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The IMACLIM-SAU model
Version 1.0

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Introduction

The IMACLIM model is an economy-wide model representing the comprehensive supply and demand of factors, goods and services, with the specific purpose of articulating with a consistent representation of energy systems to provide consistent 'economy-energy-environment' (3E) trajectories (Hourcade et al., 2006; Ghersi and Hourcade, 2006). IMACLIM is part of a tradition of "hybrid" energy/economy exercises, carried out at the *Centre International de Recherche sur l'Environnement et le Développement* (CIRED) to contribute to the economics of climate policies. It exists in a global multi-regional version (Sassi et al., 2010) and in country-specific versions. Developed variants include adaptations to France (Hourcade and Ghersi, 2000; Combet, 2013; Le Treut, 2017; De Lauretis, 2017), South Africa (Schers et al., 2015), Brazil (Lefèvre, 2016) and India (Gupta and Ghersi, 2019; Gupta et al., 2019a; 2019b). IMACLIM-SAU results from ongoing efforts to adapt the IMACLIM model to an additional set of countries via a common modelling platform (Le Treut, 2017).[1] Reflecting the IMACLIM paradigm although with some adaptation to the particulars of Saudi macroeconomics, IMACLIM-SAU deviates from the computable general equilibrium (CGE) standard by four features.

Firstly, IMACLIM-SAU calibrates on original hybrid energy-economy data reconciling national accounting and energy balance and prices statistics. This dual accounting, in physical and financial flows, links energy consumptions and expenses by a vector of agent-specific prices. To model agent-specific prices, IMACLIM considers 'specific margins' reflecting the differences of the net-of-tax prices faced by economic agents for the same energy good. Hybrid accounting has significant impacts on crucial benchmark ratios for our macroeconomic analysis: the cost shares of energy in the disaggregated productions, the budget share of energy for households and the breakdown of energy consumptions and CO_2 emissions across sectors and agents (Combet et al., 2014; Le Treut, 2017). Our hybrid Saudi dataset is available online (Soummane and Ghersi, 2019).

Secondly, the model treats as exogenous all variables pertaining to the energy system. This feature stems from the model being designed to allow coupling with bottom-up energy expertise (Ghersi, 2015). The growth trajectory traced by IMACLIM-SAU thus

[1] Current IMACLIM extensions include applications on China and Russia.

builds around exogenous energy volumes.[2] The cost structure of energy production beyond its energy intensity, as well as the specific margins on each energy sale, are also adjusted to match assumptions on the dynamics of annualised investment, operational expenses or domestic and trade prices. Such specifications allocate part of value-added to a fixed energy expense and part of primary factors' endowments to some exogenous energy volume output. These constraints on volumes, costs and prices weigh on economic growth. This IMACLIM feature is particularly relevant to represent the Saudi economy. Indeed, the energy sector accounts for a large share of Saudi GDP, with highly integrated energy branches and domestic energy tariffs fixed by the government.

Thirdly, although the model builds on Walras's law (i.e. represents balanced factors, goods and services markets), its simulated trajectories do not reflect optimal growth pathways. One first deviation from optimal growth is that IMACLIM-SAU is a simulation model that builds on exogenous investment pathways not explicitly reflecting the intertemporal optimisation of some welfare indicator. A second deviation stems from the fact that the model considers imperfect markets in the form of both mark-up pricing and under-utilisation of labour. On the labour market, inertia of real wages prevents full clearing i.e. induces equilibrium unemployment. Rather than specifying the labour supply behaviour, the model correlates the unemployment rate and the real wage in a "wage curve" following Blanchflower and Oswald (2005). The dynamics of this static correlation relate to labour productivity. This specification captures well the rigidity that characterizes the Saudi labour market (Devaux, 2013).

Finally, IMACLIM-SAU retains specifications of the investment and savings balance and of the trade balance that reflect the quite specific macroeconomics of Saudi Arabia. On the investment and savings balance, the model thus departs from the Solowian take on fixed savings driving investment to acknowledge the paramount role of the sovereign Saudi fund as a buffer against any fluctuation of oil export revenues. Variations of the sovereign fund indeed amount to variations of the national Saudi saving rate, which thus mean to smooth out the investment path of the Kingdom. IMACLIM-SAU reflects this state of affairs by implementing a Johansen closure (following Johansen, 1960) where national savings adjust to some exogenous

[2] Published scenarios (Soummane et al., 2019; Soummane et al., 2020) develop around authoritative outlooks from the King Abdullah Petroleum Studies and Research Centre (KAPSARC) Energy Model, KEM.

investment path. On the trade balance, the currency peg that has been fixing the value of the Saudi Riyal against that of the US dollar since 1986 forbids considering the neoclassical standard of an exogenous trade balance. One straightforward alternate specification is to consider a fixed ratio between Saudi and import prices as a proxy of the fixed exchange rate to the USD. However, statistics reveal that the REER of Saudi Arabia is not fixed, but correlated to the contribution of the trade balance to Saudi GDP. Soummane et al. (2019) explain this correlation by relating it to the level of the international price of oil and propose to model it rather than the exogenous trade balance assumption. The below formulary reflects such specifications.

1 Calibration of IMACLIM-SAU

1.1 Calibration of the 2013 base year

We calibrate the uses and resources of IMACLIM-SAU on original energy-economy data resulting from the hybridisation of national accounting, energy balance and energy price statistics (Soummane and Ghersi, 2019), for 13 sectors (Table 1) including 4 'hybrid' energy sectors in the sense that they are underpinned by satellite accounts of energy flows measured in kilotons of oil-equivalent (ktoe).

Table 1 Sectoral breakdown of IMACLIM-SAU

Abbreviation	Sector	Specification
OIL	Crude oil	Hybrid
GAS	Natural gas	Hybrid
REF	Refining	Hybrid
ELE	Electricity (including water desalination)	Hybrid
AGR	Agriculture, Hunting, Forestry and Fishing	Non-hybrid
MIN	Other Mining (excluding oil and gas extraction)	Non-hybrid
CHM	Chemical and Petrochemical	Non-hybrid
NMM	Non-Metallic Minerals (includes cement)	Non-hybrid
MAN	Manufacturing	Non-hybrid
WTP	Water Transport	Non-hybrid
ATP	Air Transport	Non-hybrid
OTP	Other Transport	Non-hybrid
CPS	Commercial and Public Services	Non-hybrid

The conventional process of inverting parameters and variables and solving model equations extends to original elements as the specific margins allowing differentiation of energy consumer prices. In the absence of statistics, calibration of the initial capital stock requires exposition. We define the base-year stock K_0 as:

$$K_0 = I_0\left(\frac{1}{\delta+g_1-1}\right),$$

which means recognizing the commensurability of I and K, with:

- I_0 an index of the aggregate volume of investment at calibration year, set freely without loss of generality.
- δ the depreciation rate, which divides I_0 to account for the amount of capital (δK_0) that will be retired at the end of 2013 and must therefore be replaced by I_0.
- g_1 the potential growth rate of the first year after the calibration (i.e., 2014). Dividing I_0 by g_1 warrants that the capital stock available at that year has grown from 2013 at a pace identical to that of efficient labour.

On top of hybridization of energy flows,[3] we expand the original CDSI data by disaggregating total labour costs between labour tax contributions and net labour payments. We base our disaggregation on Saudi legislation on insurance contribution. This comprises figures of the contribution that employers pay on their Saudi employees (we derive the share of Saudi employment from SAMA, 2017). This contribution amounts to 10% of the employee's salary and is due to the General Organization for Social Insurance (GOSI). We also add a 2% contribution as accident insurance for both national and non-national employees. Finally, there is also a 2% unemployment insurance, which is shared equally between employers and Saudi employees. We assume that the government perceives these contributions since GOSI is a governmental agency. We also modify the CDSI accounts to represent the substantial public subsidy on electricity prices to both activity sectors and households, which we duly subtract from the government's budget. 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 (2017); to

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

government, the dedicated series from national accounts (SAMA, 2017); 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 taxation applied by the Saudi government to this branch;
- 71% of the GOS of the refining sector, corresponding to the share of Aramco in the Saudi refining capacity;
- 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 simply 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, in the Kingdom of Saudi Arabia (KSA) corporate taxes apply at a rate of 20% on profits accruing to shareholders of other nationality 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% *zakat* 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 compute unemployment transfers from public administrations to households as the government aid implemented within the 'Hafiz' program from the Human Resource Development Fund. We assume that the 1.11 million jobseekers reported by SAMA (2017) for the year 2013 perceived the annual 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 (2017), which reflects data from the Public Pension Agency. For the remainder of social transfers, we consider a series of 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. For public administrations, we use the government's "other revenue" figures from SAMA for the year 2013, to which we subtract the perceived income tax, and other taxes. The property income of the RoW balances out the sum of domestic property incomes.

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 balance of payments (BoP) (SAMA, 2017). 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. For public administration, we compute 'other transfers' as the difference between the aggregate budget balance and all resources and expenditures elsewhere accounted for. The firms' 'other transfers' simply balance out the 'other transfers' of the other three agents.

1.2 Dynamic calibration and full-horizon investment trajectory

Beyond 2013 data, we firstly extend the calibration of IMACLIM-SAU to statistically available years (2014-2017 at the time of our research) by computing what disturbances of the productivity of primary factors, wages and non-energy trade allow IMACLIM-SAU to replicate observed trends of key macroeconomic series under constraint of reported energy trajectories.

Each year from 2014 to 2017, this first dynamic calibration procedure extends the model to 4 additional variables: Ω_L and Ω_K, impacting labour and capital productivity; Ω_w, impacting the relationship between the real wage and the unemployment rate; and Ω_B, inversely impacting non-energy exports and imports. The procedure also extends IMACLIM to three additional constraints: that the GDP, unemployment rate and trade balance computed by the model match statistical observation. Minimising the Ω adjustment factors allows selecting one of the infinite number of solutions induced each year by adding more variables than constraints to the model. Beyond 2017, we assume that all Ω adjustment factors converge at a constant rate to their average 2013-to-2017 values in 2030.[4]

The adjustment factors resulting from the above procedure are additional parameters of all further simulations of IMACLIM-SAU (Table 2). They remain within 6.9% of their 2013 values for those that concern labour, capital, and real wage expectations. They reach 25.9% 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 (International Energy Agency data), and the aggregate trade balance contribution to GDP on the other side (The World Bank data).

Table 2 IMACLIM-SAU adjustment factors resulting from 2014 to 2017 calibration

	2014	**2015**	**2016**	**2017**	**2020**	**2025**	**2030**
Ω_L	**1.010**	**1.028**	**1.069**	**1.060**	1.054	1.044	1.036
Ω_w	**1.010**	**1.013**	**1.018**	**1.018**	1.017	1.014	1.014
Ω_B	**0.741**	**0.801**	**1.026**	**1.118**	1.073	1.003	0.927
Ω_K	**0.968**	**0.971**	**1.015**	**0.986**	0.987	0.987	0.982

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

We perform a second dynamic calibration of IMACLIM-SAU on the specific issue of the investment rate. The reason for this additional calibration is the sensitivity of our unemployment results to the available stock of capital. This sensitivity comes from our wage-curve specification, which translates into employment variations any change in the purchasing power of wages induced by nominal wage adjustments. Nominal

[4] The alternative option of fading out all disturbances by 2030 would unduly lend more weight to the 2013 balance of factors and macroeconomic performance and disregard potential misalignments on underlying trends.

wage adjustments flow in turn from our various specifications of the real effective exchange rate (our translation of the Saudi currency peg, see Soummane et al., 2019), depending on the dynamics of the rental price of capital—hence the importance of controlling capital stock i.e. investment dynamics.

Beyond 2017,[5] we thus assume that the investment rate follows a trajectory that allows maintaining a stable unemployment rate in our reference projection. To estimate such trajectory, we run our reference projection in a marginally modified IMACLIM-SAU constraining the unemployment rate at the exogenous level of Oxford Economics forecasts[6] by free adjustment of the level of capital endowment. We translate the resulting capital stock trajectory in an investment trajectory based on the perpetual-inventory equation. The resulting investment trajectory is fairly stable when expressed as a share of GDP, remaining within two percentage points from its 2013 level up to 2030.

This extra calibration procedure is not some mere modelling artefact but does reflect actual Saudi macroeconomics. Despite the global economic crisis and its dramatic impact on oil markets, the Saudi unemployment rate only marginally fluctuated (+/-0.3 pts) around its average of 5.6% over the past decade, which points at public policy intervention. Our calibration procedure assumes that this policy intervention mainly takes the form of public control on the investment trajectory—which is already our justification for settling on a Johansen closure of some exogenous investment trajectory guaranteed by endogenous adjustment of the national saving rate (see our Introduction).

2 Formulary of IMACLIM-SAU

IMACLIM-SAU operates in a dynamic recursive framework where yearly economy-wide equilibria are connected by accumulation of the capital stock and financial

[5] From 2013 to 2017, we set the investment rate at the value reported by the IMF. The calibration on 2014 to 2017 macroeconomics warrants that the unemployment rate matches available statistics over that period.

[6] See https://www.oxfordeconomics.com/.

debts and chained price indexes. From a mathematical point of view, each year's equilibrium is 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 values of some variables at calibration year constitute a specific subset of parameters, which we refer to by indexing variable names with 0. The f_i functions embody constraints of either an accounting or a behavioural nature. The accounting constraints impose themselves on the modeller for the sake of consistency. The behavioural constraints, quite distinctively, convey the modeller's views on economic causalities and correlations.

More precisely, IMACLIM-SAU models each projected year as a system of 475 equations:

- Equations (4), (7), (8), (10), (11), (12), (14), (15), (16), (17), (18), (19), (20), (21), (23), (24), (25), (26), (27), (28), (31), (32), (33), (34), (37), (40), (42), (43), (45), (47), (56), and (57) count once each: 32 equations.
- Equation (9) counts 4 times.
- Equation (13) counts 8 times.
- Equations (1), (2), (3), (29), (30), (48) count 9 times each (for 9 non-energy goods): 54 equations.
- Equations (5), (6), (22), (35), (36), (38), (39), (41), (44), (46), (49), (50), (52), (53), (54) and (55), count 13 times each (one equation per sector): 208 equations.
- Equation (51) counts 169 times (cross-sectoral prices).

The following table identifies the 475 variables (Var. count of last-but-one column) matching this number of equations.[7] 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.

[7] Some shifts of variables and parameters occur in the *Transformation* scenario forthcoming in Soummane et al., 2020. The last two columns of Table 3 do not exactly apply to this scenario (see Soummane et al., 2020).

Table 3 IMACLIM-SAU notations

Notation	Description	Var.	Par.
C_i	Final consumption of good i by households. Consumption of energy goods is exogenous, consumption of AGR follows population increase.	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 for the investment.	13	0
K_i	Capital stock in good i production.	13	0
L_i	Labour demand from sector i	13	0
KL_i	Value-added KL mobilised in the production of non-energy good i.	9	0
M_i	Imports of good i. Imports of REF, OIL, GAS and ELE are exogenous—set to 0 for the three latter.	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.	11	2
Y_i	Domestic output of good i. Outputs of OIL and REF are exogenous.	11	2
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. Exogenous (administered) for energy goods.	9	4
p_{Gi}	Public price of good i.	13	0
p_{Ii}	Investment price of good i.	13	0
p_{Li}	Cost of labour input in the production of good i.	13	0
p_{Mi}	Import price of good i. The import prices of energy goods are exogenous. The import prices of non-energy goods are constant (non-energy imports are the model's numéraire).	0	13

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. Energy export prices are exogenous.	9	4
p_{Yi}	Output price of good i.	13	0
p_{ij}	Price of good i to produce good j. The prices of the 4 energy inputs are exogenous at administered levels.	117	52
s_I	Investment effort as a share of GDP at current prices.	0	1
t_{ETCi}	Excise taxes per unit of household consumption of good i.	0	13
t_{ETGi}	Excise taxes per unit of public consumption of good i.	0	13
t_{ETIi}	Excise taxes per unit of good i immobilisation.	0	13
t_{ETij}	Excise taxes 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
κ_i	Technical coefficient, capital (write-off) intensity of good i. Exogenous for energy goods.	9	4
λ_i	Technical coefficient, labour intensity of good i. Exogenous for energy goods.	9	4
π_i	Rate of net operating surplus (rent on natural resource or profit) 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 accruing to the unemployed.	1	0
σ_{KLi}	Elasticity of substitution of K to L in non-energy good i production.	0	9
σ_{Mpi}	Elasticity to the ratio of output to import prices of the contribution of imports to total non-energy good i supply.	0	9
σ_{Xpi}	Elasticity to the ratio of import to export prices of the share of exports into total good i uses (does not apply to GAS and ELE goods).	0	11
σ_{wu}	Elasticity of the purchasing power of wages to the unemployment level.	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 (labour tax) rate applicable to wages in sector i.	0	13
τ_S	Savings rate of households.	1	0
τ_{SMCi}	Specific margin on households' consumption of good i.	4	9

τ_{SMXi}	Specific margin on good i exports. Adjusts to accommodate exogenous (international) export prices of energy goods.	4	9
τ_{SMij}	Specific margin on good i consumption in good j production. Adjusts to accommodate exogenous (administered) prices of energy goods.	52	117
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_{STi}	Sales tax rate applying to the consumptions 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}	Share of not-elsewhere accounted 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 labour productivity (technical progress).	0	1
Ω_B	Adjustment factor inversely affecting imports and exports of the non-energy good (index 1 in 2013).	0	1
Ω_L	Adjustment factor affecting labour productivity (index 1 in 2013).	0	1
Ω_K	Adjustment factor affecting capital productivity (index 1 in 2013).	0	1
Ω_w	Adjustment factor affecting real wage correlated to unemployment via the wage curve (index 1 in 2013).	0	1
B	Trade balance	1	0
CPI	Consumer price index.	1	0
MPI	Import price index.	1	0
GDP	Gross domestic product.	1	0
GOS_i	Gross operating surplus of sector i.	13	0
L	Total active population (labour supply) in full-time equivalents.	0	1
SM_i	Sum of specific margins on the sales of good 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	Average net wage in sector i.	13	0

2.1 Firms

2.1.1 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 Soummane et al., 2019; Soummane and Ghersi, 2019).

Non-energy productions follow a standard nested production tree. At the bottom of the tree, capital and labour trade off with a constant σ_{KLi} elasticity of substitution to form a KL_i aggregate. The mobilized quantity of labour L_i is however augmented by a productivity factor ϕ, while both the labour and capital inputs are also adjusted by factors Ω as described in section 0. Therefore, $KL_i = (\alpha_{KLi}(\Omega_K K_i)^{\rho_{KLi}} + \beta_{KLi}(\Omega_L \phi L_i)^{\rho_{KLi}})^{\frac{1}{\rho_{KLi}}}$, with here and elsewhere, for convenience, $\rho_i = \frac{\sigma_i - 1}{\sigma_i}$. Facing prices p_K and p_{Li}, cost minimization induces:

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

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

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

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

As discussed in Soummane et al. (2019), the absence of proper estimates for Saudi substitution elasticities led us to borrow these parameters from the literature (Okagawa and Ban, 2008). Table 4 presents the elasticities of substitution used in IMACLIM-SAU.

Table 4 Elasticities of capital/labour substitution

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
CPS	0.31

2.1.2 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 $\sum_i \pi_i p_i Y_i$:

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

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

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):

$$GOS_i = p_K \, K_i + \pi_i \, p_{Y_i} \, Y_i + SM_i \quad (5)$$

The sum of specific margins on sector i sales is:

$$SM_i = \sum_j \tau_{SMij}\, p_{Si}\, \alpha_{ij}\, Y_j + \tau_{SMC_i}\, p_{Si}\, C_i + \tau_{SMX_i}\, p_{Si}\, X_i \tag{6}$$

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 the 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 CPS sector for trade and the CPS, WTP, ATP and OTP sectors for transport), adjust to warrant the accounting balances:

$$\sum_i \tau_{CMi}\, p_{Si} \left(\sum_j \alpha_{ij}\, Y_j + C_i + G_i + I_i + X_i\right) = 0 \tag{7}$$

$$\sum_i \tau_{TMi}\, p_{Si} \left(\sum_j \alpha_{ij}\, Y_j + C_i + G_i + I_i + X_i\right) = 0 \tag{8}$$

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

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

$$GFCF_F = \sum_i p_{I_i} I_i - GFCF_G - GFCF_H \tag{10}$$

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

$$NLB_F = R_F - GFCF_F \tag{11}$$

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*:

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

2.2 Households

2.2.1 Consumer trade-offs

Households' final consumption C_i are exogen17ous 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:

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

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

2.2.2 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.

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

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

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 surplus GOS, 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 (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 Introduction), 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:

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

The investment effort of households $GFCF_H$ is at calibration-year value adjusted to mirror variations of the aggregate national investment effort s_I:

$$GFCF_H = \frac{GFCF_{H_0}}{R_{H_0}} R_H \frac{s_I}{s_{I_0}} \tag{16}$$

The net lending or borrowing of households NLB_H is the difference between their disposable income and their consumption and investment:

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

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

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

2.3 Public administrations

2.3.1 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 of 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:

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

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

$$T = \sum_i \ \tau_{LTi}\, w_i\, \lambda_i\, Y_i + \tau_{Yi}\, p_{Yi}\, Y_i + \frac{\tau_{ST_i}}{1+\tau_{ST_i}} \left(p_{C_i} C_i + p_{G_i} G_i + p_{I_i} I_i\right) + \sum_i \sum_j t_{ETij}\, \alpha_{ij}\, Y_j$$

$$+\, t_{ETCi}\, C_i + t_{ETGi}\, G_i + t_{ETIi}\, I_i + \tau_{IT}\, R_H + t_H\, CPI\, N_T + \tau_{CT} \sum_i \pi_i\, p_{Yi}\, Y_i \tag{20}$$

2.3.2 Public expenditures and budget balance

The value of total direct public consumption is a constant share (s_G) of GDP:

$$\sum_i p_{G_i} G_i = s_G \, GDP \tag{21}$$

Sectoral public expenses grow homothetically from the calibration year on:

$$G_i = \beta_G \, G_{i0} \tag{22}$$

Social transfers per capita, ρ_U, ρ_P and ρ_T, evolve as the average wage:

$$\rho_P = \rho_{P_0} \frac{w}{w_0} \tag{23}$$

$$\rho_U = \rho_{U_0} \frac{w}{w_0} \tag{24}$$

$$\rho_T = \rho_{T_0} \frac{w}{w_0} \tag{25}$$

The public investment effort is assumed a constant share of total investment. This share is maintained at calibration-year level (i.e., 37.7%), which is close to the observed average share of public investment between 2010 and 2016 (SAMA, 2017) at 36.2% of total investment.

$$GFCF_G == \frac{GFCF_{G_0}}{\sum_i p_{Iio} \, I_{io}} \sum_i p_{Ii} \, I_i \tag{26}$$

Similar to firms or households, the NLB of public administrations is the difference between disposable income and investment:

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

The public debt accumulates as:

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

2.4 International trade and the foreign agent

For all energy goods, imports are exogenous, and exports are either exogenous as well, or computed as the remainder of specified energy output or domestic consumption. 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 adjustment factor Ω_B (see section 0):

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

with A_{M_i} a constant calibrated on 2013 data, except for scenarios considering structural transformation, where we can decrease A_{M_i} to assume substitution of imported products by locally manufactured products (see Soummane et al., 2020). 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_{X_i}:

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

They are adjusted by Ω_B following dynamic calibration from 2014 to 2017 (see section 0). A_{X_i} are another set of constants calibrated in 2013. Similar to import elasticities, we derive $\sigma_{X_{p_i}}$ from IMF (2016) based on Hakura and Billmeier (2008) estimating the elasticity of non-oil exports at 0.69.

The trade balance B is:

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

As we pointed at in our Introduction, the CGE standard of an exogenous trade balance is not adapted to the macroeconomics of Saudi Arabia. In IMACLIM-SAU simulations envisioning the maintained administration of energy prices close to current levels, we substitute to it the real effective exchange rate (REER) specification revealed in Soummane et al., 2019: we constrain the REER to reflect our observation of a significant statistical relationship between the REER and the trade balance contribution to GDP. To specify the relationship, 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:

$$\frac{CPI}{MPI} = C_{REER} + D_{REER}\ e^{E_{REER}\frac{B}{GDP}} \tag{32}$$

with D_{REER} and E_{REER} calibrated on 1986 to 2015 statistical observation of the two variables (see Figure 1 of Soummane et al. 2019), and C_{REER} the adjustment that allows fitting 2013 data.[8]

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

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

with:

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

2.5 Market clearings

2.5.1 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 nil, by national accounting convention for the former and by definition for the latter.

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

$$Y_i + M_i = S_i \quad (36)$$

[8] In scenarios of energy pricing reforms, this relationship cannot hold because of the direct impact of the massive increase of regulated energy prices on the REER. See Soummane et al. (2019) and Soummane et al. (2020) for a discussion of this important point and the constraint substituted to Equation 32.

2.5.2 Labour market

On the labour market, a 'wage curve' describes the elasticity of a real wage index (the ratio of a wage index to the current CPI) to unemployment u. At each projection year, the real wage attached to unemployment at 2013 level (5.6%) is defined as the 2013 real wage index multiplied by labour productivity increase ϕ and a wage moderation factor Ω_w via the calibration of one constant A_u:

$$\frac{w}{CPI} = \phi \, \Omega_w \, A_u \, u^{\sigma_{wu}} \tag{37}$$

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

$$w_i = \frac{w}{w_0} w_{i0} \tag{38}$$

where w_0 is a wage index freely set at calibration year without loss of generality.

The cost of labour corresponds to the wage increased by labour tax contributions:

$$p_{L_i} = \left(1 + \tau_{LT_i}\right) w_i \tag{39}$$

The sum of labour demands by all sectors and of unemployment balances out labour endowment L:

$$\sum_i \; L_i + u \, L = L \tag{40}$$

For each sector, labour consumption and output are conventionally related via labour intensities:

$$L_i = \lambda_i \, Y_i \tag{41}$$

The unemployed population N_U is:

$$N_U = u \, L \tag{42}$$

2.5.3 Capital market

Capital endowment grows according to the standard accumulation rule $K_{t+1} = (1 - \delta) \, K_t + I_t$ where I_t is the aggregate investment volume of year t, defined as $\beta_{I,t} \, I_0$ (see section 1.1). At each projection year, the endowment is thus exogenously constrained by the investment path of former years. On the capital market, demands balance out this exogenous endowment:

$$\sum_i K_i = K \tag{43}$$

With for each sector, similarly to labour:

$$K_i = \kappa_i Y_i \tag{44}$$

2.5.4 Investment

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

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

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

$$I_i = \beta_I \, I_{i0} \tag{46}$$

2.5.5 GDP

GDP is defined on the expenditure side as:

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

2.6 Producer and consumer prices

For non-energy goods, the price of the KL_i 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}:

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

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

We define p_{Y_i} as the sum of input costs, output taxes at a τ_{Yi} rate, and a mark-up rate π_i corresponding to the rent on natural resources and/or the net operating surplus:

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

The import prices of all non-energy goods are exogenous and constant (one of these goods acts as the numéraire of the model).

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

$$p_{S_i}\,S_i = \; p_{Y_i}\,Y_i + \; p_{M_i}\,M_i \tag{50}$$

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 $\tau_{SM_{ij}}$ and excise taxes t_{ETij}:

$$p_{ij} = p_{S_i}\left(1 + \tau_{CM_i} + \tau_{TM_i} + \tau_{SM_{ij}}\right) + t_{ETij} \tag{51}$$

The consumer prices of households, public administrations and investment goods are constructed similarly augmented by sales taxes:

$$p_{C_i} = \left(p_{Si}\left(1 + \tau_{CM_i} + \tau_{TM_i} + \tau_{SMC_i}\right) + t_{ETCi}\right)(1 + \tau_{STi}) \tag{52}$$

$$p_{G_i} = \left(p_{Si}\left(1 + \tau_{CM_i} + \tau_{TM_i}\right) + t_{ETGi}\right)(1 + \tau_{STi}) \tag{53}$$

$$p_{I_i} = \left(p_{Si}\left(1 + \tau_{CM_i} + \tau_{TM_i}\right) + t_{ETIi}\right)(1 + \tau_{STi}) \tag{54}$$

Export prices also proceed from the same elements but come net of taxes:

$$p_{X_i} = p_{Si}\left(1 + \tau_{CM_i} + \tau_{TM_i} + \tau_{SMX_i}\right) \tag{55}$$

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:

$$CPI_t = CPI_{t-1}\sqrt{\frac{\sum p_{Ci,t}\,C_{i,t-1}}{\sum p_{Ci,t-1}\,C_{i,t-1}}\frac{\sum p_{Ci,t}\,C_{i,t}}{\sum p_{Ci,t-1}\,C_{i,t}}} \tag{56}$$

$$MPI_t = MPI_{t-1}\sqrt{\frac{\sum p_{Mi,t}\,M_{i,t-1}}{\sum p_{Mi,t-1}\,M_{i,t-1}}\frac{\sum p_{Mi,t}\,M_{i,t}}{\sum p_{Mi,t-1}\,M_{i,t}}} \tag{57}$$

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