally, the exogenous prices of some energy goods are indexed on the price of value-added in the C&S sector (by adjustment of specific margins) following Annex C.1.

In scenarios of continued energy-price regulation, e.g. our *Continuity* scenario of Section 3.1, all domestic energy prices are regulated:

$$\forall\ i \in \{OIL, GAS, REF, ELE\} \quad p_{ij} = A_{pij}\ p_{KL\_CPS} \tag{A-57a}$$

$$\forall\ i \in \{OIL, GAS, REF, ELE\} \quad p_{Ci} = A_{pCi}\ p_{KL\_CPS} \tag{A-58a}$$

With A_{pij} and A_{pCi} parameters computed as the ratios of the (year-specific) regulated energy prices and the price of value-added in the C&S sector at base year (see Annex C.1).

In scenarios of energy pricing reforms like our *Transformation* scenario of Section 3.2, only the prices of OIL and GAS are anchored to exogenous assumptions, which shift from the historical low regulated prices to international references (see Annex C.1):

$$\forall\ i \in \{OIL, GAS\} \quad p_{ij} = A_{pij}\ p_{KL\_CPS} \tag{A-57b}$$

$$\forall\ i \in \{OIL, GAS\} \quad p_{Ci} = A_{pCi}\ p_{KL\_CPS} \tag{A-58b}$$

With A_{pij} and A_{pCi} defined as above. The household prices of OIL and GAS are only set up for the sake of consistency because both underlying consumptions are currently equal to zero and remain so in all scenarios (see Annex C.2).

Irrespective of energy pricing reforms, energy export prices are at exogenous values indexed on the price of value-added in the C&S sector (see Annex C.3):

$$\forall\ i \in \{OIL, GAS, REF, ELE\} \quad p_{Xi} = A_{pXi}\ p_{KL\_CPS} \tag{A-59}$$

With A_{pXi} the ratios of the (year-specific) exogenous international energy prices and the price of value-added in the C&S sector at base year.

The consumer and import price indexes CPI and MPI are computed as chained indexes, i.e. from one period to the next, according to Fisher's formula:

$$CPI_t = CPI_{t-1}\sqrt{\frac{\sum p_{Ci,t}C_{i,t-1}}{\sum p_{Ci,t-1}C_{i,t-1}}\frac{\sum p_{Ci,t}C_{i,t}}{\sum p_{Ci,t-1}C_{i,t}}} \tag{A-60}$$

$$MPI_t = MPI_{t-1}\sqrt{\frac{\sum p_{Mi,t}M_{i,t-1}}{\sum p_{Mi,t-1}M_{i,t-1}}\frac{\sum p_{Mi,t}M_{i,t}}{\sum p_{Mi,t-1}M_{i,t}}} \tag{A-61}$$

Annex B CALIBRATION OF IMACLIM-SAU

B.1 Secondary distribution of income

On top of the hybridization of energy flows,[4] we expand the original CDSI and GSTAT supply-and-use table data by disaggregating total labor costs between labor tax contributions and net labor payments. We base our disaggregation on Saudi legislation regarding insurance contributions. These comprise the social contributions that employers pay for their Saudi employees (we derive the share of Saudi employment from SAMA, 2018), which amount to 10% of the employee's salary and are due to the General Organization for Social Insurance (GOSI). Also, a 2% accident insurance for both national and non-national employees, and a 2% unemployment insurance, which is shared equally between employers and Saudi employees. We also modify CDSI accounts to represent the substantial public subsidy on electricity prices to both activity sectors and households. On the side of expenditures, we split investment among households, public administrations and firms by allocating to households the 'residential building construction' expenses from SAMA (2018); to government, the dedicated series from national accounts (SAMA, 2018); and to firms, the remainder of total investment from the original input-output table.

The additional data required to specify secondary income distribution among households, firms, public administrations and foreign agents (the 'rest-of-the-world' or RoW) are not available from the national accounts of CDSI (2014). We therefore turn to supplementary sources along the following lines.

We distribute the gross operation surplus (GOS) of sectors across the three domestic agents as follows. Firstly, we allocate to households the income from the real estate and renting activities sector of the original IOT of CDSI. Secondly, we assume that public authorities capture:

- 85% of the GOS from oil and gas extraction activities, corresponding to the upper bound of the prevailing taxation applied by the Saudi government to this branch;
- 71% of the GOS of the refining sector, corresponding to the share of the public Aramco company in the Saudi refining capacity;

[4] Which extends to energy taxes and subsidies (see Soummane et al., 2019).

- 81% of the GOS of the electricity sector, corresponding to the government's share in Saudi Electricity Company;
- 50% of the GOS of mineral activities, corresponding to the government's share in the national company Ma'aden;
- And 70% of the GOS of petrochemical activities, corresponding to the government's share in SABIC.

Firms collect the remainder of the total GOS as indicated by CDSI. The resulting distribution of GOS is of 16.4% to households, 44.7% to the government and the remaining 38.9% to firms.

Concerning direct taxes, corporate taxes apply at a rate of 20% on profits accruing to shareholders of other nationalities than those of the Gulf Cooperation Council (GCC). For GCC shareholders (including Saudi ones), there is a 2.5% *zakat* on profits. Although we already isolate energy-related activities, it remains challenging to distinguish activities attributable to non-GCC investors. Consequently, we retain only the 2.5% Z*akat* rate to compute corporate tax payments accruing to the government. Turning to households, there is currently no income tax in force in Saudi Arabia. However, there is a 2.5% *Zakat* tax, which we apply to households' disposable income.

Concerning social transfers, we calibrate unemployment transfers from public administrations to households on governmental aid in the framework of the 'Hafiz' program from the Human Resource Development Fund. We assume that the 1.11 million job seekers reported by SAMA (2018) for the year 2013 perceived the monthly financial aid of SAR 2,000. Similarly, we equate total pension disbursements from public administrations to households to the sum of pension payments and compensations to civilian and military personnel from SAMA (2018), which reflects data from the Public Pension Agency. For the remainder of social transfers, we consider total transfers from central government reported by Oxford Economics, to which we subtract the above explicit transfers.

Property incomes of the three domestic agents correspond to interest payments (or revenues) on net debt positions (which evolve with the accumulation of net lending or borrowing positions) and thus require specifying interest rates i, which we assume at 5% for firms and households. Then, the property income is calculated as follows: (i) for households and firms it corresponds to the product of the debt level (see below for calculation) and the interest rate; (ii) for public administration, we use the government's 'other revenue' figures from SAMA for the year

2013, to which we subtract 81% of the ELE operating surplus, the perceived income tax and other taxes. The computed public property income yields an apparent interest rate of 1.3%. The property income of the RoW balances out the sum of domestic property incomes.

We calibrate the net public debt position at our 2013 base year as the sum of the reserve assets reported by SAMA (2018), comprised of investment in foreign securities (71.6%), foreign currency and deposits abroad (26.3%), Special Drawing Rights (1.3%), and reserve position at the IMF (0.7%); net of the total public debt, amounting to 2.1% of GDP during that year. The households' debt for the year 2013 corresponds to the difference between outstanding personal loans, net of assets of investment funds, bank deposits and quasi-monetary (assuming a share of 70% for personal purpose), and bank claims. The ROW debt corresponds to the net international investment position from the balance of payments (BoP) minus gold reserves (SAMA, 2018). The firms' debt balances the total debt of agents.

Finally, we compute an aggregate of remaining 'other transfers' as follows. For households, we use the series of 'Personal transfers', corresponding to workers' remittances, from the Saudi BoP (SAMA, 2018). For public administration, we compute 'other transfers' as the difference between the aggregate budget balance and all resources and expenditures elsewhere accounted for. For the rest of the world, we sum up the opposite of workers' remittances and other net current transfers (i.e., credit minus debit) from the BoP and the governments' secondary income from the BoP. The firms' 'other transfers' simply balance out the 'other transfers' of the other three agents.

B.2 Calibration on 2014 to 2017 macroeconomics

Dynamic calibration of IMACLIM-SAU on years 2014 to 2017 targets the main macroeconomic indicators of GDP, the unemployment rate and the trade balance—see Annex D.2 of Soummane et al. (2019) for the detailed procedure. Adjustment factors impacting capital productivity (Ω_K), labor productivity (Ω_L), the equilibrium wage (Ω_w) and exports and imports (Ω_B) are assumed to converge to their 2014-to-2017 averages by 2030. The resulting factors remain within 7.5% of their 2013 values for those that concern labor, capital, and real wage expectations. They reach 26.4% for the non-energy trade factor Ω_B, which reflects the fact that non-energy trade, although dwarfed by oil trade, must compensate any statistical discrepancy between our sources for the oil price and exports on one side (IEA data), and the aggregate trade balance contribution to GDP on the other side (World Bank data).

Table B.1: Adjustment factors resulting from 2014-to-2017 calibration

	2014	**2015**	**2016**	**2017**	2020	2025	2030
Ω_K	**0.964**	**0.962**	**1.003**	**0.975**	0.976	0.978	0.981
Ω_L	**1.011**	**1.027**	**1.075**	**1.065**	1.058	1.047	1.036
Ω_w	**1.005**	**1.011**	**1.021**	**1.023**	1.020	1.016	1.012
Ω_B	**0.736**	**0.790**	**1.012**	**1.104**	1.061	0.992	0.928

Note: Calibrated values appear in bold script, projections to 2030 for selected years in light script.

Annex C ENERGY SCENARIOS

Parameterization of the energy consumptions and costs constraining IMACLIM-SAU projections are a combination of outputs from the Riyadh-based KAPSARC Energy Model (KEM) and complementary exogenous sources available for the KSA or the broader Middle East region. The hybrid nature of IMACLIM-SAU calibration data warrants the consistent combination of assumptions.

C.1 Domestic energy prices

After a long period of stagnation of regulated energy tariffs, Saudi Arabia recently engaged in a wide reform of energy pricing (APICORP, 2018). In 2016, the first phase of the reform increased natural gas tariffs by 67%, the price of ethane by 133%, and that of refined products (depending on fuel grade) between 50% and 79%. In 2018, the second phase of the reform targeted households' consumptions. It further increased the price of gasoline between 83% and 127% (depending on fuel grade) and that of residential electricity by 260% (for consumptions lower than 6,000 kWh per month).

Our *Continuity* scenario builds on the assumption that domestic tariffs remain constant in Saudi Riyals after the two pricing reforms of 2016 and 2018, up to 2030 (Table C.1). Because international non-energy goods act as the collective numéraire of IMACLIM-SAU (all their relative prices are fixed across time for all scenarios), and to take account of the differentiated impact of oil price variations on inflation in Saudi Arabia and abroad, particularly in the US, we follow Soummane et al. (2019, see Annex B.2) by indexing the forced exogenous tariffs on the price of value-added in the C&S sector (see Equations 57 and 58).

However, Saudi authorities are planning further reforms (IMF, 2016; Jadwa, 2018), although they have not communicated target prices. Indeed, energy-pricing reforms are implemented in other Gulf countries, and have accelerated after the sharp decline of the price of oil in 2015 to contain the consecutive massive budget deficits. Saudi plans may extend to raising energy prices to international levels, as ongoing reforms in Qatar and United Arab Emirates suggest (Krane and Shih, 2016). Our *Transformation* scenario reflects such assumptions. It assumes that domestic oil and gas prices (e.g., for power generation or water desalination) converge with international prices by 2030. Domestic oil prices consequently rise from 6.35 USD per barrel in 2017 to 69 USD per barrel in 2030, and domestic natural gas prices from 1.25 USD per million British thermal unit (MBtu) to around 4 USD MBtu (in constant 2016 dollars). These reforms annihilate opportunity costs (the national oil company becomes indifferent between selling oil domestically or abroad) and foster efficiency gains.

Table C.1: Assumptions on domestic oil and gas prices

In SAR/ton-of-oil equivalent	**Calibration 2013**	------***Continuity***------		------***Transformation***------	
		2030	**AAGR**	**2030**	**AAGR**
p_{OIL_REF}	116.5	152.7	+1.6%	2,108.7	+18.6%
p_{OIL_ELE}	108.6	131.5	+1.1%	1,832.1	+18.1%
p_{OIL_NMM}	116.5	152.7	+1.6%	2,108.7	+18.6%
p_{OIL_MAN}	116.5	152.7	+1.6%	1,965.5	+18.1%
p_{GAS_ELE}	111.6	163.5	+2.3%	630.9	+10.7%
p_{GAS_MIN}	111.6	163.4	+2.3%	630.9	+10.7%
p_{GAS_CHM}	111.6	199.5	+3.5%	767.2	+12.0%
p_{GAS_NMM}	111.6	163.4	+2.3%	630.9	+10.7%
p_{GAS_MAN}	111.6	163.4	+2.3%	630.9	+10.7%

Sources: see Annex C.1. The price of energy i input into production j is p_{i_j}, with sector codes those of Table 1. Unreported prices point at non-existing consumptions (e.g., no crude oil consumption by C&S sector or by households). AAGR is the Average Annual Growth Rate.

The exogenous prices of oil and gas affect the supply costs of refined products and electricity via the hybrid input-output matrix. Under *Transformation*, on top of increased oil and gas prices, we assume reductions of the negative margins on the sales of refined products (which reflect the differential between the average resource price and the consumption prices of each sector and households) reaching 50% in 2030. Likewise, we assume cuts on subsidies to electricity sales to both firms and households reaching 50% by 2030. Both parameters remain constant throughout our projection horizon under *Continuity*.

Additionally, we adjust the capital intensity of the ELE sector to capture the impact of changes of the energy mix backing power supply. Under continued energy-pricing regulation, KEM projects the power mix to remain based on fossil fuels, although forecasting a gradual shift toward natural gas. Under reformed energy prices, it projects the power mix to shift to solar photovoltaic (PV) and nuclear sources (Matar et al., 2016). Using capital expenditure and operation and maintenance costs from Matar et al. (2016) and IEA (2016), and accounting for the low rates of capacity use at base-year as well as for the extra costs of handling intermittency in the case of solar PV, we translate KEM projections into a gradual decrease of the capital intensity of ELE in our *Continuity* scenario, reaching 20% in 2030 compared with base year; and, conversely, in a gradual increase of the capital intensity of ELE in our *Transformation* scenario, reaching 18% in 2030 compared with base year.

Table C.2 reports the refined fuels (REF) and electricity (ELE) prices resulting from the above assumptions.

Table C.2: Projected consumer prices of refined products and electricity

In SAR/ton-of-oil equivalent	Calibration 2013	------*Continuity*------ 2030	AAGR	------*Transformation*------ 2030	AAGR
p_{REF_ELE}	85.4	147.2	+3.3%	1,183.0	+16.7%
p_{REF_CHM}	111.6	174.8	+2.7%	1,205.9	+15.0%
p_{REF_NMM}	49.5	77.6	+2.7%	1,151.7	+20.3%
p_{REF_MAN}	65.4	102.4	+2.7%	1,165.5	+18.5%
p_{REF_CPS}	654.1	671.4	+0.2%	1,679.4	+5.7%
p_{REF_WTP}	49.5	76.0	+2.5%	1,151.7	+20.3%
p_{REF_ATP}	679.7	742.3	+0.5%	1,701.7	+5.5%
p_{REF_OTP}	274.4	466.5	+3.2%	1,348.0	+9.8%
p_{ELE_REF}	1,471.7	1,510.7	+0.2%	3,106.0	+4.5%
p_{ELE_AGR}	1,183.0	1,214.4	+0.2%	2,724.0	+5.0%
p_{ELE_MIN}	1,471.7	1,812.9	+1.2%	3,106.0	+4.5%
p_{ELE_CHM}	1,471.7	1,812.9	+1.2%	3,106.0	+4.5%
p_{ELE_NMM}	1,471.7	1,812.9	+1.2%	3,106.0	+4.5%
p_{ELE_MAN}	1,471.7	1,812.9	+1.2%	3,106.0	+4.5%
p_{ELE_CPS}	1,490.7	2,540.2	+3.2%	3,131.2	+4.5%
p_{C_REF}	654.1	1,924.9	+6.6%	1,763.4	+6.0%
p_{C_ELE}	581.5	1,796.4	+6.9%	4,891.0	+13.3%

Sources: IMACLIM-SAU calibration and simulations. The price of energy i input into production j is p_{i_j}, with sector codes those of Table 1. Unreported prices point at non-existing consumptions. AAGR is the Average Annual Growth Rate.

C.2 Domestic energy flows

We resort to the KAPSARC Energy Model KEM (see Matar et al., 2017, for an application with energy pricing reforms in the KSA) to settle the impact of the energy-pricing trajectories of Annex C.1 on the energy consumptions of six industrial sectors: oil and gas upstream activities, refining, electricity, water, petrochemicals and cement. These sectors cover 71% of total domestic consumptions in 2013, the calibration year common to KEM and our own IMACLIM-SAU. To address the remainder of Saudi consumptions, we complement KEM outputs with the following assumptions.

Considering *Continuity* energy prices, KEM projects an increase of crude oil and natural consumptions into power generation (includes water desalination in KEM) of 189% and 60% from 2013 to 2030. For the remainder of firms' energy consumptions under *Continuity*, we assume constant energy intensities (constant amounts of energy input by a unit of output).

For households' consumptions, we assume that residential electricity demand grows at an average rate of 3.2% up to 2030, which is 2 percentage points below 2007-to-2016 average and close to the projected 2.8% increase of electricity demand for the Middle-East region by the IEA (2017) in its *NPS*. In fact, the first round of tariff reforms resulted in declines (for the first time) in 2016, 2017 and 2018 compared with historical growth of electricity consumption, making a structural decline of electricity demand growth plausible compared with its historical trend.

Concerning refined products, we assume that the fleet of light duty vehicles reaches 20 million units by 2030,[5] 96% of which personal cars reflecting current shares reported by GSTAT. Moreover, we assume that fuel economy increases to reach average Corporate Average Fuel Economy (CAFE) standards of 17.1 km/l, up from 8 km/l in 2012 (Alabbadi, 2012) and consider IEA estimates of average annual car mileage (IEA, 2009). According to these assumptions, households' fuel uses increase 60% from 2013 to 2030 or at a 2.8% average annual rate (Table C.3).

Under the energy-pricing reforms of *Transformation*, KEM projects a phase-out of crude oil uses and a 77% decline of refined products uses (resulting from a phase-out of diesel uses) for power generation (including water desalination) between 2013 and 2030. We additionally assume that the hikes of energy tariffs combined with efficiency measures decrease the high energy intensity of the rest of the economy, reflecting wasteful and excessive energy consumptions (Fattouh and El-Katiri, 2013).

The multisector nature of IMACLIM-SAU allows differentiating efficiency assumptions by sector and energy vector based on additional external sources. We assume that the electricity intensity of industrial sectors decreases by 1.4% annually, corresponding to projected gain by ABB (2015) based on the Saudi National Energy Efficiency Program. For air and water transport, we consider annual efficiency gains at 2.0% and 1.1% up to 2030. Both gains derive from international benchmarks (see IEA, 2016 and ICAO, 2010). Finally, for industrial processes (i.e., consumption of OIL, GAS and REF by industrial branches MIN, CHM, NMM and MAN), we take up Soummane et al. (2019) aggregate assumption of 3% annual efficiency gains, close the 2.5% annual gains projected by IEA (2016) in its *450Scenario* up to 2040. The weighted average of the above assumptions points at

[5] https://www.onlyelevenpercent.com/energy-efficiency-saudi-arabia/.

aggregate 2.7% annual energy-efficiency gains. Soummane et al. (2019) compute a low sensitivity of macroeconomic results to their 3% assumption by testing alternative 0%, 1% and 2% annual gains (see their Section 5.2).

For households' consumptions, we assume that *Transformation* pricing reforms allow containing the increase of residential electricity uses at the level of population growth (+33.2% from 2013 to 2030). Regarding transport, we maintain the assumptions of the *Continuity* scenario except for fuel economy, which we assume to reach the upper bound of CAFE standards of 22 km/l by 2030. As a result, households' fuel uses increase by 24% from 2013 to 2030 compared to 60% under *Continuity* (Table C.3).

It is important to stress that our assumptions on the energy consumptions of non-energy sectors take the form of intensities, i.e., consumptions per unit output rather than absolute consumptions. Thus, we take into account any discrepancy in sectoral activity between IMACLIM-SAU and that of KEM (see Matar et al., 2016 for the activity assumptions backing KEM).

Table C.3: Assumptions on domestic energy consumptions

Domestic energy use (index 1 in 2013)	Calibration	------*Continuity*------		------*Transformation*------	
	2013	2030	AAGR	2030	AAGR
α_{OIL_REF}	1.00	1.00	id.	1.00	id.
α_{OIL_ELE}	1.00	1.71	+3.2%	0.00	-100.0%
α_{OIL_NMM}	1.00	0.86	-0.9%	0.60	-1.9%
α_{OIL_MAN}	1.00	1.00	id.	0.60	-1.9%
α_{GAS_ELE}	1.00	0.95	-0.3%	0.93	-0.4%
α_{GAS_MIN}	1.00	1.00	id.	0.60	-1.9%
α_{GAS_CHM}	1.00	1.08	+0.4%	0.60	-1.9%
α_{GAS_NMM}	1.00	0.96	-0.3%	0.60	-1.9%
α_{GAS_MAN}	1.00	1.00	id.	0.60	-1.9%
α_{REF_ELE}	1.00	0.34	-6.1%	0.20	-9.0%
α_{REF_CHM}	1.00	1.84	+3.6%	0.60	-1.9%
α_{REF_NMM}	1.00	0.90	-0.6%	0.60	-1.9%
α_{REF_MAN}	1.00	1.00	id.	0.60	-1.9%
α_{REF_CPS}	1.00	1.00	id.	1.00	id.
α_{REF_WTP}	1.00	1.00	id.	0.83	-1.1%
α_{REF_ATP}	1.00	1.00	id.	0.71	-2.0%
α_{REF_OTP}	1.00	1.00	id.	0.80	-1.3%
α_{ELE_REF}	1.00	1.00	id.	1.00	id.
α_{ELE_AGR}	1.00	1.00	id.	0.78	-2.8%
α_{ELE_MIN}	1.00	1.00	id.	0.78	-2.8%
α_{ELE_CHM}	1.00	1.20	+1.1%	0.50	-2.8%
α_{ELE_NMM}	1.00	1.32	+1.7%	0.78	-2.8%
α_{ELE_MAN}	1.00	1.00	id.	0.78	-2.8%
α_{ELE_CPS}	1.00	1.00	id.	0.78	-2.8%
C_{REF}	1.00	1.60	+2.8%	1.24	+1.3%
C_{ELE}	1.00	1.70	+3.2%	1.33	+1.7%

The volume of energy i input into production j is α_{i_j}, with sector codes those of Table 1. Households' consumption of energy good i is C_i. Unreported volumes are non-existent. AAGR is the Average Annual Growth Rate.

C.3 Energy trade prices

Oil trade accounts for 83% of Saudi exports earning, of which 73% are crude oil exports at around 7 million barrels per day (mb/d) during the past decade (SAMA, 2018). This makes crude oil price the main variable of interest for energy trade. Although OPEC supplies 40% of world oil demand, with Saudi Arabia acting as leader with 30% of the Organization's supply, its impact on oil price is not established. There is no agreement about OPEC's market power. Many authors argue that the 'cartel' strategy was established only during some periods, and that OPEC's strategy has been evolving (Fattouh and Mahadeva, 2013). Brémond et al. (2012) show that OPEC has been acting as a price taker for most of the period following the first oil shock (1973), and that cartel behavior only concerns a sub-group of the Organization. Some even argue that the cartel status of OPEC has never existed (Cairns and Calfucura, 2012). In the light of these claims, we assume that the KSA does not influence world prices and build both our *Continuity* and *Transformation* scenarios on a common exogenous assumption of the world oil price trajectory. Blazquez et al. (2017) adopt a similar specification.

We take this trajectory from the Sustainable Development Scenario (*SDS*) of IEA (2017). The dramatic oil-price decline of the end of 2014 resulted in historically low investment levels (IEA, 2016). Facing increasing global oil demand peaking only in the mid-2020s, the current under-investment in oil resources lifts the oil price up until 2025. From then on up to 2030, the global penetration of electric mobility and higher efficiency gains in the transport sector in addition to tightened climate policies cause global oil demand to decline, ending 16.6 mb/d or 16% lower than that of the less ambitious New Policy Scenario (*NPS*) in 2030. The oil price follows a similar trend, declining to 69 USD in 2030 or 26.6% below the price of the *NPS* scenario.

A fraction of Saudi energy exports consists of refined products. We link the price of such products to that of crude oil via a differential that we assume constant over time and across scenarios. We calibrate the differential as the ratio of the weighted average of the prices of exported petroleum products to the price of crude oil. The ratio is around 0.96 in 2013. Its low level stems from the fact that Saudi exports of refined products consist mainly of both heavy (fuel oil) and extra-light products (LPG and naphtha).[6] Similarly to exports, we assume that the average import price of refined fuels is indexed on oil prices over our projection horizon and across scenarios.

[6] According to the 2013 Saudi energy balance (IEA, 2015), the export mix is 29% of LPG, 26% of naphtha, 24% of fuel oil, 10% of diesel, 9% of kerosene and 2% of gasoline.

C.4 Energy trade flows and domestic supply

The four energy goods disaggregated by IMACLIM-SAU separate in two groups as regards market balance: one group has exogenous domestic output and imports, and endogenous exports balancing resources and uses; the other group has exogenous imports and exports, and endogenous domestic output balancing resources and uses. Under *Continuity*, crude oil (OIL) and refined fuels (REF) belong to the former group and natural gas (GAS) and electricity (ELE) to the latter. *Transformation* moves OIL from the former to the latter group for reasons explained below.

Our *Continuity* scenario builds on the assumption that the Saudi output of crude oil reaches 12.7 mb/d by 2030. This corresponds to the Saudi oil supply projected by the IEA (2017) in its *NPS* scenario, i.e. surmises that shifting from *NPS* to *SDS* (whose oil prices sustain both our scenarios, see Annex C.3 above) does not affect Saudi output, mostly directed to exports, considering its very low cost—see Annex E.4 of Soummane et al., 2019, for further discussion. Indeed, the KSA is considering reaching this level of output and could already do so by mobilizing its spare capacity (Krane, 2017). Concerning the output of refined products REF, our two scenarios share the assumption that the Saudi refining capacity will increase from the current level of 2.9 mb/d to 3.3 mb/d by 2030, following up on the opening of the Jazan refinery (0.4 mb/d).

Imports of OIL, GAS and ELE are equal to zero in current statistics as well as in the outlooks of the KEM model sustaining our scenarios. IMACLIM-SAU simulations keep them so at all years and across scenarios. Imports of REF are not described by KEM and require some exogenous assumption. For lack of sources on the matter, we assume that they follow potential growth (the growth of efficient labor supply) i.e. increase by 45.7% from 2013 to 2030 under *Continuity*, while they keep at 2013 levels in the face of strongly abated domestic demand under *Transformation*.

Similarly to imports, exports of GAS and ELE are consistently equal to zero in statistics or KEM outlooks (see Matar et al., 2016). Regarding GAS, although the Kingdom is a major gas producer, all the production is directed to the domestic market. Regarding ELE, plans for regional market integration start to take effect but the traded volumes should remain negligible. We therefore keep both exports at zero across years and scenarios.

Additionally to GAS and ELE, the *Transformation* scenario considers exogenous OIL exports. The reason is that the substantial crude oil savings induced by energy-pricing reforms would liberate large additional export capacities under the assumption of maintained output. We rather assume that Saudi Arabia contains crude oil exports to avoid flooding global oil markets thus further depressing the global oil price (Blazquez et al. 2017), and adjusts output accordingly. To facilitate scenario comparison, we set the OIL exports of *Transformation* at the endogenous levels that they reach under *Continuity*. This assumption brings crude oil output under *Transformation* 11.7% below *Continuity* levels in 2030. The loss of export revenue is partially compensated by endogenous increases of REF exports flowing from maintained refining capacities and abated domestic demand. In 2030, refined products exports are 29.3% higher under *Transformation* than under *Continuity*.

Annex D SENSITIVITY OF *TRANSFORMATION* TO STRUCTURAL CHANGE DRIVERS

We test sensitivity of the *Transformation* scenario to its three major structural change drivers: energy price reforms, non-energy export boosts and corporate tax take-off.[7] We exclude the *Continuity* scenario from the sensitivity analysis as this scenario corresponds to the business-as-usual case, which assumes an increase of already established activities without reforms of energy prices or corporate tax adjustment. Concerning energy prices (E prices), we run a low variant maintaining them at 2018 levels i.e. *Continuity* values, and a high variant considering a 75% rather than a 50% decrease of explicit and implicit energy subsidies at end-horizon (see Annex C.1). Concerning export trends (X trends) of the two targeted sectors, i.e., MAN and C&S, we run a low variant bringing down MAN and C&S trends to default +3.4% per year, and a high variant setting the MAN trend at +15% per year and the C&S trend at +10.3% per year. This compounds into quadrupling C&S exports by 2030 compared with targeted tripling in *Transformation* (see section 3.2). Finally, we test corporate tax rates at the lower and upper bounds of G20 countries, i.e., 19% (low variant) and 35% (high variant). We conduct the tests all other parameters equal.

Activity (GDP and employment), public accounts and CO_2 emissions results appear qualitatively robust to the tested ranges, with altered *Tranformation* scenarios systematically more favorable than *Continuity* (Table D.1).

[7] For the sake of concision, we refer to Soummane et al. (2019) for assessment of the influence of the global oil price on Saudi macroeconomic outlooks with a 2-sector 'KLEM' aggregation of IMACLIM-SAU.

Activity responds particularly well to increased corporate taxes under the assumption of excess public surplus financing additional investment. Conversely, public budget balance and the net public debt are stable across variants because of the assumed 1% cap on budget surplus, which even the low corporate tax variant does not prevent reaching. CO_2 emissions broadly follow activity for export trend and corporate tax variants. They expectedly respond to energy pricing, although with low (negative) elasticity because of energy intensities kept constrained at (implicitly controlled) *Transformation* levels (see Annex C.2).

Table D.1: Sensitivity of *Transformation* to structural change drivers at 2030 horizon

Indicator	Low E prices	High E prices	Low X trends	High X trends	Low corp. tax	High corp. tax	*Continuity*
Real GDP	-0.4%	+0.3%	-0.6%	+0.9%	-0.5%	+1.6%	-1.3%
Trade balance, % GDP	-0.1 pts	-0.1 pts	-2.5 pts	+3.2 pts	+0.4 pts	-1.1 pts	+4.3 pts
2013-2030 trade surplus	-2.5%	+0.6%	-15.4%	+16.8%	+0.9%	-2.9%	+19.0%
Unemployment rate	-0.2 pts	+0.2 pts	+0.1 pts	-0.2 pts	+0.3 pts	-0.9 pts	+1.7 pts
Public budget balance, % GDP	+0.0 pts	-0.0 pts	-0.0 pts	+0.0 pts	+0.0 pts	-0.0 pts	-6.2 pts
Net public debt, % GDP	+1.6 pts	-1.1 pts	-0.0 pts	+0.0 pts	+1.1 pts	-1.7 pts	+35.9 pts
CO_2 emissions, Mt	+2.4%	-0.7%	-0.7%	+1.1%	-0.4%	+1.2%	+125.4%

Source: IMACLIM-SAU simulations. "Pts" stands for percentage points. The table reports deviations from Transformation results in 2030. The last column places *Continuity* relative to central parametrization *Transformation* for comparison purposes.

On trade, the high export trend variant brings the balance and surplus performance of *Transformation* close to that of *Continuity*—while it further increases the levels of activity and employment. This confirms the potential importance of non-oil, non-energy intensive trade in the successful diversification of the Saudi economy. Energy prices affect trade via contrary effects on the competitiveness of Saudi non-energy products, and the availability of refined products for exports, considering the adjustments of domestic demand (see Annex C.2). The corporate tax rate affects trade through the latter effect only, i.e. opposite to domestic refined fuels consumptions, which follow activity.

Finally, the high energy prices variant increases unemployment by reducing the purchasing power of households. This points at the necessity to factor in the ability of households to cut down their energy consumptions in reaction to energy pricing reforms.

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

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