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Using Linear Programming Techniques to Construct a General Equilibrium Model (GEM) for Saudi Arabia

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Abstract. The main objective of this paper is to construct and validate the General Equilibrium Model (GEM) using linear programming algorithm. The results of the GEM solution are almost identical to the base year SAM 1980/81. This implies that the GEM has been correctly specified and it is ready for comparative static experiments. Reducing agricultural subsidies has a significant impact on all commodity and factor prices. On the contrary, the rest of the world and investment sectors are not affected.

Introduction and Problem Statement

During the past 20 years, the Saudi Arabian economy faced various significant changes in all the economic sectors, especially the agricultural sector. These changes include, production and consumption activities as well as individual and regional income distribution. Most of the analytical and empirical research, especially in the agricultural sector, is limited to analysis of individual commodity markets. However, this type of analysis in isolation is generally misleading because of the existence of interdependencies among consumption, production, and government policies. The General Equilibrium Model (GEM) framework for analyzing market interdependencies is a helpful tool that provides information to policy makers in formulating and evaluating economic plans and government policies. This paper contains the following four sections:

1. the data sources for applying the GEM to Saudi Arabian economy,
2. the construction of the GEM for Saudi Arabia,
3. the validation of the GEM,
4. policy application on agricultural subsidies programs using the GEM.

Objectives

The main purpose of this paper is to construct and validate the GEM for Saudi Arabia, and then to evaluate agricultural subsidy policies and their impact on various (activities) sectors in the Saudi economy. The GEM construction will be based on the Social Accounting Matrix (SAM) of Saudi Arabia in 1980/1981.

Data source

A Social Accounting Matrix (SAM) is the main data source for applying the GEM for Saudi Arabia. A SAM, used in this study, has been estimated by the Saudi Central Department of Statistics for 1980/81 [1]. An aggregate SAM for 1980/81 is presented in Table 1. The principle of a SAM is to close the linkage between input-output accounts by double entry bookkeeping. A SAM has two major objectives. The first one is to organize the economic and social structures of a country's information in a particular year. The second objective is to provide the information for generating a plausible GE model [2, p. 17].

By convention, the receipts (incomes) are represented by the rows, while the expenditures (outlays) are represented by the columns. The total receipts for each account must be equal to the corresponding expenditures accounts. Therefore, the number of rows has to be equal to the number of columns.

The structure for an aggregate SAM in Saudi Arabia is classified in six major accounts:

1. factors of production (labor and capital),
2. institutional accounts (oil-sector, non-oil-sector, government-sector, and household-sector),
3. consolidated capital accounts,
4. activities,
5. commodities, and
6. rest of the world.

The intermediate input-output Table is another data source used for this study. Intermediate input-output coefficients were updated from 1976 to 1980/81. The estimated intermediate input-output Table for 1976 contains 10 economic sectors. The updated intermediate input-output Table disaggregated oil-sector into two sub-sectors (crude petroleum and natural gas and petroleum refining) in order to be consistent with the disaggregated SAM in 1980/81 for Saudi Arabia. The Updated inter-

Table 1. Aggregate social accounting matrix in Saudi Arabia: 1980/1981

			I		II				III	IV	V	VI	VII
			Factors of production		Institutional sectors				Consolid. capital account	Activit.	Comm.	The rest of world	Total
			Labor	Capital	Oil Sec.	Non O.S.	Govt.	Househ.					
			1	2	3	4	5	6	7	8	9	10	11
I.	Labor	1					29905.7			60941.1			90846.8
	Capital	2								432222.7		24368.0	456590.7
	Oil sector	3		351512.4									351512.4
	Non oil sector	4		46309.3			1656.6						47965.9
II.	Government	5			310496.4	23951.4		428.0			2594.6	232.2	337702.6
	Households	6	86671.5	26414.6		4929.1							118015.2
III.	Consolidated capital A.	7			31126.0	19078.5	211789.5	2673.1					264667.1
IV.	Activities	8					5075.3				600752.7		605828.0
V.	Commodities	9					52008.9	114905.1	112803.3	112664.2		368425.0	760806.5
VI.	The rest of the world	10	4175.3	32354.4	9890.0	4936.0	32337.5	9.0	151863.8		157459.2		393025.2
VII.	Total		90846.8	456590.7	351512.4	47965.9	337702.6	118015.2	264667.1	605828.0	760806.5	393025.2	

Source: Ministry of Finance and National Economy [1].

Table 2. Input-output coefficients of the Saudi economy for 1980/81*

Commodity	Agri.	Crud. pet.	Other min.	Pet. ref.	Other manuf.	Activity elect.	Const.	Wholesale	Trans.	Fin.	Commun.
Agriculture, forestry, and fishing	.029259	.	.	.	.000052	.	.000032	.	.002884	.	.
Crude petroleum and natural gas	.076326	.001006	.004431	.034152	.005919	.074349	.015362	.008329	.077665	.028809	.054226
Other mining	.	.000103	.102863	.003492	.002687	.001437	.053486	.000217	.000236	.000888	.000459
Petroleum refining	.003449	.000445	.000212	.001543	.000266	.003366	.000694	.000375	.003506	.001299	.002446
Other manufacturing	.017734	.005669	.425911	.192417	.466378	.349372	.359362	.086710	.335110	.174952	.375699
Electricity, gas, and water	.	.000019	.002282	.000640	.000758	.001273	.000771	.001122	.001075	.003129	.002586
Construction	.	.000005	.000026	.000162	.000570	.000534	.002489	.000142	.007550	.002513	.000347
Wholesale and retail trade, restaurant, and hotels	.001552	.000001	.000690	.000032	.001282	.001765	.000920	.001284	.001733	.001056	.001499
Transport, storage, and communication	.	.000504	.008649	.017086	.005394	.034773	.007920	.044199	.039434	.035056	.009314
Finance, insurance, real estate, and business services	.006220	.000513	.004563	.017430	.016196	.027137	.054303	.048769	.045009	.083392	.036966
Community social and personal services	.	.000089	.000371	.003018	.000499	.000780	.004766	.000767	.000839	.000677	.000703
Total	.294544	.007954	.549999	.269972	.500000	.494786	.500105	.191914	.515042	.331769	.484244

* The zero coefficient is represented by the dot, (.), notation.

Source: Ministry of Finance and National Economy [1].

mediate input-output coefficients for 1980/81 are presented in Table 2. A Ras technique was used to update the intermediate input-output coefficients from 1976 to 1980/81 [3, p. 276].

Income, direct, and cross price elasticities are essential information for applying the GEM. These elasticities were estimated by Al-Kahtani [4].

Methodology of Constructing the GEM.

The GEM construction depends upon the availability of a Social Accounting Matrix (including an input-output Table) and of elasticities (direct, cross, and income). Three steps are required for building a GEM:

1. exogenous and endogenous variables have to be identified,
2. constraints (or equations) have to be specified for the model, and
3. a decision about how to close the model must be made.

Most of the entries in the SAM are endogenous variables, such as, quantities of goods purchased by household. In general, the total row and column of a SAM are treated as endogenous variables, such as, total income for household, total inflow and outflow to the rest of the world, and aggregate saving and investment. The exogenous variables in the SAM are the entries in the rest of the world column appearing in column (10) and row (10) and the transfer payments among institutions (oil sector, non-oil sector, government sector, and household sector). The demand functions for the economic sectors have been segmented using Norton and Scandizzo procedures [5]. The demand of segmented variables is associated with constraints defining a convex combination constraints that will control the interpolation choices [5].

The structure of the General Equilibrium Model for Saudi Arabia is based on the Social Accounting Matrix of 1980/81. A number of equation (constraints) were set up the GEM as follows:

1. The objective function {1}*

In general, the objective function of the GEM is to maximize the sum of the value of final consumption plus export sales value minus factor costs. This concept is known as a net social surplus. The objective function was constructed to derive the optimal solution to a competitive general equilibrium. Competition in all markets is characterized by being marginal cost greater than or equal to market prices. Therefore, market clearing is assured under competition rather than monopolistic conditions.

* The symbol in braces is the number of constraints in each set.

In algebraic form, the objective function is set up as follows**:

$$\text{Maximize } Z = \Sigma_i \Sigma_s \pi_{is} W_{is} - \Sigma_f \Sigma_h b_{fh} p_f + \Sigma_i P_i^x E_i$$

where Z = gross revenue from sales to household consumption
– factor costs + gross revenue from sales to exports.

A grid linearization technique was used to transform the objective function from a nonlinear to a linear specification. The interpolation variables (W_{is}; $X_{ih} = \Sigma_s \pi_{is} W_{is}$) are now the expression of the quantity demanded and the value of expenditure on a convex combination of the relevant constraints [5].

In this study, linearized demand functions have been segmented into ten segments. Hazell and Norton [6] explains in detail the steps that are required for calculating each of the segment's value in a demand function. According to these authors, there are three starting parameter values (without taking into account cross price effects) which are needed for calculating the segment's values for each demand function [6, p. 176]:

1. the own price elasticity of demand (n_j),
2. the initial price (P_{jo}), and
3. the initial quantity (Q_{jo}).

The steps required for calculating the segment's value for each demand function are:

(1). Calculating the intercept (α_j) and the slope (β_j) from the prior information that is mentioned above. The formula for calculating this step is:

$$\text{(i) } \beta_j = -dP_j/dQ_j = P_{jo}/n_j \, Q_{jo} > 0$$
$$\text{(ii) } \alpha_j = P_{jo} + \beta_j Q_{jo} > 0$$

(2). The second step is to measure the relevant range of the demand function. The adequate range for most applications has been found to be (P_j^l, P_j^u) = (.5P_{jo}, 2P_{jo}). The procedure for translating the price range to the quantity axis [6, p. 176] is:

$$\text{(i) } Q_j^l = (\alpha_j - P_j^u) / \beta_j$$
$$\text{(ii) } Q_j^u = (\alpha_j - P_j^l) / \beta_j$$

Q_j value has to be positive, otherwise, the range of P_j must be changed. For this study the adequate price range was found to be (P_j^l, P_j^u) = (.5P_{jo}, 1P_{jo}) to obtain non-negative Q_i values.

** The definitions of variables and parameters are introduced in pages 16, 17, and 18.

(3). The third step is to calculate the length of the segment between points in the demand function. Therefore, quantity axis (Q_j^l, Q_j^u) and the number of the segments will affect the length of the segments in the demand function. The length of the segments can be calculated using the formula:

$$K_j = (Q_j^u - Q_j^l) / n-1$$

where n is the number of segments. The following procedure illustrates how to calculate the quantity at each point on a linearized demand function:

$$\Theta_{j0} = Q_j^l$$
$$\Theta_{j1} = Q_j^l + K_j$$
$$\Theta_{j2} = Q_j^l + 2k_j$$
$$\vdots$$
$$\Theta_{j9} = Q_j^l + 9K_j = Q_j^u$$

(4). The last step requires to calculate the value of the revenue (π) corresponding to each point on the linearized demand function. The formula is as follows:

$$R_{js} = \pi_{js} = \alpha_j \Theta_{js} - \beta_j \Theta_{js}^2$$

The results of calculating the quantities and revenues at each point in the demand function using the segment approach are shown in Table 3.
The objective function defined above is maximized subject to the following sets of constraints:

2. The factors of production {2}

The Saudi Arabia SAM contains two types of resources: labor and capital. The constraints on the available resources are treated as factor supply relationships, which means that the total resource employed in the economy will not exceed its available supply. The Saudi Arabia SAM (1980/1981) [1] shows that:

1. the total wage bill for labor supply is 90846.8 million riyals.
2. factor use for government employment is 29905.7 million riyals while labor requirements in production are 60941.1 million riyals.
3. total available supply of capital is 456590.7 million riyals.
4. resource use of capital requirements in production are 432222.7 million riyals, while capital used in the rest of the world is 24368 million riyals.

Table 3. Gross revenue at each point in the demand functions.

Segment	Commodity							
	Agri-culture	Petroleum refining	Other manufacturing	Elect-ricity	Wholesale	Trans-port	Finance	Community social
π_{i1}	9491.0	2985.9	22163.8	885.7	1638.3	545.1	9036.7	1934.7
π_{i2}	11583.3	3538.9	34445.7	999.4	1897.8	1673.8	10545.0	4224.0
π_{i3}	13192.8	3958.0	44341.1	1082.0	2091.2	2603.2	11675.9	6097.8
π_{i4}	14319.5	4243.1	51850.1	1133.3	2218.6	3333.1	12429.5	7556.1
π_{i5}	14963.3	4394.1	56972.7	1153.5	2280.0	3863.6	12805.7	8598.9
π_{i6}	15124.2	4411.2	59708.9	1142.5	2275.3	4194.8	12804.5	9226.2
π_{i7}	14802.3	4294.2	60058.7	1100.3	2204.6	4326.5	12425.9	9438.0
π_{i8}	13997.6	4043.3	58022.1	1027.0	2067.8	4258.8	11670.0	9234.3
π_{i9}	12710.0	3658.4	53599.0	922.4	1865.0	3991.7	10536.7	8615.2
π_{i10}	10939.5	3139.4	46789.5	786.7	1596.2	3525.3	9026.0	7580.5

Source : Calculated from information compiled by the Ministry of Finance and National Economy [1].

The total factor supply is regarded as an exogenous variable which must be fully employed. The production function is assumed to be Leontief and, therefore, no substitution between labor and capital is allowed.

(i) Labor constraint*:

$$\Sigma_j r_{1j} X_j \leqq \bar{s}_1 - \bar{G}\bar{E}\bar{M}\bar{P}$$

(ii) Capital constraint:

$$\Sigma_j r_{2j} X_j \leqq \bar{s}_2 - \bar{C}\bar{R}\bar{O}\bar{W}\bar{I}$$

3. Institutional accounts {8}

The Saudi Arabia SAM d specifies four institutional accounts:

1- oil sector,

2- non-oil sector,

3- government sector, and

4- household sector.

Using the information from Saudi SAM, two constraints are generated for each account in the economic system. One constraint contains the revenue and the other contains expenditure.

A. Oil accounts

The oil sector revenue is the result of the value of returns to factor endowments. The value of the returns to factor endowments in the oil sector entry can be seen in row 3, column 2 in the aggregate SAM. The income of the oil sector is treated as an exogenous variable while the values of the return to factor endowments are regarded as endogenous variables. In contrast, oil expenditures are found by transferring the oil sector income to revenue paid to the government, to the oil sector savings, and to the rest of the world. Column 3 and rows 4,7, and 10 represent the oil sector expenditure for the aggregate SAM 1980/81 presented in Table 1.

(i) Oil sector revenue constraint:

$$\Sigma_f \bar{b}_{f1} P_f = \text{OILR}$$

(ii) Oil sector expenditures constraint:

$$\text{GOILR} + \text{OILSAV} + \bar{O}\bar{I}\bar{L}\bar{R}\bar{O}\bar{W}\bar{O} \leqq \text{OILR}$$

* Terms with overline are considered exogenous.

where

$$OILSAV = S_1\, OILR$$

B. Non-oil sector accounts

The non-oil sector generates its revenue from the value of returns to factor endowments plus government transfer to non-oil sector (row 4 and columns 2 and 5), while its expenditures are transfered to government, to saving, and to the rest of the world. Non-oil savings is a function of the non-oil sector income so that as the non-oil sector revenue goes up, savings will increase too.

(i) Non-oil sector revenue constraint:

$$\Sigma_f\, \bar{b}_{f1}\, P_f + \bar{G}\bar{T}\bar{R}\bar{N}\bar{O} = NOILR$$

(ii) Non-oil sector expenditures constraint:

$$GNOILR + NOILSAV + \bar{N}\bar{O}\bar{I}\bar{L}\bar{R}\bar{O}\bar{W}\bar{O} \leqq NOILR$$

where

$$NOILSAV = S_2\, NOILR$$

C. Government accounts

The government accounts have two constraints, receipts and expenditure constraints. The government receipts are transferred from the oil sector, non-oil sector, household sector, indirect taxes, and the rest of the world. All the variables that enter the solution are regarded as endogenous variables, except for the rest of the world's payments to the government which is regarded as an exogenous variable. Row 5 and columns 3, 4, 6, 9, and 10 represent the government revenue in the aggregate SAM (Table 1). On the other hand, government expenditures are divided into government transfers to the labor sector (row 1, column 5), to the non-oil sector (row 4, column 5), to the household sector (row 6, column 5), government savings (row 7, column 5), government subsidies (row 8, column 5), government final consumption (row 9, column 5), and the rest of the world (row 10, column 5).

Government savings and government subsidies are treated as endogenous variables, while the rest of the payments are regarded as exogenous in the government expenditures constraint. Government savings and subsidies are functions of government revenue and total output respectively.

Government constraints:

(i) Revenue

$$GOILR + GNOILR + GHHR + \Sigma_j T_j + \overline{GROW} = GREV$$

(ii) Expenditures

$$\overline{GEMP} + \overline{GTRNO} + \overline{GTRHH} + GSAV + \Sigma_j GSUB_j + \Sigma_i \overline{GCON}_i + \overline{GROWO} + \overline{GI1.10} \leqq GREV$$

where

$$GSAV = S_3 GREV$$
$$GSUB_j = \mu_j X_j$$

D. Household accounts

The household sector derives its income from the value of returns to factor endowments, plus government's transfers to the households. The household sector receives 86671.5, 26414.6 and 49291.1 million riyals from the labor, capital, and government sectors respectively (Table 1 row 6, columns 1,2, and 5).

The household sector's budget is divided into transfer payments to the government, household savings, the rest of the world, and final consumption. Household savings is a constant share of the total income. Transfers from the household sector to the government sector, to household savings, and to final consumption are treated as endogenous variables, while transfers to the rest of the world are considered as an exogenous variable.

Household constraints:

(i) Revenue

$$\Sigma_f \bar{b}_{f4} p_f + \overline{GTRHH} = Y$$

(ii) Budget constraints:

$$GHHR + HHSAV + \overline{HHROWO} + HH\overline{11.20} + \Sigma_i \Sigma_s \pi_{js} W_{js} \leqq Y$$

where

$$HHSAV = S_4 Y$$

4. Commodity balances

Market-clearing behavior is the result of the commodity balance equations in the product markets. The disaggregate SAM of 1980/81 for Saudi Arabia has eleven commodity balance restrictions.

In order to be consistent with general equilibrium theory, aggregate commodity supplies (which are the domestic productions), imports, trade and transport margins, and indirect taxes, must be equal to aggregate demand, which includes household final demand, government final consumption, purchases for capital formation, exports, and intermediate input-output demand. Hence, the GEM solution should not contain excess supply. This event is possible in the presence of inequality constraints. Each equation is expressed in real (constant-price) terms, although it holds in current price as well. To simplify the model solution, commodity balance accounts are divided into three different equation groups. The first group, with eleven constraints, comprises the commodity demand equations. The second group, with eleven constraints, includes the commodity supply equations. The last group of equations represents the accounting constraints that link the demand to the supply equations.

(i) Demand constraints {11}:

$$\Sigma_s \Theta_{is} W_{is} + \bar{G}\bar{C}\bar{O}\bar{N}_i + \bar{I}\bar{N}\bar{V}_i + E_i + \Sigma_j a_{ij} X_j = Q_i^d$$

(ii) Supply constraints:

a. All sectors except trade and transport {9}:

$$(1 - \mu_i) X_i + Tr_i + T_i + M_i = Q_i^s$$

b. Trade sector {1}:

$$X_{tr} - \Sigma_j tr_j Q_i^s = Q_{tr}^s$$

c. Transport sector {1}:

$$(1 - \mu_{tt}) X_{tt} - \Sigma_j tt_j Q_i^s + M_{tt} = Q_{tt}^s$$

where

$$\mu_i = GSUB_i/X_i$$
$$Tr_i = tr_i Q_i^s$$
$$T_{ti} = tt_i Q_i^s$$
$$T_i = t_i \mu_i$$
$$M_i = m_i Q_i^s$$
$$a_{ij} = x_{ij}/X_j$$

(iii) Commodity balance constraints:

$$Q_i^d \leqq Q_i^s$$

The variables W_{is} are called choice variables and identify the demand segments in the solution, while the parameters Q_{is} are the quantity demanded at each segment in the demand function. The sum of the variables W_{is} are adjacent to unity in the base solution. The Leontief matrix $(I - A)$ is expressed by a_{ij} coefficients which can be calculated directly from the base period SAM by subtracting the intermediate coefficients from the identity matrix. Trade, transport margins, and imports are a linear function of aggregate commodity supplies. Indirect taxes are a linear function of imports. Government subsidies for each sector, divided by the total output, produce the subsidy per unit of output activity.

5. Rest of the world

The rest of the world is divided into three equations:

1. outflow constraints,
2. inflow constraints, and
3. balance of payments constraints.

Outflows are represented in row 10 while inflows are in column 10 in Table 1. Balance of payment constraints enter the base period solution in order to assure that total inflow minus total outflow must be less or equal to the net available foreign capital. Imports are assumed to be a linear function of the aggregate commodity supply and non-competitive products. While exports are assumed to be fixed in the base period solution.

The outflows go to returns to factor endowments, to value of commodity imports, and to capital payments to the rest of the world, while inflows come from the value of exports, and remittances from abroad. Capital payments to foreign sectors and remittances from abroad are exogenously determined for (comparative statics) purposes of sensitivity analysis.

(i) Outflow constraints {1}:

$$\Sigma_f \bar{b}_f \, \mathrm{ROW}\, P_f + \Sigma_i P_i^m M_i + \overline{\mathrm{OILROWO}} + \overline{\mathrm{NOILROWO}}$$

$$+ \overline{\mathrm{GROWO}} + \overline{\mathrm{HHROWO}} + \overline{\mathrm{INVROWO}} + \overline{\mathrm{G11.10}} + \overline{\mathrm{HH11.20}} = \mathrm{ROWOF}$$

Let

$$\overline{\mathrm{BOF}} = \overline{\mathrm{OILROWO}} + \overline{\mathrm{NOILROWO}} + \overline{\mathrm{GROWO}} + \overline{\mathrm{HHROWO}} + \overline{\mathrm{INVROWO}} + \overline{\mathrm{G11.10}} + \overline{\mathrm{HH11.20}}$$

Then

$$\Sigma_f \bar{b}_f \, ROW \, P_f + \Sigma_i P^m_i M_i - ROWOF = -\bar{B}\bar{O}\bar{F}$$

(ii) Inflow constraints {1}:

$$\Sigma_i P^x_i E_i + \bar{H}\bar{H}\bar{1}\bar{1}.\bar{2}\bar{1} + \bar{C}\bar{R}\bar{O}\bar{W}\bar{I} + \bar{G}\bar{R}\bar{O}\bar{W}\bar{R} = ROWIF$$

Let

$$\bar{B}\bar{I}\bar{F} = \bar{H}\bar{H}\bar{1}\bar{1}.\bar{2}\bar{1} + \bar{C}\bar{R}\bar{O}\bar{W}\bar{I} + \bar{G}\bar{R}\bar{O}\bar{W}\bar{R}$$

Then

$$\Sigma_i P^x_i E_i - ROWIF = -\bar{B}\bar{I}\bar{F}$$

(iii) Balance of payments constraints:

$$ROWIF - ROWOF \leqq \bar{B}$$

where

$\bar{B} = \bar{B}\bar{O}\bar{F} - \bar{B}\bar{I}\bar{F}$ is the net available foreign capital.

6. Import constraints {11}

$$M_i - m_i \, Q^s_i = 0$$

where

$$m_i = M_i / Q^s_i$$

7. Export constraints {11}

$$E_i - \bar{E}_i = 0$$

8. Household demand {11}

$$-(1/W_{io}) \, \Sigma_s \, \Theta_{is} \, W_{is} + \Sigma_j \, (n_{ij}/P_{jO}) + \varepsilon_i / \, Y^d_O \, (1 - \bar{a}_h) \, Y = -1$$

The household demand functions are linearized and segmented as mentioned earlier. These equations serve the purpose of defining an explicit price variable P_j from the demand side [6, p. 176].

The parameters W_{is} and Y^d_O represent the commodities demanded and disposable income in the base period, respectively. The parameter n_{ij} is the direct and cross elasticity for commodity i with respect to the price of commodity j. The coefficient ε_i is the expenditures elasticity of ith demand. The parameter $\bar{a}_h$ is the household tax plus the propensity to save. For simplicity, all prices are set equal to unity in the base year so that the model is expressed in terms of price indexes.

Household Demand Convexity Constraints:

$$\Sigma_s W_{is} - (\varepsilon_i / Y^d{}_o)(1 - \bar{a}_h) Y - \Sigma_{j \neq i} (n_{ij}/P_{jO}) P_j \leqq 1 + n_{ii}$$

These constraints are called technical constraints. Their main function is to force the model's solution to lie on the demand functions and, therefore, these constraints can control the choice of demand segment variables [5].

9. Marginal cost pricing {11}

$$P_i - \Sigma_j a'_{ij} P_j - \Sigma_f r_{fi} P_f \leqq O$$

Marginal cost princing is a fundamental attribute of a competitive market. This model comprises the unit value of output, cost intermediate goods per unit of output, and factor costs per unit of output. P_i is equal to unity. a'_{ij} is the transpose of the intermediate input-output coefficient. Therefore, the Leontief cost functions are the result of subtracting the a'_{ij} coefficient from the identity matrix for each corresponding production activity. The sum of the marginal cost pricing constraints should be less than or equal to zero. Factor costs per unit of output is the supply price. Hence, the module guarantees that marginal cost pricing is equal to price which is the competition market characteristic. The exchange rate is assumed to be fixed. The validation of assuming fixed exchange rates will be terminated with very large changes in the balance of payments [7].

10. Capital accounts {3}

Capital accounts are divided into three groups of constraints:

(i) Savings constraints {1}:

$$OILSAV + NOILSAV + GSAV + HHSAV = AGGSAV$$

(ii) Investment constraints {1}:

$$\Sigma_i \overline{INV}_i + \overline{INVROWO} = AGGINV$$

(iii) Equilibrium constraints {1}:

$$AGGINV \leqq AGGSAV$$

Savings and investment identities are represented in row 7, column 7 in Table 1. Aggregate savings costraints comprise oil savings, non-oil savings, government savings, and household savings. Aggregate investment constraints comprise purchases for capital formation plus investment transfers to the rest of the world. Aggregate investment must be less than aggregate savings. Savings constraints, aggregate savings, and aggregate investment are treated as endogenous variables, while investment constraints are regarded as exogenous variables.

Definition of endogenous variables

W_{is} = segment choice variables on domestic demand functions
P_f = normalized factor price
P_j = normalized commodity price
X_j = production level of activity j
X_{TR} = trade production
X_{tt} = transport production
OILR = oil sector income
NOILR = non-oil sector income
T_j = indirect taxes
T_r = trade sector
GREV = aggregate government revenue
Y = household income
GOILR = government revenue from oil sector
GNOILR = government revenue from non-oil sector
GHHR = government revenue from household sector
OILSAV = oil sector savings
NOILSAV = non-oil sector savings
GSAV = government savings
HHSAV = household savings
$GSUB_j$ = government subsidy by activity
Q^s_j = aggregate commodity supply
Q^d_i = aggregate commodity demand
Q^s_{tr} = aggregate of trade supply
Q^s_{tt} = aggregate of transport supply
M_i = commodity imports
E_j = commodity exports
ROWOF = outflow to rest of the world (ROW)
ROWIF = inflow from rest of the world (ROW)
AGGSAV = aggregate savings
AGGINV = aggregate investment

Definition of exogenous variables

(I) Noncontrolled
P^x_i = export price
$\overline{CROWI}$ = capital in use in rest of the world (ROW)
$\overline{GROWR}$ = government revenue from rest of the world (ROW)

$\overline{OILROWO}$	= oil sector transfers to rest of the world (ROW)
$\overline{NOILROWO}$	= non-oil sector transfers to rest of the world (ROW)
$\overline{GROWO}$	= government transfers to rest of the world (ROW)
$\overline{HHROWO}$	= household transfer to rest of the world (ROW)
$\overline{HH11{:}20}$	= direct purchases by households from rest of the world (ROW)
$\bar{b}_{fROW}$	= resources from rest of the world (ROW)
p^{m}_{i}	= import price
$\overline{HH11{:}21}$	= direct purchases by nonresidents in domestic market
$\overline{INV}_i$	= purchases for capital formation

(2) Controlled

$\bar{s}_1$	= labor supply
$\bar{s}_2$	= capital supply
$\bar{E}_i$	= exports
$\overline{GEMP}$	= government employment
$\overline{GTRNO}$	= government transfers to non-oil sector
$\overline{GTRHH}$	= government transfers to household sector
s_1	= savings ratio for oil sector
$\overline{GCON}_i$	= government final consumption
$\overline{G11{:}10}$	= government direct purchases from rest of the world
s_3	= savings ratio by government
μ_j	= subsidy per unit of activity output
t_i	= indirect tax (import duty) rate
$\overline{INVROWO}$	= investment transfer to rest of the world (ROW)
$\bar{B}$	= net available foreign capital

Definition of parameters

π_{is}	= gorss revenue (price times quantity) from sales to consumers
$\bar{b}_{fh}$	= intial endowment of resource f held by institution h
r_{fj}	= resource requirements per unit of activity production
s_2	= propensity to save by non-oil sector
s_4	= propensity to save by households
$\bar{a}_h$	= household tax rate plus propensity to save
W_{iO}	= base commodity demand
P_{jO}	= base commodity price
Θ_{is}	= quantity demand in domestic market by segment
n_{ij}	= direct and cross price elasticities of demand
Y^{d}_{O}	= base disposable income
ε_i	= Engel elasticities
m_i	= import coefficient
a_{ij}	= input-output coefficients
tr_j	= trade margin for commodity j
tt_j	= transport margin for commodity j

Indices

i=j	=	1,.......N (N=11), activities and commodities
s	=	1,.......S (S=10), demand segments
f	=	1,.......F (F= 2), factors (resources)
h	=	1,.......H (H= 4), institutional sectors

Validation Results of the GEM for Saudi Arabia.

After the model has been constructed, the next step is to run the model to compare the GEM solution with the base year from the SAM data. The GEM should reproduce exactly the results of the base period SAM. If this is not achieved, otherwise, there are errors in the model specification. When the base period solution is replicated successfully, the GEM is ready for comparative statics analysis. Comparative statics requires changing some of the exogenous paramters such as agricultural subsidies, imports, exports, and then rerun the model. To obtain a corresponding solution the new results show a new equilibrium for the economy. Results from the validation of the Saudi applied general equilibrium model are presented in Table 4. All institutional income levels in the solution are almost identical to their corresponding values in the SAM of Table 1. All activity production levels are identical to corresponding values in the base year of SAM 1980/81. All factor and commodity prices are unity. In general, the results of the GEM are quite close to the base year except some minor discrepancies due to rounding errors. This implies that the GEM has been correctly specified and it is ready for sensitivity analysis.

Policy applications on agricultural subsidies program using the applied GEM

The validated GEM will be used to analyze the impact of different alternative agricultural subsidy policies on various activities in the Saudi economy. Results of a GEM analysis of agricultural program under different policies are shown in Table 5. Column 1 represents the general equilibrium results for the initial state of the economy, while columns (2), (3), (4), and (5) represent agricultural subsidies policies under 0.0, 25, 50 and 75 percent, respectively. A complete removal of subsidies as shown in column (2) causes all commodity and factor prices, except the price of capital, to increase. The price of labor, for example, increases from 1.00 in the base year solution to 1.0584 (a 5.8 percent increase). The same removal causes also the increase of the following commodity prices: agriculture, forestry, and fishing, crude petroleum and natural gas, other mining, petroleum refining, other manufacturing, electricity, gas, and water, construction, wholesale and retail trade, restaurants, and hotels, transport, storge, and communication, finance, insurance, real estate, and business services, and community social and personal services by 9.3, 0.1, 3.6, 0.9, 2.5, 3.5, 2.7, 1.3, 3.1, 1.2, and 2.6 percent, respectively. The aggregate price index increases by 3.2 percent.

Removing all subsidies causes output of the agriculture, forestry, and fishing sector to decrease by 89.2 percent. This implies a reduction in total supply of this sector.

Table 4. General equilibrium model solution for Saudi Arabia.

Items	Base SAM 1980/81	GEM Solution
Input prices (Indices)		
1. Labor	1.0000	1.0001
2. Capital	1.0000	1.0002
Institutional accounts (Million Riyals)		
1. Oil sector	351512.4	351519.5
2. Non-oil sector	47965.9	47966.9
3. Government sector	337702.6	337709.5
4. Household sector	118015.2	118016.8
Production (Million Riyals)		
1. Agriculture, forestry, and fishing	8698.2	8698.2
2. Crude petroleum and natural gas	343730.9	343730.9
3. Other mining	3769.1	3769.1
4. Petroleum refining	24687.0	24687.0
5. Other manufacturing	15442.4	15442.3
6. Electricity, gas, and water	2435.8	2435.6
7. Construction	100716.4	100714.9
8. Wholesale and retail trade, restaurant, and hotels	30917	30916.7
9. Transport, storage, and communication	36823.4	36823.1
10. Finance, insurance, real estate and business services	27935.7	27935.5
11. Community social and personal services	10672.1	10672.1
Commodity Prices (Indices)		
1. Agriculture, forestry, and fishing	1.0000	1.00002
2. Crude petroleum and natural gas	1.0000	1.00002
3. Other mining	1.0000	1.00002
4. Petroleum refining	1.0000	1.00002
5. Other manufacturing	1.0000	1.00002
6. Electricity, gas, and water	1.0000	1.00002
7. Construction	1.0000	1.00002
8. Wholesale and retail trade, restaurant, and hotels	1.0000	1.00002
9. Transport, storage, and communication	1.0000	1.00002
10. Finance, insurance, real estate, and business services	1.0000	1.00002
11. Community social and personal services	1.0000	1.00002
Aggregate price index	1.0000	1.00002
Rest of the world (Million Riyals)		
1. Rest of the world inflow	393025.2	393025.2
2. Rest of the world outflow	393025.2	393025.2
Capital Accounts (Million Riyals)		
1. Savings	264667.1	264672.4
2. Investment	264667.1	264667.1

Source: Calculated from Ministry of Finance and National Economy [1], and from the results of GEM.

Table 5. General equilibrium results (indices) for subsidy program on agricultural sector in Saudi Arabia

Impact Varibles	Policy Alternatives				
	Base SAM 1980/81	Removal of all subsidy	Removal of 25 percent	Removal of 50 percent	Removal of 75 percent
Input prices					
Labor	1.00000	1.01449	1.02907	1.04369	1.05838
Capital	1.00000	0.99982	0.99982	0.99982	0.99982
Inst. accounts					
Oil sector	1.00000	0.99999	0.99999	0.99999	0.99999
Nonoil sector	1.00000	0.99999	0.99999	0.99999	0.99999
Govt. sector	1.00000	1.00002	1.00004	1.00007	1.00009
HH. sect.	1.00000	1.01071	1.02142	1.03215	1.04294
Production					
Agri.	1.00000	0.97251	0.94531	0.91837	0.89165
Crude pet.	1.00000	0.99997	0.99994	0.99992	0.99989
Other min.	1.00000	1.00002	1.00010	1.00015	1.00013
Pet. ref.	1.00000	1.00115	1.00229	1.00344	1.00460
Other manuf.	1.00000	1.00184	1.00367	1.00551	1.00734
Elect.	1.00000	1.00102	1.00205	1.00307	1.00406
Const.	1.00000	1.00004	1.00009	1.00001	1.00002
Wholesale.	1.00000	1.00123	1.00241	1.00354	1.00464
Trans.	1.00000	1.00104	1.00204	1.00301	1.00393
Fin.	1.00000	1.00307	1.00617	1.00921	1.01228
Commun.	1.00000	1.00388	1.00775	1.01162	1.01549
Commodity price					
Agri.	1.00000	1.02201	1.04479	1.06838	1.09284
Crude pet.	1.00000	1.00018	1.00036	1.00055	1.00074
Other min.	1.00000	1.00901	1.01803	1.02708	1.03617
Pet. ref.	1.00000	1.00233	1.00466	1.00700	1.00935
Other manuf.	1.00000	1.00642	1.01285	1.01930	1.02578
Elect.	1.00000	1.00870	1.01741	1.02614	1.03491
Const.	1.00000	1.00682	1.01365	1.02050	1.02738
Wholesale	1.00000	1.00323	1.00646	1.00970	1.01296
Trans.	1.00000	1.00767	1.01535	1.02305	1.03079
Fin.	1.00000	1.00288	1.00576	1.00865	1.01156
Commun.	1.00000	1.00656	1.01313	1.01971	1.02632
Agg. pr. index	1.00000	1.00801	1.01614	1.02440	1.03279
Real HH. inc.	1.00000	1.00265	1.00516	1.00754	1.00979
Rest of the world					
ROWIF	1.00000	1.00054	1.00108	1.00162	1.00214
ROWOF	1.00000	1.00000	1.00000	1.00000	1.00000
Capit. account					
Saving	1.00000	1.00012	1.00025	1.00038	1.00051
Investment	1.00000	1.00000	1.00000	1.00000	1.00000

Source: Calculated from the results of GEM.

Outputs of crude petroleum and natural gas, and construction sectors show no affect. The output of other sectors increase by different percentages as shown in Table 5, which indicate an increase in total supply for these sectors.

The impact of removing all agricultural subsidies has no significant impact on institutional income except household income which increases by 4.3 percent. Real household income, rest of the world's inflow, and savings have increased by 0.98, 0.2, and 0.05 percent, respectively. On the other hand, a reduction of agricultural subsidies under alternative policies has no impact on the rest of the world's outflow and investment.

Summary and Recommendations

The GEM solution is a very useful tool for analyzing the impact of alternative economic policies on all the sectors of the economy. The construction of the GEM required four main information and analytical components: (1) a Social Accounting Matrix (SAM) for Saudi Arabia, (2) the input-output table for Saudi Arabia, (3) income, direct, and cross price demand elasticities which satisfy the homogeneity, Cournot aggregation, and Engel aggregation, and (4) the specification of a General Equilibrium Model (GEM).

The GEM solution obtained in this paper is almost identical to the base period SAM of 1980/81. This result indicates that the applied GEM has been specified correctly and it is ready for developing simulated scenarios. Reducing agricultural subsidies by 75, 50, 25, and 0.0 percent has a significant effect on output and commodity and factor prices. On the other hand, the same reductions do not have any impact on the rest of the world outflow and investment.

A GEM constructed and validated from all updated SAM database may be useful for other policy applications. Disaggregated SAM data on income, labor categories, and other activities will improve the scope of using a GEM. Exchange rates are assumed to be fixed, an assumption might not capture the impact of changing government policies.

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استخدام البرامج الخطية لتصميم نموذج التوازن العام في المملكة العربية السعودية

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الولايات المتحدة الأمريكية

ملخص البحث. الهدف الأساسي لهذا البحث هو تصميم نموذج التوازن العام عن طريق استخدام البرامج الخطية ثم التأكد من صحة تصميم هذا النموذج. حل نموذج التوازن العام أعطى نتائج مطابقة تقريبًا إلى بيانات مصفوفة الدخل القومي عام ١٩٨١/٨٠م والتي تعتبر سنة الأساس لهذا البحث. هذا يدل على أن نموذج التوازن العام قد صمم بطريقة صحيحة وهو جاهز لعمل تجارب المقارنة الاستاتيكية. تخفيض الإعانات الزراعية سوف يؤثر معنويًا على أسعار جميع السلع وعوامل الإنتاج ولكن لا يؤثر على الاستثمارات أو العالم الخارجي.