Chapter 3. Supply and demand of agricultural products

1. Supply and demand of grains

This model incorporates the following four crops: rice (*RI*), wheat (*WH*), maize (*MZ*), and other grains (*XG*). Crop *Gi* is investigated as described in this section.

The production of crop *Gi* is calculated as

$$Q_{Git} = Y_{Git} A_{Git}, \qquad (6\text{-}1)$$

where *Gi* is an index of crops, i.e., *RI*, *WH*, *MZ*, or *XG*. In addition, t denotes the year, Y_{Git} represents the yield, and A_{Git} stands for the planted area. For this model, the planted area is assumed as equal to the harvested area.

The supply of crop *Gi* is obtained from the following identity as

$$QD_{Git} = Q_{Git} + IM_{Git} + ST_{Git-1} - EX_{Git} - ST_{Git}, \qquad (6\text{-}2)$$

where IM_{Git} stands for imports, ST_{Git-1} denotes the beginning stock, EX_{Git} expresses exports, and ST_{Git} signifies the ending stock. Identity (6-2) can be rewritten as

$$QD_{Git} = Q_{Git} - NEX_{Git} - STC_{Git}, \qquad (6\text{-}3)$$

where $NEX_{Git} = EX_{Git} - IM_{Git}$, i.e. net exports, $STC_{Git} = ST_{Git} - ST_{Git\text{-}1}$, i.e. stock change.

The net exports are obtained from identity (6-3) as

$$NEX_{Git} = Q_{Git} - QD_{Git} - STC_{Git}\ . \qquad (6\text{-}4)$$

The stock change of the crop is calculated as

$$STC_{Git} = STC_{Git-1}\frac{Q_{Git} - Q_{Git-1}}{Q_{Git-1} - Q_{Git-2}} \qquad (6\text{-}5)$$

The rate of change of ending stock is assumed to be equal to that of production.

The supply of crop *Gi* is also obtained from the following identity.

$$QD_{Git} = QDF_{Git} + QDL_{Git} + QDS_{Git} + QDW_{Git} + QDP_{Git} + QDO_{Git} + QDX_{Git} \qquad (6\text{-}6)$$

Variables used in that identity are QDF_{Git} as food demand, GDL_{Git} as feed demand, QDS_{Git} as seed demand, QDW_{Git} as waste, QDP_{Git} as process demand, QDO_{Git} as other use, and QDX_{Git} as the error in FAOSTAT.

For simplification, the food demand function for grains of crop *Gi* is specified as the following linear function in this section.

$$QDF_{Git} = \gamma_{0Gi} + \sum_l \gamma_{Gi,l}\, p_{lt} + \gamma_{Mi}\frac{GDP_t}{POP_t} \qquad (6\text{-}7)$$

This demand function is based on the input demand function (5-9). A per-capita income term is added. In that function, l represents food goods, i.e., *RI*, *WH*, *MZ*, *XG*, soybeans (*SB*), other oil crops (*XS*), soybean oil (*OS*), other vegetable oil (*OX*), beef (*BF*), mutton (*SH*), pork (*PK*), poultry meat (*PM*), other meats (*XM*), poultry eggs (*EG*), and raw milk (*MK*), skim milk (*SK*), butter (*BT*), or cheese (*CH*); also, p_{it} represents the price of crop *Gi*. Variables GDP_t, POP_t respectively denote the gross domestic products (GDP) and population of the country.

The feed demand of crop *Gi* is specified as the following linear function.

$$QDL_{Gijt} = \delta_{0Gij} + \delta_{Gij,j}\, p_{jt} + \sum_k \delta_{Gij,k}\, p_{kt} \qquad (6\text{-}8)$$

Therein, k can be any of feed crops and cakes, i.e., *RI*, *WH*, *MZ*, *XG*, *SB*, *XS*, soybean cake (*CS*), or other cakes (*CX*). Also, j is meats, eggs, and milk, i.e., beef (*BF*), mutton (*SH*), pork (*PK*), poultry meat (*PM*), other meats (*XM*), poultry eggs (*EG*), or raw milk (*MK*).

The quantities of feed for livestock production are not apparent. Therefore, the following aggregated feed demand function is inferred.

$$QDL_{Git} = \sum_j QDL_{Gijt} = \sum_j \delta_{0Gij} + \sum_j \delta_{Gij,j}\, p_{jt} + \sum_j \sum_k \delta_{Gij,k}\, p_{kt} \qquad (6\text{-}9)$$

The seed supply of the crop is calculated using the following equation.

$$QDS_{Git} = QDS_{Git-1}\frac{Q_{Git}}{Q_{Git-1}} \qquad (6\text{-}10)$$

The rate of increase of seed supply is assumed to be equal to that of production.

The quantity of crop waste is obtained using the following equation.

$$QDW_{Git} = QDW_{Git-1}\frac{QD_{Git}}{QD_{Git-1}} \qquad (6\text{-}11)$$

The rate of waste increase is assumed to be equal to that of the supply.

The process supply and other use are calculated respectively using the following equations.

$$QDP_{Git} = QDP_{Git-1}\frac{GDP_t}{GDP_{t-1}} \qquad (6\text{-}12)$$

$$QDO_{Git} = QDO_{Git-1}\frac{GDP_t}{GDP_{t-1}} \qquad (6\text{-}13)$$

The rate of increase of the process and other use are assumed to be equal to those of GDP.

Substituting equations (6-10)–(6-13) into equation (6-6) yields the equation shown below.

$$QD_{Git} = QDF_{Git} + QDL_{Git} + QDS_{Git-1}\frac{Q_{Git}}{Q_{Git-1}} + QDW_{Git-1}\frac{QD_{Git}}{QD_{Git-1}} + (QDP_{Git-1} + QDO_{Git-1})\frac{GDP_t}{GDP_{t-1}} + QDX_{Git}$$

$$QDF_{Git} = QD_{Git} - QDL_{Git} - QDS_{Git-1}\frac{Q_{Git}}{Q_{Git-1}} - QDW_{Git-1}\frac{QD_{Git}}{QD_{Git-1}}$$

$$-(QDP_{Git-1}+QDO_{Git-1})\frac{GDP_t}{GDP_{t-1}}-QDX_{Git} \tag{6-14}$$

By substituting (6-3) into (6-14), the following equation is obtained.

$$QDF_{Git}=-QDL_{Git}-\frac{QDS_{Git-1}}{Q_{Git-1}}Q_{Git}$$
$$+\left(1-\frac{QDW_{Git-1}}{QD_{Git-1}}\right)(Q_{Git}-NEX_{Git}-STC_{Git})$$
$$-(QDP_{Git-1}+QDO_{Git-1})\frac{GDP_t}{GDP_{t-1}}+QDX_{Git}$$

$$QDF_{Git}+QDL_{Git}$$
$$=\left(1-\frac{QDS_{Git-1}}{QD_{Git-1}}-\frac{QDW_{Git-1}}{Q_{Git-1}}\right)Q_{Git}$$
$$-\left(1-\frac{QDW_{Git-1}}{QD_{Git-1}}\right)(NEX_{Git}+STC_{Git})$$
$$-(QDP_{Git-1}+QDO_{Git-1})\frac{GDP_t}{GDP_{t-1}}+QDX_{Git} \tag{6-15}$$

Substituting the food demand function (6-7) and the feed demand function (6-9) into equation (6-15) gives the following equation.

$$\gamma_{0Gi}+\sum_l \gamma_{Gi,l}p_{lt}$$
$$+\sum_j \delta_{0Gij}+\sum_j \delta_{Gij,j}p_{jt}+\sum_j\sum_k \delta_{Gij,k}p_{kt}$$
$$=\left(1-\frac{QDS_{Git-1}}{QD_{Git-1}}-\frac{QDW_{Git-1}}{Q_{Git-1}}\right)Q_{Git}$$
$$-\left(1-\frac{QDW_{Git-1}}{QD_{Git-1}}\right)(NEX_{Git}+STC_{Git})$$
$$-(QDP_{Git-1}+QDO_{Git-1})\frac{GDP_t}{GDP_{t-1}}+QDX_{Git}$$
$$-\gamma_{MGi}\frac{GDP_t}{POP_t} \tag{6-16}$$

Equation (6-16) consists of the four crop *Gi*: those of *RI*, *WH*, *MZ*, and *XG*.

The left side of equation (6-16) is a summation of a part of the food demand function for which explanatory variables are the prices of the 18 food goods and the feed demand function for which explanatory variables are the prices of the six crops and two cakes. Therefore, this equation includes prices of all 20 goods, quantities such as production or net exports of the four crops, GDP, and population. Variables aside from prices are obtained as exogenous or predetermined variables. NEX_{Git} is inferred from the world clearing condition.

Solving the simultaneous equations requires 16 other functions. The respective functions for production of two oil crops, two oils, two cakes, five meats, one egg, one milk, and three dairy products are shown next.

The supply equations of the four crops are summarized from equation (6-14) for convenience as presented below.

$$QD_{Git}-QDW_{Git-1}\frac{QD_{Git}}{QD_{Git-1}}=QDF_{Git}+QDL_{Git}$$
$$+QDS_{Git-1}\frac{Q_{Git}}{Q_{Git-1}}$$
$$+(QDP_{Git-1}+QDO_{Git-1})\frac{GDP_t}{GDP_{t-1}}+QDX_{Git}$$

$$QD_{Git}\left(1-\frac{QDW_{Git-1}}{QD_{Git-1}}\right)=QDF_{Git}+QDL_{Git}$$
$$+QDS_{Git-1}\frac{Q_{Git}}{Q_{Git-1}}$$
$$+(QDP_{Git-1}+QDO_{Git-1})\frac{GDP_t}{GDP_{t-1}}+QDX_{Git}$$

$$QD_{Git}=\frac{QD_{Git-1}}{QD_{Git-1}-QDW_{Git-1}}$$
$$\times\left[QDF_{Git}+QDL_{Git}+QDS_{Git-1}\frac{Q_{Git}}{Q_{Git-1}}\right.$$
$$\left.+\left(QDP_{Git-1}+QDO_{Git-1}\right)\frac{GDP_t}{GDP_{t-1}}+QDX_{Git}\right] \tag{6-17}$$

2. Supply and demand of oil crops

The oil crops incorporated into this model consist of the following two crops: soybeans (*SB*) and other oil crops (*XS*). Oil crop *Si* is investigated in this section.

The production of oil crop *Si* is calculated using the following equation.

$$Q_{Sit}=Y_{Sit}A_{Sit} \tag{7-1}$$

In that equation, *Si* is an index of oil crops, i.e., *SB* and *XS*, *t* represents the year, Y_{Sit} denotes yield, and A_{Sit} expresses the planted area.

The supply equation is written as

$$QD_{Sit}=Q_{Sit}-NEX_{Sit}-STC_{Sit}, \tag{7-2}$$

where NEX_{Sit} denotes net exports and STC_{Sit} denotes the stock change.

The net exports are obtained from identity (7-2).

$$NEX_{Sit}=Q_{Sit}-QD_{Sit}-STC_{Sit} \tag{7-3}$$

The stock change of the oil crop is calculated using the following equation.

$$STC_{Sit}=STC_{Sit-1}\frac{Q_{Sit}-Q_{Sit-1}}{Q_{Sit-1}-Q_{Sit-2}} \tag{7-4}$$

The supply of oil crop *Si* is obtained from the following identity.

$$QD_{Sit}=QDF_{Sit}+QDL_{Sit}+QDS_{Sit}$$
$$+QDW_{Sit}+QDP_{Sit}+QDO_{Sit}+QDX_{Sit} \tag{7-5}$$

Therein, QDF_{Sit} stands for food demand, QDL_{Sit} denotes feed demand, QDS_{Sit} represents seed demand, QDW_{Sit} stands for waste, QDP_{Sit} denotes process demand, QDO_{Sit} signifies other use, and QDX_{Sit} expresses error in the FAOSTAT.

For simplification, the food demand function of beans or seeds of oil crop Si is specified in this section as the following linear function.

$$QDF_{Sit} = \gamma_{0Si} + \sum_l \gamma_{Si,l}\, p_{lt} + \gamma_{MSi} \frac{GDP_t}{POP_t} \quad (7\text{-}6)$$

Therein, l represents the 18 food goods in this model.

The feed demand of oil crop Si is specified as the following linear function where the quantity is small.

$$QDL_{Sijt} = \delta_{0Sij} + \delta_{Sij,j}\, p_{jt} + \sum_k \delta_{Sij,k}\, p_{kt} \quad (7\text{-}7)$$

In that equation, k represents feed crops and cakes. j is livestock products.

The aggregated feed demand is the following.

$$QDL_{Sit} = \sum_j QDL_{Sijt}$$
$$= \sum_j \delta_{0Sij} + \sum_j \delta_{Sij,j}\, p_{jt} + \sum_j \sum_k \delta_{Sij,k}\, p_{kt} \quad (7\text{-}8)$$

The seed supply of the oil crop is calculated using the following equation.

$$QDS_{Sit} = QDS_{Sit-1} \frac{Q_{Sit}}{Q_{Sit-1}} \quad (7\text{-}9)$$

The rate of increase of the seed supply is assumed to be equal to that of production.

The quantity of waste of the oil crop is obtained using the following equation.

$$QDW_{Sit} = QDW_{Sit-1} \frac{QD_{Sit}}{QD_{Sit-1}} \quad (7\text{-}10)$$

The rate of increase of waste is assumed to be equal to that of the total supply.

The oil crop input demand function of the oil production is specified as follows. In this case, oil alone is the processed product of the oil crop.

$$QDP_{Sit} = \zeta_{0Si} + \zeta_{Si,Oi}\, p_{Oit} + \zeta_{Si,i}\, p_{Sit} \quad (7\text{-}11)$$

In that equation, p_{Oit} signifies the oil price of the oil crop Si; p_{Sit} stands for the price of the oil crop. Labor and capital inputs for oil production are omitted for simplification.

The process supply of the oil crop is calculated as

$$QDP_{Sit} = QDP_{Sit-1} \frac{QD_{Sit}}{QD_{Sit-1}}, \quad (7\text{-}12)$$

The rates of increase of the process supply are assumed to be equal to that of the total supply.

The other use of the oil crop is calculated using the following equation.

$$QDO_{Sit} = QDO_{Sit-1} \frac{GDP_t}{GDP_{t-1}} \quad (7\text{-}13)$$

The rates of increase of other use are assumed to be equal to that of GDP.

Substituting equations (7-9), (7-10), and (7-13) into equation (7-5) yields the equation shown below.

$$QD_{Sit} = QDF_{Sit} + QDL_{Sit} + QDP_{Sit}$$
$$+ QDS_{Sit-1} \frac{Q_{Sit}}{Q_{Sit-1}} + QDW_{Sit-1} \frac{QD_{Sit}}{QD_{Sit-1}}$$
$$+ QDO_{Sit-1} \frac{GDP_t}{GDP_{t-1}} + QDX_{Sit} \quad (7\text{-}14)$$

Rewriting (7-14) for food demand, and substituting (7-2) yields the equation shown below.

$$QDF_{Sit} = QD_{Sit} - QDL_{Sit} - QDP_{Sit}$$
$$- QDS_{Sit-1} \frac{Q_{Sit}}{Q_{Sit-1}} - QDW_{Sit-1} \frac{QD_{Sit}}{QD_{Sit-1}}$$
$$- QDO_{Sit-1} \frac{GDP_t}{GDP_{t-1}} - QDX_{Sit}$$
$$= - QDL_{Sit} - QDP_{Sit}$$
$$- \frac{QDS_{Sit-1}}{Q_{Sit-1}} Q_{Sit}$$
$$+ \left(1 - \frac{QDW_{Sit-1}}{QD_{Sit-1}}\right)\left(Q_{Sit} - NEX_{Sit} - STC_{Sit}\right)$$
$$- QDO_{Sit-1} \frac{GDP_t}{GDP_{t-1}} - QDX_{Sit}$$

$$QDF_{Sit} + QDL_{Sit} + QDP_{Sit}$$
$$= \left(1 - \frac{QDS_{Sit-1}}{Q_{Sit-1}} - \frac{QDW_{Sit-1}}{QD_{Sit-1}}\right) Q_{Sit}$$
$$- \left(1 - \frac{QDW_{Sit-1}}{QD_{Sit-1}}\right)\left(NEX_{Sit} + STC_{Sit}\right)$$
$$- QDO_{Sit-1} \frac{GDP_t}{GDP_{t-1}} - QDX_{Sit} \quad (7\text{-}15)$$

Substituting the food demand function (7-6), the feed demand function (7-8), and the process demand function (7-11) into equation (7-15) yields the equation shown below.

$$\gamma_{0Si} + \sum_l \gamma_{Si,l}\, p_{lt}$$
$$+ \sum_j \delta_{0Sij} + \sum_j \delta_{Sij,j}\, p_{jt} + \sum_j \sum_k \delta_{Sij,k}\, p_{kt}$$
$$+ \zeta_{0Si} + \zeta_{Si,Oi}\, p_{Oit} + \zeta_{Si,i}\, p_{Sit}$$

$$= \left(1 - \frac{QDS_{Sit-1}}{Q_{Sit-1}} - \frac{QDW_{Sit-1}}{QD_{Sit-1}}\right) Q_{Sit}$$

$$- \left(1 - \frac{QDW_{Sit-1}}{QD_{Sit-1}}\right)\left(NEX_{Sit} + STC_{Sit}\right)$$

$$- QDO_{Sit-1} \frac{GDP_t}{GDP_{t-1}} - QDX_{Sit} - \gamma_{MSi} \frac{GDP_t}{POP_t} \tag{7-16}$$

The left side of equation (7-16) includes prices of all 20 goods. Quantities on the right side include of exogenous variables and predetermined variables of the two oil crops.

The supply equations of the two oil crops are summarized by substituting equations (7-9), (7-10), (7-12), and (7-13) into equation (7-5).

$$\begin{aligned} QD_{Sit} &= QDF_{Sit} + QDL_{Sit} \\ &+ QDP_{Sit-1} \frac{QD_{Sit}}{QD_{Sit-1}} + QDS_{Sit-1} \frac{Q_{Sit}}{Q_{Sit-1}} \\ &+ QDW_{Sit-1} \frac{QD_{Sit}}{QD_{Sit-1}} + QDO_{Sit-1} \frac{GDP_t}{GDP_{t-1}} \\ &+ QDX_{Sit} \end{aligned} \tag{7-17}$$

$$\begin{aligned} &= QDF_{Sit} + QDL_{Sit} \\ &+ \frac{QDP_{Sit-1} + QDW_{Sit-1}}{QD_{Sit-1}} QD_{Sit} \\ &+ QDS_{Sit-1} \frac{Q_{Sit}}{Q_{Sit-1}} \\ &+ QDO_{Sit-1} \frac{GDP_t}{GDP_{t-1}} + QDX_{Sit} \end{aligned}$$

$$\begin{aligned} &\frac{QD_{Sit-1} - QDP_{Sit-1} - QDW_{Sit-1}}{QD_{Sit-1}} QD_{Sit} \\ &= QDF_{Sit} + QDL_{Sit} + QDS_{Sit-1} \frac{Q_{Sit}}{Q_{Sit-1}} \\ &+ QDO_{Sit-1} \frac{GDP_t}{GDP_{t-1}} + QDX_{Sit} \end{aligned}$$

$$\begin{aligned} QD_{Sit} &= \frac{QD_{Sit-1}}{QD_{Sit-1} - QDP_{Sit-1} - QDW_{Sit-1}} \\ &\times \left(QDF_{Sit} + QDL_{Sit} + QDS_{Sit-1} \frac{Q_{Sit}}{Q_{Sit-1}} \right. \\ &\left. + QDO_{Sit-1} \frac{GDP_t}{GDP_{t-1}} + QDX_{Sit} \right) \end{aligned} \tag{7-18}$$

3. Supply and demand of vegetable oils

The vegetable oils incorporated into this model are of the two oil classifications: soybean oil (*OS*) and other vegetable oils (*OX*). Vegetable oil *Oi* is investigated in this section.

Production of vegetable oil is a process supply of the oil crop multiplied using the coefficient shown below.

$$Q_{Oit} = c_{Oit}\, QD_{Sit-1} \tag{8-1}$$

Therein, QD_{Sit} is the supply of oil crop *Oi*. If *Oi* is *OS*, then *Si* is *SB*. If *Oi* is *OX*, then *Si* is *XS*.

The parameter c_{OSt} is around 0.18. It is slightly different by country and year. However, c_{OXt} exceeds one in many countries. Therefore, the weight of the produced oil is heavier than the raw material. Although the cause is unclear, the parameters calculated from data of the FAOSTAT are used in this model.

The simulation results obtained using equation (8-1) are not good. Therefore, the following equation, which is the same as that in the IFPSIM, is used in the simulation.

$$Q_{Oit} = Q_{Oit-1} \frac{QD_{Sit}}{QD_{Sit-1}} \tag{8-2}$$

Therein, QD_{Sit} is the supply of oil crop *Oi*.

The supply equation of vegetable oils is expressed as

$$QD_{Oit} = Q_{Oit} - NEX_{Oit} - STC_{Oit}, \tag{8-3}$$

where NEX_{Oit} denotes net exports and STC_{Oit} represents the stock change.

The net exports are obtained from identity (8-3) as

$$NEX_{Oit} = Q_{Oit} - QD_{Oit} - STC_{Oit}. \tag{8-4}$$

The stock change of the oil crop is calculated using the following equation just as it was for oil crops.

$$STC_{Oit} = STC_{Oit-1} \frac{Q_{Oit} - Q_{Oit-1}}{Q_{Oit-1} - Q_{Oit-2}} \tag{8-5}$$

The supply of vegetable oil *i* is obtained from the following identity.

$$\begin{aligned} QD_{Oit} &= QDF_{Oit} \\ &+ QDW_{Oit} + QDP_{Oit} + QDO_{Oit} + QDX_{Oit} \end{aligned} \tag{8-6}$$

Therein, the variables are the same as those used for oil crops. However, seed demand of vegetable oil has been deleted because that value is apparently zero.

The food demand function of vegetable oil *Oi* is specified as the following linear function for simplification in this section.

$$QDF_{Oit} = \gamma_{0Oi} + \sum_l \gamma_{Oi,l}\, p_{lt} + \gamma_{MOi} \frac{GDP_t}{POP_t} \tag{8-7}$$

Therein, *l* represents the 18 food goods in this model.

The quantity of vegetable oil waste is obtained as

$$QDW_{Oit} = QDW_{Oit-1} \frac{QD_{Oit}}{QD_{Oit-1}}. \tag{8-8}$$

The rate of increase of supply of vegetable oil is assumed to be equal to that of the total supply.

The process supply of the vegetable oil is calculated as

$$QDP_{Oit} = QDP_{Oit-1} \frac{QD_{Oit}}{QD_{Oit-1}}. \tag{8-9}$$

The rates of increase of the supply of oil for process are assumed to be equal to that of the total supply.

The other use of vegetable oil is calculated as

$$QDO_{Oit} = QDO_{Oit-1}\frac{GDP_t}{GDP_{t-1}}. \tag{8-10}$$

The rate of increase of the other use of vegetable oil is assumed to be equal to that of GDP.

Substituting equations (8-8)–(8-10) into equation (8-6) yields the equations shown below.

$$\begin{aligned}QD_{Oit} &= QDF_{Oit} \\ &+ QDW_{Oit-1}\frac{QD_{Oit}}{QD_{Oit-1}} + QDP_{Oit-1}\frac{QD_{Oit}}{QD_{Oit-1}} \\ &+ QDO_{Oit-1}\frac{GDP_t}{GDP_{t-1}} + QDX_{Oit}\end{aligned}$$

$$\begin{aligned}QDF_{Oit} &= QD_{Oit} - QDW_{Oit-1}\frac{QD_{Oit}}{QD_{Oit-1}} \\ &- QDP_{Oit-1}\frac{QD_{Oit}}{QD_{Oit-1}} \\ &- QDO_{Oit-1}\frac{GDP_t}{GDP_{t-1}} - QDX_{Oit} \\ &= \left(1-\frac{QDW_{Oit-1}}{QD_{Oit-1}}-\frac{QDP_{Oit-1}}{QD_{Oit-1}}\right)QD_{Oit} \\ &- QDO_{Oit-1}\frac{GDP_t}{GDP_{t-1}} - QDX_{Oit}\end{aligned} \tag{8-11}$$

Substituting equation (8-3) into (8-11) produces the equations shown below.

$$\begin{aligned}QDF_{Oit} &= \left(1-\frac{QDW_{Oit-1}}{QD_{Oit-1}}-\frac{QDP_{Oit-1}}{QD_{Oit-1}}\right) \\ &\times (Q_{Oit} - NEX_{Oit} - STC_{Oit}) \\ &- QDO_{Oit-1}\frac{GDP_t}{GDP_{t-1}} - QDX_{Oit}\end{aligned} \tag{8-12}$$

Substituting the food demand function (8-7) and production equation (8-2) into (8-12) produces the equation shown below.

$$\begin{aligned}\gamma_{0Oi} &+ \sum\nolimits_l \gamma_{Oi,l}\,p_{lt} \\ &= \left(1-\frac{QDW_{Oit-1}}{QD_{Oit-1}}-\frac{QDP_{Oit-1}}{QD_{Oit-1}}\right) \\ &\times \frac{Q_{Oit-1}}{QD_{Sit-1}} QD_{Sit} \\ &+ \left(1-\frac{QDW_{Oit-1}}{QD_{Oit-1}}-\frac{QDP_{Oit-1}}{QD_{Oit-1}}\right) \\ &\times (-NEX_{Oit} - STC_{Oit}) \\ &- QDO_{Oit-1}\frac{GDP_t}{GDP_{t-1}} - QDX_{Oit} - \gamma_{MOi}\frac{GDP_t}{POP_t}\end{aligned} \tag{8-13}$$

The left side of equation (8-13) includes prices of the 18 food goods. The quantities on the right side are exogenous variables and predetermined variables of the two vegetable oils.

The supply equations of the two vegetable oils are summarized for convenience by substituting equation (8-2) into equation (8-11).

$$\begin{aligned}&\left(1-\frac{QDW_{Oit-1}}{QD_{Oit-1}}-\frac{QDP_{Oit-1}}{QD_{Oit-1}}\right)QD_{Oit} \\ &= QDF_{Oit} + QDO_{Oit-1}\frac{GDP_t}{GDP_{t-1}} + QDX_{Oit}\end{aligned}$$

$$\begin{aligned}QD_{Oit} &= \frac{QD_{Oit-1}}{QD_{Oit-1} - QDW_{Oit-1} - QDP_{Oit-1}} \\ &\times \left[QDF_{Oit} + QDO_{Oit-1}\frac{GDP_t}{GDP_{t-1}} + QDX_{Oit}\right]\end{aligned} \tag{8-14}$$

The vegetable oil food demand and oil crop supply are necessary to calculate the vegetable oil supply.

4. Supply and demand of oil cakes

The oil cakes in this model consist of the following two oil cake classifications: soybean cake (*CS*) and other oil cakes (*CX*). Oil cake *Ci* is investigated in this section.

Production of oil cake is a process supply of the oil crop multiplied by a coefficient as shown below.

$$Q_{Cit} = (1 - c_{it} - x_{it})\, QD_{Sit-1} \tag{9-1}$$

Therein, QD_{Sit} is the oil crop supply. If *Ci* is *CS*, then *Si* is *SB*. If *Ci* is *CX*, then *Si* is *XS*. In addition, c_{it} is the rate of oil production from oil crop *Oi*; x_{it} is an adjustment factor.

Substituting equation (8-1) for vegetable oil production into equation (9-1) produces the equation shown below.

$$Q_{Cit} = (1 - x_{it})\, QD_{Sit} - Q_{Oit} \tag{9-2}$$

Variables Q_{Oit} denote the vegetable oil production from oil crop *Oi*. Adjustment factor x_{it} absorbs the shock if parameter c_{it} exceeds one.

The demand of oil cakes is found using the following feed input demand of livestock products as

$$QDL_{Cijt} = \delta_{0Cij} + \delta_{Cij,j}\,p_{jt} + \sum\nolimits_k \delta_{Cij,k}\,p_{kt} \tag{9-3}$$

where *k* represents feed crops and cakes, i.e., *RI*, *WH*, *MZ*, *XG*, *SB*, *XS*, *CS*, *CX*, and where *j* represents livestock products *BF*, *SH*, *PK*, *PM*, *XM*, *EG*, and *MK*.

The aggregated feed demand is shown below.

$$\begin{aligned}QDL_{Cit} &= \sum\nolimits_j QDL_{Cijt} \\ &= \sum\nolimits_j \delta_{0Cij} + \sum\nolimits_j \delta_{Cij,j}\,p_{jt} + \sum\nolimits_j \sum\nolimits_k \delta_{Cij,k}\,p_{kt}\end{aligned} \tag{9-4}$$

The other uses of oil cake are calculated using the following equation.

$$QDO_{Cit} = QDO_{Cit-1}\frac{GDP_t}{GDP_{t-1}} \quad (9\text{-}5)$$

The rates of increase of the other use of oil cake are assumed to be equal to that of GDP.

The supply identity of oil cakes is

$$QD_{Cit} = Q_{Cit} - NEX_{Cit} - STC_{Cit}. \quad (9\text{-}6)$$

Furthermore, the supply of oil cakes includes feed demand, other uses, and statistical error as

$$QD_{Cit} = QDL_{Cit} + QDO_{Cit} + QDX_{Cit}. \quad (9\text{-}7)$$

Substituting identity (9-6) into the other identity (9-7) yields the following equation for feed demand.

$$QDL_{Cit} = Q_{Cit} - NEX_{Cit} - STC_{Cit} - QDO_{Cit} - QDX_{Cit} \quad (9\text{-}8)$$

If the oil cake production equation (9-1), the feed demand function (9-3), and other use equation (9-5) are substituted into equation (9-8), then the following function is obtained.

$$\sum_j \delta_{0Cij} + \sum_j \delta_{Cij,j} p_{jt} + \sum_j \sum_k \delta_{Cij,k} p_{kt} = (1 - c_{it} - x_{it})\, QDP_{Sit} - NEX_{Cit} - STC_{Cit} - QDO_{Cit-1}\frac{GDP_t}{GDP_{t-1}} - QDX_{Cit} \quad (9\text{-}9)$$

The left side of equation (9-9) includes prices of four grains, two oil crops, two oil cakes, and seven livestock products. The right side of this equation includes the predetermined endogenous variables, exogenous variables, and the process supply of the oil crop.

The supply equations of the two oil cakes are summarized by substituting equation (9-5) into equation (9-7) for convenience.

$$QD_{Cit} = QDL_{Cit} + QDO_{Cit-1}\frac{GDP_t}{GDP_{t-1}} + QDX_{Cit} \quad (9\text{-}10)$$

5. Supply and demand of meats and eggs

Meats and eggs in this model include the following six livestock products: beef (*BF*), mutton (*SH*), pork (*PK*), poultry meat (*PM*), other meats (*XM*), and poultry eggs (*EG*). Meats and eggs *Mi* is investigated as described in this section.

Production of meats and eggs is the yield multiplied by the number of head of the livestock as

$$Q_{Mit} = Y_{Mit} H_{Mit}, \quad (10\text{-}1)$$

where Y_{Mit} is the weight of meats or eggs per head and H_{Mit} is the number of slaughtered head animals or the number of hens.

The supply equation of meats or eggs is

$$QD_{Mit} = Q_{Mit} - NEX_{Mit} - STC_{Mit}, \quad (10\text{-}2)$$

where NEX_{Mit} represents net exports and STC_{Mit} stands for the stock change.

The net exports are obtained from identity (10-2).

$$NEX_{Mit} = Q_{Mit} - QD_{Mit} - STC_{Mit} \quad (10\text{-}3)$$

The stock change of the meats or eggs is calculated using the following equation similarly to other agricultural products.

$$STC_{Mit} = STC_{Mit-1}\frac{Q_{Mit} - Q_{Mit-1}}{Q_{Mit-1} - Q_{Mit-2}} \quad (10\text{-}4)$$

It is assumed that the change in the rate of increase of stock is equal to that of the rate of increased production.

The supply of meats and eggs *Mi* is obtained from the following identity.

$$QD_{Mit} = QDF_{Mit} + QDL_{Mit} + QDW_{Mit} + QDP_{Mit} + QDO_{Mit} + QDX_{Mit} \quad (10\text{-}5)$$

As shown there, QDF_{Mit} expresses food demand, QDL_{Mit} signifies feed demand, QDW_{Mit} represents waste, QDP_{Mit} denotes process demand, QDO_{Mit} denotes other use, and QDX_{Mit} stands for error in the FAOSTAT.

For simplification, the food demand function of meats and eggs *Mi* is specified in this section as the following linear function.

$$QDF_{Mit} = \gamma_{0Mi} + \sum_l \gamma_{Mi,l}\, p_{lt} + \gamma_{Mi}\frac{GDP_t}{POP_t} \quad (10\text{-}6)$$

In that equation, *l* is the 18 food goods used in this model.

The feed supply of meats and eggs is obtained using the following equation, but the case in which meats or eggs are feed for other livestock production is rare.

$$QDL_{Mit} = QDL_{Mit-1}\frac{QD_{Mit}}{QD_{Mit-1}} \quad (10\text{-}7)$$

The rates of increased feed supply of meats and eggs are assumed to be equal to that of the total supply.

The quantity of waste of meats and eggs is obtained as shown below.

$$QDW_{Mit} = QDW_{Mit-1}\frac{QD_{Mit}}{QD_{Mit-1}} \quad (10\text{-}8)$$

The rate of increase in the supply of meats and eggs is assumed to be equal to that of the total supply.

The process supply of the meats and eggs is calculated using the following equation.

$$QDP_{Mit} = QDP_{Mit-1}\frac{GDP_t}{GDP_{t-1}} \quad (10\text{-}9)$$

The rates of increase rates of supply of meats and eggs for process are assumed to be equal to that of GDP. Meats used for process food production are few in the FAOSTAT.

The other use of meats and eggs is calculated as

$$QDO_{Mit} = QDO_{Mit-1}\frac{GDP_t}{GDP_{t-1}}. \quad (10\text{-}10)$$

The rates of increase of the other use of meats and eggs are assumed to be equal to that of GDP.

A reduced form equation is producible using other equations. Substituting equations (10-7)–(10-10) into identity (10-5) yields the following equation.

$$QD_{Mit} = QDF_{Mit} + (QDL_{Mit-1} + QDW_{Mit-1})\frac{QD_{Mit}}{QD_{Mit-1}} + (QDP_{Mit-1} + QDO_{Mit-1})\frac{GDP_t}{GDP_{t-1}} + QDX_{Mit} \quad (10\text{-}11)$$

Solving for food demand yields the following equation.

$$QDF_{Mit} = QD_{Mit} - (QDL_{Mit-1} + QDW_{Mit-1})\frac{QD_{Mit}}{QD_{Mit-1}} - (QDP_{Mit-1} + QDO_{Mit-1})\frac{GDP_t}{GDP_{t-1}} - QDX_{Mit}$$

$$QDF_{Mit} = \left(1 - \frac{QDL_{Mit-1} + QDW_{Mit-1}}{QD_{Mit-1}}\right)QD_{Mit} - (QDP_{Mit-1} + QDO_{Mit-1})\frac{GDP_t}{GDP_{t-1}} - QDX_{Mit} \quad (10\text{-}12)$$

Substituting (10-2) into the equation produces the equation shown below.

$$QDF_{Mit} = \left(1 - \frac{QDL_{Mit-1} + QDW_{Mit-1}}{QD_{Mit-1}}\right) \times (Q_{Mit} - NEX_{Mit} - STC_{Mit}) - (QDP_{Mit-1} + QDO_{Mit-1})\frac{GDP_t}{GDP_{t-1}} - QDX_{Mit} \quad (10\text{-}13)$$

By substituting demand function (10-6) into equation (10-13), the following reduced form of the equation is obtained.

$$\gamma_{0Mi} + \sum_l \gamma_{Mi,l}\, p_{lt} = \left(1 - \frac{QDL_{Mit-1} + QDW_{Mit-1}}{QD_{Mit-1}}\right) \times (Q_{Mit} - NEX_{Mit} - STC_{Mit}) - (QDP_{Mit-1} + QDO_{Mit-1})\frac{GDP_t}{GDP_{t-1}} - QDX_{Mit} - \gamma_{Mi}\frac{GDP_t}{POP_t} \quad (10\text{-}14)$$

The left side of equation (10-14) includes the prices of the 18 food goods. The right side of this equation comprises the predetermined endogenous variables and the exogenous variables.

The supply equations of the five meats and one egg are summarized by solving the supply of equation (10-12).

$$\left(1 - \frac{QDL_{Mit-1} + QDW_{Mit-1}}{QD_{Mit-1}}\right)QD_{Mit} = QDF_{Mit} + (QDP_{Mit-1} + QDO_{Mit-1})\frac{GDP_t}{GDP_{t-1}} + QDX_{Mit}$$

$$QD_{Mit} = \frac{QD_{Mit-1}}{QD_{Mit-1} - QDL_{Mit-1} - QDW_{Mit-1}} \times \left[QDF_{Mit} + \left(QDP_{Mit-1} + QDO_{Mit-1}\right)\frac{GDP_t}{GDP_{t-1}} + QDX_{Mt}\right] \quad (10\text{-}15)$$

6. Supply and demand of raw milk

Raw milk (*MK*) is investigated as described in this section. Production of raw milk is the yield multiplied by the number of cows as

$$Q_{MKt} = Y_{MKt} H_{MKt}, \quad (11\text{-}1)$$

where Y_{MKt} represents the weight of raw milk and H_{MKt} signifies the number of cows.

The supply equation of raw milk is

$$QD_{MKt} = Q_{MKt} - NEX_{MKt} - STC_{MKt}, \quad (11\text{-}2)$$

where NEX_{MKt} represents net exports and STC_{MKt} denotes the stock change.

The net exports are obtained from identity (11-2) as

$$NEX_{MKt} = Q_{MKt} - QD_{MKt} - STC_{MKt}. \quad (11\text{-}3)$$

The stock change of raw milk is calculated using the following equation similarly to other agricultural products.

$$STC_{MKt} = STC_{MKt-1}\frac{Q_{MKt} - Q_{MKt-1}}{Q_{MKt-1} - Q_{MKt-2}} \quad (11\text{-}4)$$

The rate of increase of the stock change is assumed to be equal to that of the rate of increase in change in production. The quantity of the ending stock is small because raw milk is perishable.

The raw milk supply is obtained from the following identity.

$$QD_{MKt} = QDF_{MKt} + QDL_{MKt} + QDW_{MKt} + QDP_{MKt} + QDO_{MKt} + QDX_{MKt} \quad (11\text{-}5)$$

Therein, QDF_{MKt} represents food demand, QDL_{MKt} is feed demand, QDW_{MKt} expresses waste, QDP_{MKt} signifies process demand, QDO_{MKt} denotes other use, and QDX_{MKt} stands for error in the FAOSTAT.

In this sense, for simplification, the food demand function of raw milk is specified as the following linear function.

$$QDF_{MKt} = \gamma_{0MK} + \sum_l \gamma_{MK,l}\, p_{lt} + \gamma_{MK}\frac{GDP_t}{POP_t} \quad (11\text{-}6)$$

Therein, l represents the 18 food goods in this model.

The feed supply of raw milk is obtained as

$$QDL_{MKt} = QDL_{MKt-1}\frac{QD_{MKt}}{QD_{MKt-1}}. \quad (11\text{-}7)$$

Rates of increase of the feed supply of raw milk are assumed as equal to that of the total supply. The quantity of raw milk for feed is large, although cases in which meats are feed for other livestock production are rare.

The quantity of waste of raw milk is obtained as

$$QDW_{MKt} = QDW_{MKt-1}\frac{QD_{MKt}}{QD_{MKt-1}}. \quad (11\text{-}8)$$

The rate of increase in the supply of raw milk is assumed to be equal to that of the total supply.

Next, the demand function is set for raw milk for dairy products Di in this model, which includes skimmed milk (SK), butter (BT), and cheese (CH). The input demand function of raw milk of these dairy products is specified as the following linear functions.

$$QDP_{MK,Dit} = \zeta_{0MKDi} + \zeta_{MKDi,Di}p_{Dit} + \zeta_{MKDi,MK}\,p_{MKt} \quad (11\text{-}9)$$

The price of the dairy products and the price of raw milk are variables of the input demand function. Labor and capital inputs are omitted for simplification.

The total process demand of raw milk is obtained by summation for Di of (11-9) as

$$QDP_{MKt} = \sum_{Di}\zeta_{0MKDi} + \sum_{Di}\zeta_{MKDi,Di}p_{Dit} + \sum_{Di}\zeta_{MKDi,MK}\,p_{MKt}. \quad (11\text{-}10)$$

The other use of raw milk is calculated using the following equation.

$$QDO_{MKt} = QDO_{MKt-1}\frac{GDP_t}{GDP_{t-1}} \quad (11\text{-}11)$$

The rates of increase of the other use of raw milk are assumed to be equal to that of GDP.

Substituting equations (11-7), (11-8), and (11-11) into equation (11-5) produces the equation shown below.

$$\begin{aligned}QDF_{MKt} + QDP_{MKt} &= QD_{MKt} - QDL_{MKt} - QDW_{MKt} - QDO_{MKt} - QDX_{MKt}\\
&= QD_{MKt} - QDL_{MKt-1}\frac{QD_{MKt}}{QD_{MKt-1}} - QDW_{MKt-1}\frac{QD_{MKt}}{QD_{MKt-1}} - QDO_{MKt-1}\frac{GDP_t}{GDP_{t-1}} - QDX_{MKt}\\
&= \left(1 - \frac{QDL_{MKt-1} + QDW_{MKt-1}}{QD_{MKt-1}}\right)QD_{MKt} - QDO_{MKt-1}\frac{GDP_t}{GDP_{t-1}} - QDX_{MKt}\end{aligned} \quad (11\text{-}12)$$

It is possible to set a reduced form equation of raw milk supply and demand. Substituting the food demand function (11-6), input demand function of production of dairy products (11-10), and the supply equation (11-2) into equation (11-12) yields the equation below.

$$\begin{aligned}&\gamma_{0MK} + \sum_{l}\gamma_{MK,l}\,p_{lt} + \sum_{Di}\zeta_{0MKDi} + \sum_{Di}\zeta_{MKDi,Di}p_{Dit} + \sum_{Di}\zeta_{MKDi,MK}\,p_{MKt}\\
&= \left(1 - \frac{QDL_{MKt-1} + QDW_{MKt-1}}{QD_{MKt-1}}\right) \times (Q_{MKt} - NEX_{MKt} - STC_{MKt})\\
&\quad - QDO_{MKt-1}\frac{GDP_t}{GDP_{t-1}} - QDX_{MKt} + \gamma_{MK}\frac{GDP_t}{POP_t}\end{aligned} \quad (11\text{-}13)$$

The left side of this equation includes the prices of the 18 food goods. The right side of this equation has predetermined endogenous variables and exogenous variables.

The supply equation of raw milk is summarized by solving the supply of equation (11-13).

$$\left(1 - \frac{QDL_{MKt-1} + QDW_{MKt-1}}{QD_{MKt-1}}\right)QD_{MKt} = QDF_{MKt} + QDP_{MKt} + QDO_{MKt-1}\frac{GDP_t}{GDP_{t-1}} + QDX_{MKt}$$

$$QD_{MKt} = \frac{QD_{MKt-1}}{QD_{MKt-1} - QDL_{MKt-1} - QDW_{MKt-1}} \times \left[QDF_{MKt} + QDP_{MKt} + QDO_{MKt-1}\frac{GDP_t}{GDP_{t-1}} + QDX_{MKt}\right] \quad (11\text{-}14)$$

7. Supply and demand of dairy products

This model covers the following three dairy products: skimmed milk (SK), butter (BT), and cheese (CH). The conversion rates to raw milk of these dairy products are presented in Table 3-1.

Dairy products are produced from raw milk through processing by separation, fermentation, and condensation. All raw milk in this model is assumed to be used for the processing and production of skimmed milk, butter, or cheese. Dairy products Di are investigated as explained in this section.

Table 3-1. Conversion rates of raw milk to dairy products.

Dairy product	Variable name	Conversion rate
Raw milk	C_{MK}	1.00
Skimmed milk	C_{SK}	6.48
Butter	C_{BT}	12.34
Cheese	C_{CH}	12.66

Source: Japan Dairy Industry Yearbook, 2018

The production of dairy products Di is obtained using the quantity of raw milk for processing multiplied by the following conversion rate.

$$Q_{Dit} = (1/c_{Dit})\, QD_{MKt} \tag{12-1}$$

The supply equation of dairy products Di is

$$QD_{Dit} = Q_{Dit} - NEX_{Dit} - STC_{Dit}. \tag{12-2}$$

Therein, NEX_{Dit} denotes net exports; STC_{Dit} is the stock change.

The net exports are obtained from identity (12-2) as

$$NEX_{Dit} = Q_{Dit} - QD_{Dit} - STC_{Dit}. \tag{12-3}$$

The stock change of the dairy products is calculated similarly to other agricultural products using the following equation.

$$STC_{Dit} = STC_{Dit-1}\frac{Q_{Dit} - Q_{Dit-1}}{Q_{Dit-1} - Q_{Dit-2}} \tag{12-4}$$

The rate of increase of the stock change is assumed to be equal to that of the rate of increase of the changes in production.

The supply of dairy products is obtained from the following identity.

$$QD_{Dit} = QDF_{Dit} + QDL_{Dit} + QDW_{Dit} + QDO_{Dit} + QDX_{Dit} \tag{12-5}$$

In that equation, QDF_{Dit} signifies food demand, QDL_{Dit} stands for feed demand, QDW_{Dit} denotes waste, QDO_{Dit} expresses other use, and QDX_{Dit} is the error term reflecting error in the FAOSTAT.

For simplicity, the food demand function of the dairy products is specified as the following linear function for this section.

$$QDF_{Dit} = \gamma_{0Di} + \sum_{l}\gamma_{Di,l}\, p_{lt} + \gamma_{Di}\frac{GDP_t}{POP_t} \tag{12-6}$$

Therein, l denotes the 18 food goods in this model.

The feed supply of the dairy products is obtained as

$$QDL_{Dit} = QDL_{Dit-1}\frac{QD_{Dit}}{QD_{Dit-1}}. \tag{12-7}$$

The rates of increase of the feed supply of the dairy products are assumed to be equal to that of the total supply. Skimmed milk is used as feed in many countries. Butter is used only rarely as feed in some countries.

The quantity of waste of dairy products is obtained as shown below.

$$QDW_{Dit} = QDW_{Dit-1}\frac{QD_{Dit}}{QD_{Dit-1}} \tag{12-8}$$

The rate of increase of the supply of the dairy products is assumed to be equal to that of the total supply.

The other use of dairy products is calculated as

$$QDO_{Dit} = QDO_{Dit-1}\frac{GDP_t}{GDP_{t-1}}. \tag{12-9}$$

The rate of increase of the other use of the dairy products is assumed to be equal to that of GDP.

A reduced form of the equation of dairy products can be made. By substituting (12-7)–(12-9) into equation (12-5), the following equation is obtained.

$$\begin{aligned} QDF_{Dit} &= QD_{Dit} - QDL_{Dit} - QDW_{Dit} - QDO_{Dit} - QDX_{Dit} \\ &= QD_{Dit} \\ &\quad - QDL_{Dit-1}\frac{QD_{Dit}}{QD_{Dit-1}} - QDW_{Dit-1}\frac{QD_{Dit}}{QD_{Dit-1}} \\ &\quad - QDO_{Dit-1}\frac{GDP_t}{GDP_{t-1}} - QDX_{Dit} \\ &= \left(1 - \frac{QDL_{Dit-1} + QDW_{Dit-1}}{QD_{Dit-1}}\right) QD_{Dit} \\ &\quad - QDO_{Dit-1}\frac{GDP_t}{GDP_{t-1}} - QDX_{Dit} \end{aligned} \tag{12-10}$$

Substituting the food demand function (12-6) and the supply equation (12-2) into equation (12-10), the following equation is obtained.

$$\begin{aligned} &\gamma_{0Di} + \sum_{l}\gamma_{Di,l}\, p_{lt} \\ &= \left(1 - \frac{QDL_{Dit-1} + QDW_{Dit-1}}{QD_{Dit-1}}\right) \\ &\times (Q_{Dit} - NEX_{Dit} - STC_{Dit}) \\ &\quad - QDO_{Dit-1}\frac{GDP_t}{GDP_{t-1}} - QDX_{Dit} - \gamma_{Di}\frac{GDP_t}{POP_t} \end{aligned} \tag{12-11}$$

The left side of this equation includes the prices of the 18 food goods. The right side of this equation comprises predetermined endogenous variables and exogenous variables.

The dairy product supply equation is summarized by solving the supply of equation (12-10).

$$\begin{aligned} &\left(1 - \frac{QDL_{Dit-1} + QDW_{Dit-1}}{QD_{Dit-1}}\right) QD_{Dit} = QDF_{Dit} \\ &\quad + QDO_{Dit-1}\frac{GDP_t}{GDP_{t-1}} + QDX_{Dit} \end{aligned}$$

$$QD_{Dit} = \frac{QD_{Dit-1}}{QD_{Dit-1} - QDL_{Dit-1} - QDW_{Dit-1}} \times \left(QDF_{Dit} + QDO_{Dit-1} \frac{GDP_t}{GDP_{t-1}} + QDX_{Dit} \right) \tag{12-12}$$

8. Calculation routine

Table 3-2 shows the calculation routine, functions and corresponding equation numbers. Before starting of the routine, yields of crops and productions of livestock per head are calculated according to the yield functions.

Derivation of yield functions of cereals and oil crops are written in the next chapter. Yield functions of meats, egg, and raw milk are estimated linearly using only the time trend.

In the yearly loop, first, planted areas of crops and the number of head of livestock are estimated. These are equivalent to the supply functions. Production of the crops and the livestock products is calculated using the estimated yields and the areas or the number of head of livestock. Supply of vegetable oils, oil cakes, and dairy products are estimated directly using by the supply functions. These area or head functions and supply functions are specified as the adaptive expectation model. The explanatory variables are the area, number of animals, supply quantities, and output prices of the prior year.

In the price convergence loop, food demand, feed demand, supply, production of dairy products, stock changes, net exports, and equilibrium prices are calculated in the iteration for the convergence.

After exiting the convergence loop, seeds, processes, other uses, and wastes are calculated using the obtained supply and production values.

Figure 3-1 portrays a flowchart of the crop sector. The macroeconomic and climate variables are exogenous variables. Feed demand is determined in the livestock sector.

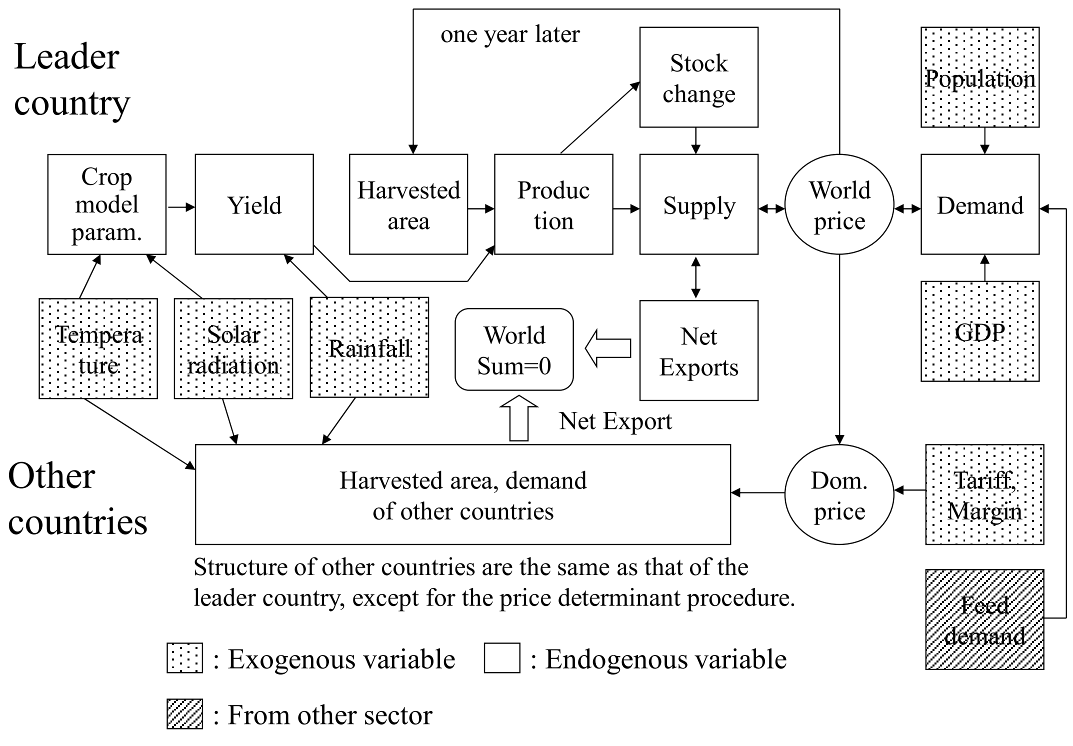

Figure 3-1. Flowchart of the crop sector.

Table 3-2. Calculation routine and functions.

Routine and function	Equation no.
Yield of grains: $Y_{Gi}=f$(climate variables, etc. for the crop model, GDP_t, POP_t)	(13-46), (13-47)
Yield of oil crops: $Y_{Si}=f$(climate variables, etc. for the crop model, GDP_t, POP_t)	(13-46), (13-47)
Yield of meats and egg: $Y_{Mi}=f$(time trend), Yield of raw milk: $Y_{MK}=f$(time trend)	
Year loop	
Planted area function of grains: $A_{Git}=f(A_{Git-1}, p_{RIt-1}, p_{WHt-1}, p_{MZt-1}, p_{XGt-1}, p_{SBt-1}, p_{XSt-1})$	(1-41)
Planted area function of oil crops: $A_{Sit}=f(A_{Sit-1}, p_{RIt-1}, p_{WHt-1}, p_{MZt-1}, p_{XGt-1}, p_{SBt-1}, p_{XSt-1})$	(1-41)
Slaughtered head and hen function: $H_{Mit}=f(H_{Mit-1}, p_{RIt-1}, p_{WHt-1}, p_{MZt-1}, p_{XGt-1}, p_{SBt-1}, p_{XSt-1}, p_{CSt-1}, p_{CXt-1})$	(2-19)
Cow head function: $H_{MKt}=f(H_{MKt-1}, p_{RIt-1}, p_{WHt-1}, p_{MZt-1}, p_{XGt-1}, p_{SBt-1}, p_{XSt-1}, p_{CSt-1}, p_{CXt-1})$	(2-19)
Production of grains: $Q_{Git}=Y_{Git}\,A_{Git}$, Production of oil crops: $Q_{Sit}=Y_{Sit}\,A_{Sit}$	(6-1), (7-1)
Production of meats and egg: $Q_{Mit}=Y_{Mit}\,H_{Mit}$, Production of milk: $Q_{MKt}=Y_{MKt}\,H_{MKt}$	(10-1), (11-1)
Supply function for oil: $Q_{Oit}=f(Q_{Oit-1}, p_{Oit-1}, p_{Sit-1})$	(3-22)
Supply function for cake: $Q_{Cit}=f(Q_{Cit-1}, p_{Cit-1}, p_{Sit-1})$	(3-23)
Supply function for dairy products: $Q_{Dit}=f(Q_{Dit-1}, p_{Dit-1}, p_{MKt-1})$	(4-18)
International equilibrium price recalculation loop	
Goods loop for the 20 commodities, Gauss−Seidel iteration	
International price loop for the 140 countries	
Domestic price (p_i): International price (pw_i) + margin	
Food demand: $QDF_{it}=f_{QDF}(p_{RIt}, \cdots, p_{CHt}, GDP_t, POP_t)$	(5-9)
Feed demand: $QDL_i=f_{QDL}(p_{BFt}, \cdots, p_{MKt}, p_{RIt}, \cdots, p_{CXt})$	(6-9), (7-8), (9-3)
Supply of grains: $QD_{Git}=f_{QDG}(QDF_{Git}, QDL_{Git}, QDX_{Git}, GDP_t, QD_{Git-1}, QDS_{Git-1}, QDW_{Git-1}, QDP_{Git-1}, QDO_{Git-1}, GDP_{t-1})$	(6-17)
Supply of oil crops: $QD_{Sit}=f_{QDS}(QDF_{Sit}, QDL_{Sit}, QDX_{Sit}, GDP_t, QD_{Git-1}, QDS_{Sit-1}, QDW_{Sit-1}, QDP_{Sit-1}, QDO_{Sit-1}, GDP_{t-1})$	(7-14)
Supply of oils: $QD_{Oit}=f_{QDO}(QDF_{Oit}, QDX_{Oit}, GDP_t, QD_{Oit-1}, QDW_{it-1}, QDP_{it-1}, QDO_{it-1}, GDP_{t-1})$	(8-14)
Supply of cakes: $QD_{Cit}=f_{QDC}(QDL_{Cit}, QDX_{Cit}, GDP_t, QDO_{Cit-1}, GDP_{t-1})$	(9-10)
Supply of meats and egg: $QD_{Mit}=f_{QDM}(QDF_{Mit}, QDX_{Mit}, GDP_t, QD_{Mit-1}, QDL_{Mit-1}, QDW_{Mit-1}, QDP_{Mit-1}, QDO_{Mit-1}, GDP_{t-1})$	(10-15)
Supply of milk: $QD_{MKt}=f_{QDMK}(QDF_{MKt}, QDP_{MKt}, QDX_{MKt}, GDP_t, QD_{MKt}, QDL_{MKt-1}, QDW_{MKt-1}, QDO_{MKt-1}, GDP_{t-1})$	(11-14)
Supply of dairy products: $QD_{Dit}=f_{QDD}(QDF_{Dit}, QDX_{Dit}, GDP_t, QD_{Dit-1}, QDL_{Dit-1}, QDW_{Dit-1}, QDO_{Dit-1}, GDP_{t-1})$	(12-12)
Dairy products production: $Q_{Dit}=f(QD_{MKt})$	(12-1)
Stock change: $STC_{it}=f(STC_{it-1}, Q_{it}, Q_{it-1}, Q_{it-2})$	(6-5), etc.
International price (pw_i): equilibrium price of the leader country	
Net exports: $NEX_{it}=f_{NEX}(Q_{it}, QD_{it}, STC_{it})$	(6-4), etc.
Summation of net exports > 0 → decrease in the international price (pw_i) Summation of net exports < 0 → increase in the international price (pw_i) Summation of net exports ≈ 0 → exit from the loop	
End of the international price loop	
End of the goods loop	
Recalculation of food and feed demand using the equilibrium price	
End of recalculation equilibrium price	
Seed demand: $QDS_{it}=f_{QDS}(QDS_{it-1}, Q_{it}, Q_{it-1})$	(6-10), etc.
Process demand: $QDP_{it}=f_{QDP}(QDP_{it-1}, GDP_t, GDP_{t-1})$	(6-12), etc.
Other use: $QDO_{it}=f_{QDO}(QDO_{it-1}, GDP_t, GDP_{t-1})$	(6-13), etc.
Feed demand of livestock products: $QDL_{it}=f_{QDL}(QDL_{it-1}, QD_{it}, QD_{it-1})$	(12-7), etc.
Wastes: $QDW_{it}=f_{QDW}(QDW_{it-1}, QD_{it}, QD_{it-1})$	(6-11), etc.
End of year loop	