THE AGLINK-COSIMO MODEL

A PARTIAL EQUILIBRIUM MODEL OF WORLD AGRICULTURAL MARKETS

OECD

Food and Agriculture Organization of the United Nations

Aglink-Cosimo:
A brief overview

Aglink-Cosimo is an economic model that analyses supply and demand of world agriculture. It is managed by the Secretariats of the OECD and Food and Agriculture Organization of the United Nations (FAO) and is used to generate *the OECD-FAO Agricultural Outlook* and policy scenario analysis.

Aglink-Cosimo is a recursive-dynamic, partial equilibrium model used to make projections of the developments of annual market balances and prices for the main agricultural commodities produced, consumed and traded worldwide. The Aglink-Cosimo country and regional modules are maintained and developed by OECD and FAO in conjunction with country experts and national administrations.

Key characteristics of the model are as follows.

- World markets for agricultural commodities are competitive, with buyers and sellers acting as price takers. Market prices are determined through a global or regional equilibrium in supply and demand. Production costs of agricultural commodities are only represented as indices. Consequently, no complete production function is included.

- Domestically produced and traded commodities are assumed to be homogeneous and thus perfect substitutes by buyers and sellers. International trade is represented as a single world market where total export and import are in equilibrium (traded commodities are not distinguished by country of origin as Aglink-Cosimo is not a spatial model). Each country's imports and exports are determined separately.

- Aglink-Cosimo is a "partial equilibrium" model for the main agricultural commodities and biofuels. Other non-agricultural markets are not modelled and are treated exogenously to the model. As non-agricultural markets are exogenous, hypotheses concerning the paths of key macroeconomic variables are predetermined with no accounting of feedback from developments in agricultural markets to the economy as a whole.

- Aglink-Cosimo is recursive-dynamic. Thus, the generated market balances depend on the outcomes of previous years. Aglink-Cosimo projects annual agricultural market figures ten years into the future.

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1 Introduction

Aglink-Cosimo is the model used to generate the market projections provided in the *OECD-FAO Agricultural Outlook*. This annual publication has wide outreach and serves as a reference to policy makers, stakeholders, and researchers to identify possible future challenges and opportunities for the agricultural sector. Researchers and policy analysts also use this model to assess possible future economic, weather, and political developments that differ from those presented in the *Outlook*.

The present documentation builds on the one issued in 2015. It contains the latest model developments, including the modelling of biofuels and land use, and the calculation of post-model indicators.

Considering the outreach of the agricultural market projections generated by Aglink-Cosimo and its multiple uses, as well as the continuous developments of the modelling framework, this documentation seeks to:

- consolidate the information on the core Aglink-Cosimo model and its modules to provide a reference manual that explains the model's equations, variables and properties; and

- provide insights into the model's design and attributes, as well as how it captures interactions among international commodity markets and market responses to various shocks to improve transparency and facilitate the interpretation of the results.

Section 2 deals with Aglink-Cosimo's core equations – such as world and domestic price clearing – as well as production, consumption, trade, and stock equations (the elements of the domestic commodity balances).

The concept and equations for the modelling of biofuels are explained in Section 3. Section 4 presents details of the land use representation. The post-model computation of several indicators associated with the generated agricultural market projections (e.g. the value of trade or the emission of greenhouse gases) are described in Section 5. Finally, Section 6 briefly describes the process used to generate the *OECD-FAO Agricultural Outlook* and provides a brief introduction to the application of partial stochastics with Aglink-Cosimo.

This documentation describes Aglink-Cosimo's general features and logic, covering some but not all specificities. For further details on specific equations (e.g. the treatment of national policies), the graphical user interface (GUI) should be used (documentation is available on request). The main linkages within the model are presented in Annex D.

2 The core model in detail

2.1. Coverage and technicalities

The Aglink-Cosimo model is composed of the Aglink and the Cosimo regional components. Aglink consists of 15 modules: ten OECD countries and regions (Australia, Canada, the European Union, Switzerland, Norway, Japan, Korea, Mexico, New Zealand, the United Kingdom, and the United States), and four non-OECD countries (Argentina, Brazil, the People's Republic of China (hereafter "China") and the Russian Federation (hereafter "Russia"). The Cosimo component consists currently of 32 modules: four OECD countries (Chile, Colombia, Israel, and Türkiye), 17 other single countries, and 11 regional aggregates (Costa Rica is part of a regional aggregate). Annex C displays the countries and regions covered by each of the regional components, along with the corresponding three-letter label used in the model code.

Aglink-Cosimo covers over 90 commodities (Annex A) and 39 world market-clearing prices (Annex B). Fish and seafood commodities are not part of the core model; their market figures are generated by a separate model that interacts with Aglink-Cosimo via the exchange of key assumptions and outcomes.

Box 1. Technical structure of variables and coefficients

The variables of Aglink-Cosimo have four dimensions: "regions", "commodities", "items" (or measures), and "years". In this documentation, the dimensions "regions", "commodities", and "years" generally serve as identifiers, with the dimension "items" defining the variable or equation.

Variables in the model can be endogenous and exogenous. Endogenous variables need to be declared as such and are calculated during the model simulation. In most equations, endogenous variables are on the left-hand side of the equations. All other variables are exogenous and fixed for the run of the simulation, but can take different values for different years. Specific exogenous variables are the "residuals", or so-called "r-factors". Residuals are considered exogenous variables during simulation exercises and endogenous variables during calibration. They are used to calibrate Aglink-Cosimo to historical data. For projections, the r-factors are fixed to assumed values. Aglink-Cosimo is flexible in this respect since residuals are allowed to take different values per behavioural equation and year.

Model-coefficients are, in contrast to variables, constant for all years of the simulation and define the form of specific functions (e.g. the intercept with the y axis or the slope of a determined curve). There are two general types: equation constants and parameters. Similar to the variables, coefficients must be declared as such in the modelling system. In Aglink-Cosimo, elasticities are key parameters which are used in many behavioural equations to link variables (e.g. the link between yields and producer prices). These are estimated in such a way that they fulfil several economic conditions. The constants are typically re-estimated to scale the residuals (r-factors) close to 1 and should therefore be interpreted carefully.

A large share of the behavioural equations in Aglink-Cosimo is specified in double-log form, in which both the explanatory and the dependent variables are expressed in logarithmic terms: log(Y) = α+β*log(X). Double-log is a convenient transformation of power functions (e.g. the iso-elastic supply and demand functions used in Aglink-Cosimo) to linear functions (in logarithmic 'y' and 'x' scales), as it is easier to work with linear *vs*. non-linear functions (e.g. solvers are more stable if equations are specified in log-linear terms).

2.2. Nomenclature

The following general nomenclature is used in the equations.

- α --> equation-specific constants.
- β --> equation-specific parameters (e.g. elasticities); subscripts are used to distinguish different parameters in one equation.
- γ --> factors, technical parameters, etc., which are equation-specific and could also be time-specific. In that case, the parameter will obtain a subscript 't'.
- 'R' --> equation-specific and year-specific residuals.
- The variable name refers only to the 'item' (or measure) of the variable as explained in Box 1; subscripts indicate the other dimensions (region, commodity, and time).
  - In general, the subscripts 'r', 'c' and 't' refer to specific regional, commodity and time dimension and are displayed in that order.
  - In some cases, specific groups of commodities are displayed in the position for 'c'. In these cases, it is highlighted that the equation is only used for the specific group indicated by the subscript. For example, in $QP_{r,c(crops),t}$ the subscripts indicate the equation is used for all regions ('r') and all years considered in the projection period ('t'), but only for the crop commodities ('c(crops)').
  - (t-1) --> In some cases the subscript '(t-1)' will be displayed in the position for the time 't' dimension. It refers to the value of a variable from the year before year 't'.

2.3. World price clearing

Aglink-Cosimo assumes homogeneity on the world market for all commodities. All modelled countries can import from this market and/or export to it. The market is cleared by an equilibrium world price for each commodity that ensures world demand is equal to world supply, taking the statistical differences observed in the historical data into account.

$$0 = NT_{WLD,c,t} - SD_{WLD,c,t} \tag{1}$$

Where:

NT =   Net trade (in kt)
SD =   Statistical difference (in kt)
WLD =   Sub index indicating that the measure is for the region 'world'

The statistical difference is the amount of a product which is assumed to be lost between leaving one country and entering another – either physical or in statistical accounting. It is set in accordance with historical observations.

World net trade is the sum of the net trade of all countries.

$$NT_{WLD,c,t} = \sum_r NT_{r,c,t} \qquad (2)$$

For the commodities 'pig meat' and 'beef and veal', Aglink-Cosimo is based on a segmented market approach: (i) the Pacific market: free of foot and mouth disease (FMD), and (ii) the Atlantic market: the FMD-controlled and the residual FMD market. The markets are defined according to the classification and geographical patterns from the World Organisation for Animal Health (OIE). These markets are generally clearly separate, although some countries are active on both markets since selling to a less restrictive market is possible. The shares with which these countries act on the two markets are fixed based on historical trade patterns.

The world price is directly converted into an import and export price in each of the local currencies.

$$IMP_{r,c,t} = XP_{WLD,c,t} * XR_{r,c,t} \qquad (3)$$

$$EXP_{r,c,t} = XP_{WLD,c,t} * XR_{r,c,t} \qquad (4)$$

Where:

IMP =	Import price (in local currency/t)
EXP =	Export price (in local currency/t)
XP =	World price (in USD/t)
XR =	Exchange rate of domestic currency vis-à-vis USD
WLD=	Sub index indicating that the measure is for the region 'world'

In the model code, the equations include a factor that is not included in Equations (3) and (4). That factor is foreseen to include a transport cost equivalent to convert between FOB and CIF prices as it applies to the corresponding country and commodity combination. However, to date, the factor has not been populated with data due to the lack of robust transport cost information.

2.4. Domestic markets

2.4.1. Domestic market clearing

In addition to the world market clearing, the Aglink-Cosimo model has a second market-clearing price in each domestic market. This means that domestic prices are not traceable through a set of transmission equations, as can be the case in partial equilibrium models. Domestic market clearance[1] for each country and commodity is assured through a producer price in domestic currency, $PP_{r,c,t}$, which satisfies

$$0 = QP_{r,c,t} - QC_{r,c,t} + IM_{r,c,t} - EX_{r,c,t} + ST_{r,c,(t-1)} - ST_{r,c,t} \qquad (5)$$

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[1] For several smaller markets (e.g. beet pulp, cereal brans, dried distillers grains), it is assumed that the domestic producer price is directly linked to the world market price and an adjustment for the net-trade position is included. In these cases, net trade is closing the balance.

Where:

QP = Quantity produced domestically (in kt)
QC = Quantity consumed domestically (in kt)
IM = Imports (in kt)
EX = Exports (in kt)
ST = Year-end stocks (in kt)

For dairy products and eggs, the general approach for domestic market clearing is slightly altered. For dairy a two-step procedure is applied: (i) markets for milk fat and non-fat solids are cleared (Equations (6) and (7)), and (ii) linked to the previous fat and non-fat balances, a milk producer price is derived (Equation (8)).

$$0 = \left(QP_{r,MK,t} - FU_{r,MK,t}\right) * FAT_{r,MK,t} - \sum_{c(dairy)} QP_{r,c,t} * FAT_{r,c,t} - QP_{r,OFP,t} \tag{6}$$

$$0 = \left(QP_{r,MK,t} - FU_{r,MK,t}\right) * NFS_{r,MK,t} - \sum_{c(dairy)} QP_{r,c,t} * NFS_{r,c,t} - QP_{r,ONP,t} \tag{7}$$

$$PP_{r,MK,t} = \frac{PP_{r,MK,t}^{FAT} * FAT_{r,MK,t} + PP_{r,MK,t}^{NFS} * NFS_{r,MK,t}}{PM_{r,MK,t}} * R \tag{8}$$

Where:

QP = Production quantity (in kt)
FU = Farm use of milk (in kt)
FAT = Fat content of milk (in kt)
c(dairy) = Set of dairy commodities: fresh dairy products, butter, cheese, skimmed milk powder (SMP), whole milk powder (WMP), whey and casein powder
OFP = Set of other milk fat commodities
NFS = Non-fat solid content of milk (in kt)
ONP = Set of other non-fat solids commodities
PP = Producer price (in local currency/t)
MK = Sub index indicating that the measures is for the commodity 'milk'
PP^{FAT} = Milk-fat price at dairy factory (in local currency/t)
PP^{NFS} = Non-fat solid price based on the SMP price (in local currency/t)
PM = Processor margin, a multiplier for the value of dairy products in relation to the farm gate milk price

In the case of eggs, neither trade nor stocks are modelled. In consequence, a domestic price clearing as applied in Equation (5) is not possible. Alternatively, the domestic producer price for eggs is based on the development of costs (feed and other inputs costs approximated by the domestic GDP deflator) and on a trend. Slight variations to the general equation presented below might apply according to different country situations.

$$\log\left(PP_{r,EG,t}\right) = \alpha + \beta_1 * \log\left(0.5 * FECI_{r,NR,(t-1)} + 0.5 * FECI_{r,NR,t}\right) + (1 - \beta_1) * \log\left(GDPD_{r,t}\right) \\ + \beta_2 * TRD + \log(R) \tag{9}$$

Where:

PP = Producer price (in local currency/t)
EG = Eggs (in kt)
FECI = Feed cost index

NR =   Sub index indicating that the measure is for 'non-ruminants'
GDPD =   Deflator of the gross domestic product (2010=1)
TRD =   Trend

Each of the items of the domestic clearance equations (QP, QC, IM, EX, and ST) are discussed below, addressing details on the differences across commodities and on the incorporation of standard policies.

2.4.2. Production

For the modelling of the quantities produced (QP) no general principle exists. Instead, different approaches are applied depending on the commodity or commodity group. Due to the nature of agricultural policies, most policy specifications can be found in the equations related to production.

While supply in Aglink-Cosimo is largely determined by gross returns, production costs are represented in the model in the form of a cost index used to deflate gross production revenues. In most cases, gross returns are expressed per unit of activity (e.g. returns per hectare or the meat price per tonne) relative to the overall production cost level as expressed by the index.

Energy prices can significantly impact international markets for agricultural products since crops and livestock productions are highly dependent on energy. Fuel is required for tractors and other machinery, as well as heating and other forms of energy that are directly used in the production process. In addition, other inputs such as fertilisers and pesticides have high energy content, and costs for these inputs are driven to a significant extent by energy prices. It is therefore important to explicitly consider energy prices in the representation of the cost index.

For crop commodities, the index is constructed using four sub-indices representing the input costs of seeds, energy, and other tradable and non-tradable inputs (Fertilisers are represented exlicitely as shown below). For livestock products, the index is constructed using three sub-indices representing non-tradable inputs, energy inputs, and other tradable inputs. The non-tradable sub-index approximates labour costs by using the domestic GDP deflator. Since this approximation is not always perfect – labour costs might detach from inflation in certain situations – then an exogeneous adjustment factor is used to adjust the sub-index. The energy sub-index considers the developments of crude oil world market prices and of the country's exchange rate. Finally, the tradable sub-index is linked to global inflation (approximated by the US GDP deflator) and the country's exchange rate. The sum of the components is multiplied to a total factor productivity index, which is by now just a placeholder for scenario analysis.

$$
\begin{aligned}
CPCI_{r,c,t} = [\ & CPCS_{r,c,t}^{NT} * \frac{GDPD_{r,t}}{GDPD_{r,2008}} * LCA_{r,t} + CPCS_{r,c,t}^{EN} \frac{XP_{wld,OIL,t} * XR_{r,t}}{XP_{wld,OIL,2008} * XR_{r,2008}} + CPCS_{r,c,t}^{TR} \\
& * \frac{GDPD_{USA,t} * XR_{r,t}}{GDPD_{USA,2008} * XR_{r,2008}} + +CPCS_{r,c,t}^{SD} * \frac{PP_{r,c,(t-1)}}{PP_{r,c,2007}}] * TFPI_{r,t}
\end{aligned}
\tag{10}
$$

Where:

CPCI =   Commodity production cost index (2008 = 1)
CPCS^{NT} =   Share of non-tradable inputs in commodity production costs
CPCS^{EN} =   Share of energy in commodity production costs
CPCS^{TR} =   Share of other tradable inputs in commodity production costs

CPCS^{SD} =   Share of seeds input in commodity production costs (element only used in the CPCI equations of crops)
GDPD =   Deflator of the gross domestic product (2010=1)
LCA =   Labour cost adjustment factor
TFPI =   Total factor productivity index

XP =   World price (in US Dollar/t)

PP =   Producer price (in local currency/t)

XR =   Nominal exchange rate with respect to the US Dollar

OIL =   Sub index indicating that the measures is for 'crude oil'

The shares of the various cost categories are country specific and always sum to one. They are estimated based on historic cost structures in individual countries. Shares also vary depending on the development stage of the country's economy. Developed economies tend to have higher shares of energy and tradable input costs than emerging market and developing economies.

Crops

The modelling of crop production occurs at the disaggregated level, e.g. maize, barley, soybeans, and rapeseed, and not at the level of aggregates, e.g. other coarse grains or other oilseeds.

$$QP_{r,c(crop),t} = AH_{r,c(crop),t} * YLD_{r,c(crop),t} \tag{11}$$

Where:

QP =   Quantity produced (in kt)

AH =   Area harvested (in kha)

YLD =   Yield (in t/ha)

c(crops) =   Set of crop commodities

Crop yields are calculated with the following equation.

$$
\begin{aligned}
log(YLD_{r,c,t}) = {} & \alpha_{r,c} + \beta^1_{r,c} log\left(\frac{PP_{r,c,t} + EPY_{r,c,t}}{\mu CPCI_{r,c,t} + (1-\mu)CPCI_{r,c,t-1}}\right) + \beta^2_{r,c} log(QCHA..c_{r,N,t}) \\
& + \beta^3_{r,c} log\left(0.5(QCHA..c_{r,P,t} + QCHA..c_{r,P,t-1})\right) \\
& + \beta^4_{r,c} log\left(0.5(QCHA..c_{r,K,t} + QCHA..c_{r,K,t-1})\right) + \beta^t_{r,c} trnd + log(R)
\end{aligned}
\tag{12}
$$

Where:

QCHA..c   Nutrient application for crop *c* per hectare (kg/ha)

PP =   Producer price (in local currency/t)

EPY =   Expected crop payment per tonne (in local currency/t)

CPCI =   Cost of production index (2008 = 1)

γ_c =   Share of production cost occurring in the previous marketing year

TRD =   Trend

Fertiliser demand per ha per crop for the 3 major component Nitrate (N) Phosphorus (P) and Potassium (K) is defined as a function of actual and lagged relations between costs of fertilisers and output prices of crops as well as fertiliser prices relative to the production cost index of all other inputs and a trend component:

$$
\begin{aligned}
ln(QCHA..c_{r,p,t}) = {} & \alpha_{r,p} + 0.8 * \beta^2_{r,p} log\left(\frac{CP_{r,p,t}}{PP_{r,c,t-1} + EPY_{r,c,t-1}}\right) \\
& + 0.2 * \beta^2_{r,p} log\left(\frac{CP_{r,p,t-1}}{PP_{r,c,t-1} + EPY_{r,c,t-1}}\right) \\
& + \beta^3_{r,p} log\left(\frac{CP_{r,p,t-1}}{CPCI_{r,c,t-1}}\right) + \beta^t_{r,p} trnd + log(R)
\end{aligned}
\tag{13}
$$

Where:

QCHA..c =	Nutrient application for crop *c* per hectare (kg/ha)
PP =	Producer price of crop c (in local currency/t)
CPCI =	Cost of production index (2008 = 1)
EPY =	Expected crop payment per tonne (in local currency/t)
CP=	Consumer price of fertilisers p (in local currency/t)

The fertiliser price formation follows this logic: International prices are derived from the Urea (46/0/0), Diamonium sulfat (DAP 18/46/0) and Potassium Clorid (MOP 0/0/60) prices available from the world bank pink sheets. Those are converted to pure nutrient equivalents of N,P and K. In Aglink-Cosimo, the fertiliser three prices are represented equation responding to lagged fertiliser, crude oil, and crop prices. These global prices are then transmitted to local producer prices applying border measures and exchange rates. Finally, margins are added to derive the farm gate consumer price (CP) that farmers pay for the fertiisers.

The area harvested per crop is determined by a sequence of land use modelling steps and constraints explained in the land market module in Section 5.

Sugar and by-products

The production of sugarcane and sugar beet follows the same structure for crops described above. However, sugarcane and beet are feedstocks required in the production process of sugar, molasses, by-products (e.g. sugar beet pulp), and biofuels. These feedstocks do not have an own clearance price, but are derived from the prices of the final products adjusted by a processing margin. The feedstock prices are used in the yield equations for sugarcane and beet.

From the production of sugar feedstock to sugar, further modelling steps are required, i.e. the production of SUMOL (an intermediate product) from which sugar is produced. SUMOL can be interpreted as the sugarcane or sugar beet juice, which is the output of the first processing stage in the production process.

The additional steps and equations differ (in detail) amongst countries. The equations differ since they consider the different conditions under which the production of sugar is subject to. For example, the use of sugarcane, beet or both as a feedstock and the products obtained from SUMOL (sugar, molasses, and by-products, e.g. beet pulp) differ by country. The different products from SUMOL, the prices considered in the returns are also different (and use different weights to reflect the importance of the products in the in the individual countries), as is a country's political support to sugar production.

In many country modules, the production of SUMOL is computed by multiplying the feedstock with a SUMOL productivity coefficient.

$$QP_{r.SUMOL,t} = SCA^{SU} * \gamma_r \tag{14}$$

Where:

QP_{r,SUMOL,t} =	The quantity of SUMOL produced in country 'r', in year 't' (in kt)
SCA^{SU}	SUMOL feedstock (in this case sugarcane) used for sugar (in kt)
γ_r =	Coefficient with the country specific rate of production of SUMOL from the corresponding feedstock

To obtain the SUMOL feedstock (used only for sugar), the feedstock used to produce biofuels must be subtracted from the total quantity produced. The equation below uses sugarcane as an example.

$$SCA_{r,t}^{SU} = QP_{r,SCA,t} - SCA_{r,t}^{BF} \tag{15}$$

Where:

SCA^{SU} =   The quantity of sugarcane used only to produce sugar (in kt)

QP$_{SCA}$=   The total quantity of sugarcane produced (in kt)

SCA^{SU} SUMOL feedstock (in this case sugarcane) used for sugar (in kt)

In general, the production of SUMOL is a function of the quantity of feedstock. However, it also considers the commodity returns (e.g. to sugar, molasses and by-products) that are depreciated with the GDPD, and in some cases a trend and an R-factor that allow for calibration. The equations are in double log form.

$$\log\left(QP_{r.SUMOL,t}\right) = \alpha + \beta_1 * TRD + \beta_2 * \log\left(\frac{RET_{r,c,t}}{GDPD_r}\right) + \log(QP^{SCA} + QP^{SBE} - SCA^{BF} - SBE^{BF})$$
$$+ \log(R) \tag{16}$$

Where:

$QP_{r,SUMOL,t}$ =   The quantity of SUMOL produced in country 'r', in year 't' (in kt)

TRD   Trend

RET   Average returns, considering prices for sugar, molasses, and by-products according to the situation in the country

GDPD   Deflator of the gross domestic product (2010=1)

QP^{SCA} Quantity produced of sugarcane (in kt)

QP^{SBE} Quantity produced of sugar beet (in kt)

SCA^{BF} Sugarcane used for biofuels (in kt)

SBE^{BF} Sugar beet used for biofuels (in kt)

In some country modules, the production of sugar and molasses is then computed by multiplying the SUMOL with the corresponding shares which depend on the profitability of molasses versus sugar.

$$QP_{r,SU,t} = QP_{r,SUMOL,t} * QP^{SH}_{r,SU,t} \tag{17}$$

$$QP_{r,MOL,t} = QP_{r,SUMOL,t} * QP^{SH}_{r,MOL,t} \tag{18}$$

Where:

$QP^{SH}_{r,SU,t}$ Share of sugar produced out of a unit of SUMOL

$QP^{SH}_{r,MOL,t}$ Share of molasses produced out of a unit of SUMOL

The production of sugar is obtained using an identity equation for SUMOL. Setting this equal to the quantity produced of sugar plus the quantity of molasses.

$$QP_{r,SUMOL,t} = QP_{r,SU,t} - QP_{r,MOL,t} \tag{19}$$

The production of molasses has its own behavioural equation, while the production of sugar is obtained as the residual from the identity equation above. In general, the equation for molasses follows the production of SUMOL, the relative prices between sugar and molasses, and a trend.

$$\log(QP_{r,MOL,t}) = \alpha + \log\left(QP_{r,SUMOL,t}\right) + \beta_1 * \log\left(\frac{PP^{SU}}{PP^{MOL}}\right) + \beta_2 * TRD + \log(R) \tag{20}$$

Where:

PP^{SU} Producer price for sugar (in local currency/t)

PP^{MOL} Producer price for molasses (in local currency/t)

Some country modules use a similar behavioural equation, but for QPsh instead of QP.

Beet pulp is a by-product in the processing of sugar beet and a simple technical coefficient is applied for its production. Beet pulp is used in the model as a feed component.

$$QP_{r,BP,t} = \gamma * QP_{r,SBE,t} \qquad (21)$$

Where:

BP =	Beet pulp (in kt)
SBE =	Sugar beet (in kt)
γ =	Technical conversion factor (0.058 tonnes of beet pulp is obtained from each tonne of sugar beet)

Meat and eggs

Meat production (equation (22)) is modelled using the product of the number of animals marketed and their average carcass weight. The formula mirrors the approach used in the crop sector (equation 11). The equation is:

$$QP_{r,c(meats),t} = MKG_{r,c(meats),t} * CW_{r,c(meats),t} \qquad (22)$$

Where:

QP =	Quantity produced (in kt)
MKG =	Number of animals marketed (in thousands)
CW =	Carcass weight (in t/head)
c(meats) =	Set of meat commodities

The carcass weight element of the previous equation is designed to reflect responses to economic conditions. The equation incorporates the effects of current producer prices and government support payments as well as feed costs, all elements normalised by the cost of production index. Additionally, a trend component account for long-term changes.

$$\log(CW_{r,c,t}) = \alpha + \beta_1 * \log\left(\frac{PP_{r,c,t} + EPY_{r,c,t}}{CPCI_{r,MD,t}}\right) + \beta_2 * \log\left(\frac{FECI_{r,c,t}}{CPCI_{r,MD,t}}\right) + \beta_3 * TRD + \log(R) \qquad (23)$$

Where:

CW =	Carcass weight (in t/head)
PP =	Producer price (in local currency/t)
EPY =	Effective support payments (in local currency/t)
CPCI =	Cost of production index (2008 = 1)
MD =	Sub index indicating that the measure is for 'meat and dairy'
FECI =	Feed cost index
TRD =	Trend

The other element of the production equation (22), the number of animals marketed for each type of meat, is influenced by another combination of factors, including animal inventory, previously marketed animals' number, production return per head, and costs associated with pasture and with both straight and compound animal feeds. They are detailed in the individual meat marketing sections below (Equations (27), (30) to (32)).

Domestic slaughter production

In the case of beef and veal, pig meat, and sheep and goat meat, a domestic slaughter production is calculated (Equation (24)). This considers the quantity produced in the country, exports and imports of live animals. For poultry, live trade is not recorded; consequently, the production quantity and the domestic slaughter production are considered equal.

$$QPS_{r,c,t} = QP_{r,c,t} - EXL_{r,c,t} + IML_{r,c,t} \qquad (24)$$

Where:

QPS =	Production of meat from domestic slaughtering (in kt)
QP =	Domestic production quantity of meat (in kt)
EXL =	Export of live animals (in carcass weight equivalent, in kt)
IML =	Import of live animals (in carcass weight equivalent, in kt)

Livestock inventory

Beef and veal overall livestock inventory consider lagged (t-1) cow inventories for suckler and dairy cows (indices BV and MKC in the equation below). First, there is the suckler cow inventory, which consists of cows specifically bred to produce calves that are then raised for meat production. Additionally, the inventory of dairy cows contributes to the beef supply due to their dual purpose. Not only are dairy cows used for milk production, but they also provide beef by culling older cows and raising male calves for meat. The combined inventory of both types of cows provides a more stable prediction of the overall animal inventory. The Aglink countries equation for beef and veal livestock inventory is (while the COSIMO countries follow an adapted version -using LI instead of CI- of the equation (29)):

$$\log(LI_{r,BV,t}) = \alpha + \beta_1 * \log(CI_{r,BV,(t-1)} + CI_{r,MKC,(t-1)}) + \log(R) \qquad (25)$$

Where:

LI =	Livestock inventory (in heads)
CI =	Cow inventory (in heads)
BV =	Sub index indicating that the measure is for 'suckler cows'
MKC =	Sub index indicating that the measure is for 'dairy cows'

For other meats, such as poultry, pig meat, sheep, and goats, the inventory model relies directly on the number of animals marketed and a trend (not shown only for Cosimo countries). These follow a simpler approach.

$$\log(LI_{r,c,t}) = \alpha + \log(MKG_{r,c,t}) + \log(R) \qquad (26)$$

Where:

LI =	Livestock inventory (in heads)
MKG =	Number of animals marketed (in thousands)

Beef and veal marketing numbers

The determinants of beef and veal (BV) animal marketing numbers are complex due to several factors, e.g. joint production with milk, lengthy production horizons, use of animals for draught, and the ruminant nature that requires significant arable land or pasture for roughage feed. In general, BV marketing is a function of lagged beef cow inventories (or overall bovine inventory for the COSIMO countries), prices and

incentives (return per head, see equation (28)), pasture and fodder production incentives, cost indices (meat and dairy CPCI, feed cost index or pasture and fodder cost index, cross-commodity cost indices), and a trend (only for Cosimo countries). The standard BV marketing equation is:

(27)

$$\log(MKG_{r,BV,t}) = \alpha + \beta_1 * \log\left(\frac{(RH_{r,BV,t})}{CPCI_{r,MD,t}}\right) + \beta_2 * \log\left(\frac{(RH_{r,BV,t-1})}{CPCI_{r,MD,t-1}}\right) + \beta_3 * \log\left(\frac{(RH_{r,BV,t-2})}{CPCI_{r,MD,t-2}}\right) + \beta_4$$
$$* \log\left(\frac{FECI_{r,c,t}}{CPCI_{r,MD,t}}\right) + \beta_5 * \log\left(\frac{FECI_{r,c,t-1}}{CPCI_{r,MD,t-1}}\right) + \beta_6 * \log\left(\frac{IP_{r,PAF,t}}{PCST_{r,PAF,t}}\right) + \beta_7$$
$$* \log\left(\frac{IP_{r,PAF,(t-1)}}{PCST_{r,PAF,(t-1)}}\right) + \beta_8 * \log(CI_{r,BV,t-1}) + \beta_9 * \log(CI_{r,BV,t-2}) + \beta_{10} * \log(R_{r,BV,t})$$

Where:

MKG =	Number of animals marketed (in thousands)
RH =	Returns per head (in local currency/head)
CPCI =	Cost of production index (2008 = 1)
MD =	Sub index indicating that the measure is for 'meat and dairy'
FECI =	Feed cost index
BV =	Sub index indicating that the measure is for 'beef and veal'
CI =	Cow inventory (in heads)
IP =	Production incentive (in local currency/t)
PAF =	Sub index indicating that the measure is for 'pasture and fodder'
PCST =	Production cost index

The return per head (RH) is calculated as the sum of the producer price PP per tonne, including effective support payments per ton (EPY) transformed into carcass weight equivalent, adding any other effective support payments per head (EPA):

$$RH_{r,c,t} = (PP_{r,c,t} + EPY_{r,c,t}) * CW_{r,c,t} + EPA_{r,c,t} \tag{28}$$

Where:

PP =	Producer price (in local currency/t)
EPY =	Effective support payments (in local currency/t)
CW =	Carcass weight (in t/head)
EPA =	Effective support payments (in local currency/head)

The Aglink countries animal marketing numbers for beef and veal are also based on the lagged (t-1) cow inventory for suckler cows (indices BV in the equation below) plus the influence of prices and incentives pasture and fodder production incentive, cost indices (meat and dairy CPCI, feed cost index or pasture and fodder cost index, cross-commodity cost indices). The standard BV cow inventory equation is:

$$\log(CI_{r,BV,t}) = \alpha + \beta_1 * \log\left(\frac{RH_{r,BV,t} + EPI_{r,BV,t}}{CPCI_{r,MD,t}}\right) + \beta_2 * \log\left(\frac{RH_{r,BV,(t-1)} + EPI_{r,BV,(t-1)}}{CPCI_{r,MD,(t-1)}}\right) + \beta_3$$
$$* \log\left(\frac{RH_{r,BV,(t-2)} + EPI_{r,BV,(t-2)}}{CPCI_{r,MD,(t-2)}}\right) + \beta_4$$
$$* \log\left(\frac{FECI_{r,c,(t-1)}}{CPCI_{r,MD,(t-1)}}\right) + \beta_5 * \log\left(\frac{FECI_{r,c,(t-2)}}{CPCI_{r,MD,(t-2)}}\right) + \beta_6 * \log\left(\frac{IP_{r,PAF,t}}{PCST_{r,PAF,t}}\right)$$
$$+ \beta_7 * \log\left(\frac{IP_{r,PAF,(t-1)}}{PCST_{r,PAF,(t-1)}}\right) + \beta_8 * \log(CI_{r,BV,(t-1)}) + \log(R)$$

(29)

Where:

CI =	Cow inventory (in heads)	
RH =	Return per head (in local currency/head)	
EPI =	Effective payment (subsidy based on animal numbers) (national currency/head)	
CPCI =	Cost of production index (2008 = 1)	
MD =	Sub index indicating that the measure is for 'meat and dairy'	
FECI =	Feed cost index	
BV =	Sub index indicating that the measure is for 'beef and veal'	
IP =	Production incentive (in local currency/t)	
PAF =	Sub index indicating that the measure is for 'pasture and fodder'	
PCST =	Production cost index	

Pig meat and poultry marketing numbers

Pig meat or pork (PK) and poultry (PT) marketing are modelled similarly and influenced by return per head prices, feed costs and a lagged variable on the number of marketed heads (t-1)), and a trend (only for Cosimo countries). However, in the case of pig meat (Equation (30)), the marketing responds to lagged return per head and feed cost, while for poultry (Equation (31)), the short production cycle has the marketing number responding to the current period for return per head and feed costs. Slight variations may apply depending on the political and production conditions of the countries. The reference equations in the model are presented below.

$$
\log(MKG_{r,PK,t}) = \alpha + \beta_1 * \log\left(\frac{RH_{r,PK,(t-1)}}{CPCI_{r,MD,(t-1)}}\right) + \beta_2 * \log\left(\frac{FECI_{r,c,(t-1)}}{CPCI_{r,MD,(t-1)}}\right) + \beta_3 \\
* \log(MKG_{r,PK,(t-1)}) + \log(R)
\tag{30}
$$

$$
\log(MKG_{r,PT,t}) = \alpha + \beta_1 * \log\left(\frac{RH_{r,PT,t}}{CPCI_{r,MD,t}}\right) + \beta_2 * \log\left(\frac{FECI_{r,c,t}}{CPCI_{r,MD,t}}\right) + \beta_3 \\
* \log(MKG_{r,PT,(t-1)}) + \log(R)
\tag{31}
$$

Where:

QP =	Production quantity (in kt)	
RH =	Return per head (in local currency/head)	
CPCI =	Cost of production index (2008 = 1)	
MD =	Sub index indicating that the measure is for 'meat and dairy'	
FECI =	Feed cost index	
PK =	Sub index indicating that the measure is for 'pork'	
PT =	Sub index indicating that the measure is for 'poultry'	

Sheep and goat meat marketing numbers

The marketing of sheep and goat meat (SH) uses a template equation that considers lagged and current own return per head (price and subsidies) and feed costs, lagged pasture and fodder prices, and the lagged marketing quantity, and a trend (only for Cosimo countries).

$$\log(MKG_{r,SH,t}) = \alpha + \beta_1 * \log\left(\frac{(RH_{r,SH,t})}{CPCI_{r,MD,t}}\right) + \beta_2 * \log\left(\frac{(RH_{r,SH,t-1})}{CPCI_{r,MD,t-1}}\right) + \beta_3 * \log\left(\frac{FECI_{r,t}}{CPCI_{r,MD,t}}\right)$$
$$+ \beta_4 * \log\left(\frac{FECI_{r,t-1}}{CPCI_{r,MD,t-1}}\right) + \beta_5 * \log\left(\frac{IP_{r,PAF,(t-1)}}{PCST_{r,PAF,(t-1)}}\right) + \beta_6 \tag{32}$$
$$* \log(MKG_{r,c,(t-1)}) + \beta_7 * \log(R_{r,t})$$

Where:

QP =	Production quantity (in kt)
SH =	Sub index indicating that the measure is for 'sheep and goat meat'
PP =	Producer price (in local currency/t)
CPCI =	Cost of production index (2008 = 1)
MD =	Sub index indicating that the measure is for 'meat and dairy'
IP =	Production incentive (in local currency/t)
PAF =	Sub index indicating that the measure is for 'pasture and fodder'
PCST =	Production cost index
TRD =	Trend

Eggs

The production of eggs (EG) follows one of two general approaches. The first approach defines egg production as the closing variable of in the commodity balance. Thus, the other measures are the ones with behavioural relationships and the production is obtained as the solving variable.

$$0 = QP_{r,EG,t} - QC_{r,EG,t} - NT_{r,EG,t} + ST_{r,EG,(t-1)} - ST_{r,EG,t} \tag{33}$$

Where:

QP =	Quantity produced domestically (in kt)
QC =	Quantity consumed domestically (in kt)
NT =	Net trade (in kt)
ST =	Year-end stocks (in kt)

In the second approach egg production ($QP_{r,EG,t}$) is a function of current prices (PP) and a cost of production index (CPCI). The CPCI for meat and dairy (MD) is used to approximate the costs in the production of eggs.

$$\log(QP_{r,EG,t}) = \alpha + \beta_1 * \log\left(\frac{PP_{r,EG,t}}{CPCI_{r,MD,t}}\right) + \log(R) \tag{34}$$

Milk and dairy products

Milk production is modelled in a similar way to crops, with a cow inventory (homologous to area for crops) and a yield component. In China and the European Union, milk from other animals is added exogenously to the equation.

$$QP_{r,MK.t} = CI_{r,MK,t} * YLD_{r,MK,t} \tag{35}$$

Where:

QP =	Quantity produced domestically (in kt)
MK =	Sub index indicating that the measure is for 'milk'

CI = Cow inventory
YLD = Milk yield (in tonnes per dairy cow)

The calculation of the cow inventory for dairy cows is described below. This is a simplification of the general form given that for milk and beef prices, up to two lags exist and for feed cost up to three lags. Note that in several cases, some of the elasticities are set to zero and subsequently the respective section does not have any influence.

$$
\log(CI_{r,MK,t}) = \alpha + \beta_1 * \log\left(\frac{PP_{r,MK,t} + EPI_{r,MK,t}}{CPCI_{r,MD,t}}\right) + \beta_2 * \log\left(\frac{PP_{r,MK,(t-1)} + EPI_{r,MK,(t-1)}}{CPCI_{r,MD,(t-1)}}\right) + \beta_3 *
$$
$$
\log\left(\frac{PP_{r,BV,t} + EPQ_{r,BV,t}}{CPCI_{r,MD,t}}\right) + \beta_4 * \log\left(\frac{FECI_{r,RU,t}}{CPCI_{r,MD,t}}\right) + \beta_5 * \log\left(\frac{FECI_{r,RU,(t-1)}}{CPCI_{r,MD,(t-1)}}\right) + \beta_6 * \log(CI_{r,MK,(t-1)}) + \quad (36)
$$
$$
\beta_7 * TRD + \log(R)
$$

Where:

CI = Cow inventory (in heads)
MK = Sub index indicating that the measure is for 'milk'
PP = Producer price (in local currency/t)
EPI = Effective payment (subsidy based on animal numbers) (national currency/head)
CPCI = Cost of production index (2008 = 1)
MD = Sub index indicating that the measure is for 'meat and dairy'
EPQ = Effective payment (subsidy based on quantity produced) (local currency/t)
BV = Sub index indicating that the measure is for 'beef and veal'
FECI = Feed cost index
RU = Sub index indicating that the measure is for 'ruminants'

The milk yield depends on output prices, subsidies, feed costs and a trend factor. Feed costs are calculated as the average of the current and, in some cases, the previous year. For Canada, yield is calculated as residual, while production is linked to demand for "fluid milk" and milk for processing.

$$
\log(YLD_{r,MK,t}) = \alpha + \beta_1 * \log\left(\frac{PP_{r,MK,t} + EPY_{r,MK,t}}{CPCI_{r,MD,t}}\right) + \beta_2
$$
$$
* \log\left(\frac{0.5 * (FECI_{r,RU,t} - FECI_{r,RU,(t-1)})}{CPCI_{r,MD,t}}\right) + \beta_3 * TRD + \log(R) \quad (37)
$$

Where:

YLD = Milk yield (in tonnes per dairy cow)
MK = Sub index indicating that the measure is for 'milk'
PP = Producer price (in local currency/t)
EPY = Effective support payment (policy variable) (in local currency/t)
CPCI = Cost of production index (2008 = 1)
MD = Sub index indicating that the measure is for 'meat and dairy'
FECI = Feed cost index
RU = Sub index indicating that the measure is for 'ruminants'
TRD = Trend

Dairy products contain different levels of fat and non-fat solids. Consequently, through clearing fat and non-fat prices, the system assures that demand for both ingredients is balanced (see Equations (6), (7) and (8)). The production of the dairy products is then a function of the relation between the own price of

the dairy product and the sum of weighted milk fat and non-fat prices (to keep the whole system of dairy products balanced).

$$\log\left(QP_{r,c(dairy),t}\right) = \alpha + \beta * \log\left(\frac{PP_{r,c(dairy),t}}{PP_{r,MK,t}^{FAT} * FAT_{r,c(dairy),t} + PP_{r,MK,t}^{NFS} * NFS_{r,c(dairy),t}}\right) + \log(R) \quad (38)$$

Where:

QP =	Quantity produced domestically (in kt)	
c(dairy) =	Set of dairy commodities: fresh dairy products, butter, cheese, skimmed milk powder (SMP), whole milk powder (WMP), whey and casein powder	
PP =	Producer price (in local currency/t)	
PP^{FAT} =	Milk-fat price (in local currency/t)	
FAT =	Milk-fat content	
PP^{NFS} =	Milk-non-fat price (in local currency/t)	
NFS =	Milk-non-fat content	

The elasticity β should be the same for all dairy products in one country as this assures stability for the fat and non-fat balances.

Fresh dairy products (FDP) production is matching consumption. Whey powder (WYP) production is modelled as a by-product of cheese.

2.4.3. Processed commodities and by-products

Protein meal and vegetable oil

The crushing of oilseeds (soybean, rapeseed, sunflower seed, and groundnut) is covered systematically in Aglink-Cosimo and is driven by the crush margin, which is described in the demand section (briefly, the crush margins drive the quantity of oilseeds used for crushing). To compute the production of protein meal and vegetable oil, a simple conversion is then used.

$$QP_{r,c(oilmeal),t} = CR_{r,c(oilseed),t} * YLD_{r,c(oilmeal),t} \quad (39)$$

$$QP_{r,c(oilseed\ oil),t} = CR_{r,c(oilseed),t} * YLD_{r,c(oilseed\ oil),t} \quad (40)$$

Where:

QP =	Quantity produced domestically (in kt)
CR =	Quantity of oilseed for crushing into meal and oil (in kt)
YLD$_{c(oilmeal)}$ =	Oilmeal per tonne of oilseed crushed
YLD$_{c(oilseed\ oil)}$ =	Oilseed oil per tonne of oilseed crushed

The production of processed products made from cottonseed, palm kernels, and coconut (copra or coconut oil) is modelled in a similar way, with the difference that the production of the corresponding oils or meals is directly linked to the total domestic production of the feedstock. Thus, the computation of a separate quantity of the feedstock destined only for crushing/processing is not necessary. This approach assumes no trade with the respective seeds.

For example, the production of cottonseed oil is calculated as a ratio of cottonseed. Cottonseed is computed using a ratio from the production of cotton.

$$QP_{r,CSL,t} = QP_{r,CSE,t} * YLD_{r,CSL,t} \quad (41)$$

$$QP_{r,CSE,t} = QP_{r,CT,t} * YLD_{r,CSE,t} \qquad (42)$$

Where:

QP =	Quantity produced domestically (in kt)
CSL =	Sub index indicating that the measure is for 'cottonseed oil'
YLD$_{r,CSE,t}$ =	Ratio between cotton and cottonseed
CSE =	Sub index indicating that the measure is for 'cottonseed'
CT =	Sub index indicating that the measure is for 'cotton'

In a similar way, 'palm kernel oil' (KL) is modelled as a fixed ratio from 'palm kernel production' (PKL). PKL is computed as a fixed ratio in relation to 'palm oil production' (PL).

$$QP_{r,KL,t} = QP_{r,PKL,t} * \gamma_1 \qquad (43)$$

$$QP_{r,PKL,t} = QP_{r,PL,t} * \gamma_2 \qquad (44)$$

Finally, copra (CL) is modelled as a ratio from the domestic production of coconuts (CN).

$$QP_{r,CL,t} = QP_{r,CN,t} * \gamma \qquad (45)$$

Balances, including trade and producer prices, are only modelled at the aggregate level of vegetable oil and protein meal. These are unweighted sums of all vegetable oils and protein meal. Soybean, rapeseed, sunflower and groundnut oil and meal are grouped into oilseed oil (OL) and oilseed meal (OM).

$$QP_{r,VL,t} = QP_{r,OL,t} + QP_{r,PL,t} + QP_{r,KL,t} + QP_{r,CL,t} + QP_{r,CSL,t} \qquad (46)$$

$$QP_{r,PM,t} = QP_{r,OM,t} + QP_{r,KM,t} + QP_{r,CM,t} + QP_{r,CSM,t} \qquad (47)$$

Where

QP =	Quantity produced domestically (in kt)
VL =	Sub index indicating that the measure is for 'vegetable oils'
OL, PL, KL, CL, and CSL	Sub indices indicating that the measures are for 'oilseed oil', 'palm oil', 'palm kernel oil', 'copra (coconut) oil', and 'cotton seed oil' respectively
PM =	Sub index indicating that the measure is for 'total protein meals'
OM, KM, CM, and CSM =	Sub indices indicating that the measures are for 'oilseed meal', 'palm kernel meal', 'copra (coconut) meal', and 'cotton seed meal' respectively

High fructose corn syrup (isoglucose) and corn gluten feed

High Fructose Corn Syrup (isoglucose) is a cereal-based sweetener that competes with sugar. Production is based mainly on maize.

$$\log(QP_{r,HFCS,t}) = \alpha + \beta_1 * \log\left(\frac{MAR_{r,HFCS,t}}{GDPD_{r,t}}\right) + \beta_2 * \log(QP_{r,HFCS,(t-1)}) + \log(R) \qquad (48)$$

$$MAR_{r,HFCS,t} = \frac{\gamma_1 * PP_{r,HFCS,t} + \gamma_2 * PP_{r,PM,t} + \gamma_3 * PP_{r,VL,t} + \gamma_4 * PP_{r,CGF,t}}{PP_{r,CG,t}} \qquad (49)$$

Where:

QP =		Quantity produced domestically (in kt)
MAR =		Margin per tonne of HFCS (in local currency/t)
GDPD =		Deflator of the gross domestic product (2010=1)
PP =		Producer price (in local currency/t)
HFCS =		Sub index indicating that the measure is for 'High Fructose Corn Syrup (isoglucose)'
γ_1 =		Tonnes of HFCS produced from one tonne of coarse grain (normally 0.6)
γ_2 =		Tonnes of corn gluten meal produced in the conversion of one tonne of coarse grain to HFCS (normally 0.06)
γ_3 =		Tonnes of corn oil produced in the conversion of one tonne of coarse grain to HFCS (normally 0.03)
γ_4 =		Tonnes of corn gluten feed produced in the conversion of one tonne of coarse grain to HFCS (normally 0.24)

Corn gluten feed is considered a by-product of the processing of coarse grains into HFCS (isoglucose).

$$QP_{r,CGF,t} = HFCS_{r,CG,t} * \gamma \tag{50}$$

Where:

QP =	Quantity produced domestically (in kt)
HFCS =	Coarse grains used for HFCS production
CGF =	Sub index indicating that the measure is for 'corn gluten feed'
CG =	Sub index indicating that the measure is for 'coarse grains'
γ =	Tonnes of corn gluten feed produced in the conversion of one tonne of coarse grain to HFCS (normally 0.24)

Dried distillers grains (DDG)

The production of dried distillers grains (DDG) is directly linked to the production of ethanol. A specific conversion for the different feedstocks used for production is applied. This conversion ratio is time dependent as the process is still in the innovation phase. DDGs are used in the feed module; they are traded and the balance is closed for major countries. Otherwise, the domestic price is derived from the world market price and trade closes the balance.

$$QP_{r,DDG,t} = \gamma_{1,t} * QP_{r,ET,t}^{CG} * 10 + \gamma_{2,t} * QP_{r,ET,t}^{WT} * 10 + \gamma_{3,t} * QP_{r,ET,t}^{RT} * 10 \tag{51}$$

Where:

QP =	Quantity produced domestically (in kt)
DDG =	Sub index indicating that the measure is for 'dried distillers grains'
QP^{CG} =	Production of ethanol based on 'coarse grains'
ET =	Sub index indicating that the measure is for 'ethanol'
QP^{WT} =	Production of ethanol based on 'wheat'
QP^{RT} =	Production of ethanol based on 'roots and tubers'

The production of other protein feed (PF) and energy feed (EF) as a by-product of ethanol is carried out in a similar way for the United States and Canada. Both are used only in the calculation of the net production cost of ethanol.

Milling by-products and cereal brans

Milling by-products and cereal brans are a by-product in the processing of cereals for human consumption.

$$\log(QP_{r,CEB,t}) = \alpha + \beta_1 * \log(FO_{r,CG,t} + FO_{r,RI,t} + FO_{r,WT,t}) + \beta_2 * TRD + \log(R) \tag{52}$$

Where:

QP =	Quantity produced domestically (in kt)
CEB =	Sub index indicating that the measure is for 'milling by-products, cereal bran'
FO =	Food use
TRD =	Trend
CG =	Sub index indicating that the measure is for 'coarse grains'
RI =	Sub index indicating that the measure is for 'rice'
WT =	Sub index indicating that the measure is for 'wheat'

The elasticity β_1 has a value between 0.8 and 1 to reflect the strong direct linkage between the food use of cereals and the production of milling by-products and cereal brans (CEB). CEB are used in the feed module and are traded globally. The balance is closed with a domestic market price for major countries (Argentina, Australia, Canada, China, European Union, Korea, New Zealand, Russian Federation and the United States). Otherwise, the domestic price is derived from the world market price and trade closes the balance.

Meat and bone meal

The calculation of meat and bone meal (MBM) production is challenging. Being able to calculate the data directly from beef and veal, pig meat, sheep meat and poultry slaughter, production has the advantage of avoiding the annual collection of data that is difficult to find. As an example, the equation for MBM rendering from pig meat is used. A similar equation applies to the other meats and total MBM production is the sum of all meats.

$$QP_{r,MBM,t}^{PK} = \frac{QPS_{r,PK,t}}{CY_{r,c,t}} * \gamma * \left(QP_{r,PK,t}^{FD} + \left(1 - QP_{r,PK,t}^{FD}\right) * 0.5\right) \tag{53}$$

Where:

QP^{PK} =	Production of meat and bone meal based on 'pork' (in kt)
MBM =	Sub index indicating that the measure is for 'meat and bone meal'
QPS =	Domestic slaughtered production; total weight of carcasses (in kt)
CY =	Conversion between carcass and live weight
QP^{FD} =	Production share of pork commercial farming
PK =	Sub index indicating that the measure is for 'pig meat'
γ =	Conversion factor

For backyard livestock production, it is assumed that 50% are not subject to rendering. Conversion factors (γ) were obtained from livestock experts and the results were compared to sparsely available data. In Aglink-Cosimo, this conversion factor includes several assumptions about the rendering share, rendering yield, etc. For sheep and goat meat, a single conversion factor is applied in only Australia, the European Union, and New Zealand.

2.4.4. Domestic disappearance

Aglink-Cosimo uses the concept of domestic disappearance that implies a closing of the commodity balance. Actual consumption for feed or human nutrition, however, might be lower due to processing, value chain losses, waste at the retail distribution, etc. Domestic disappearance is the sum of different consumption components which are populated only where significant.

$$QC_{r,c,t} = FO_{r,c,t} + FE_{r,c,t} + BF_{r,c,t} + CR_{r,c,t} + SWG_{r,c,t} + OU_{r,c,t} + WST..DIST + LO..VC \qquad (54)$$

Where:

QC =	Total quantity consumed (domestic disappearance) (in kt)	
FE =	Feed use (in kt)	
FO =	Food consumption (in kt)	
BF =	Use as feedstock to produce biofuels (in kt)	
CR =	Use for crushing into meal and oil (in kt)	
SWG =	Use for processing of grains into sweetener (in kt)	
OU =	Other uses (e.g. industrial use, seed, losses) (in kt)	
WST..DIST =	Food lost at retail distribution level (in kt)	
LO..VC =	Value chain losses recorded between production and up to but not including retail level (in kt)	

These components are treated differently and briefly described below. Only the use of the feedstocks to produce biofuels is treated in the section on biofuels.

Food use

Food use is a core item of the domestic disappearance. Aglink-Cosimo has shifted towards consumer prices instead of producer prices to better account for the driver of consumer decisions. Consumer prices are computed referring to nominal producer prices, and include a margin and consumer taxes.

$$CP_{r,c,t} = \left(PP_{r,c,t} + MAR_{r,c,t}\right) * \left(1 + \frac{TAX_{r,c,t}^{rel}}{100}\right) + TAX_{r,c,t}^{add} \qquad (55)$$

Where

CP =	Consumer price (in local currency/t)
MAR =	Consumer price margin
TAX^{rel} =	Relative (ad valorem) taxes
TAX^{add} =	Additive (single) taxes; or the equivalent of other taxes included as single tax

The consumer price margin (MAR) from the equations above is on the other hand a function of the deflator of the gross domestic product (GDPD).

$$\log\left(MAR_{r,c,t}\right) = \alpha + \log\left(GDPD_{r,t}\right) + \log(R) \qquad (56)$$

Now, food demand responds to own prices as well as to the prices of all other food items, to income (approximated with per capita GDP using the ratio of GDPI and a population index), to population growth, and to a trend.

$$\log(FO_{r,c(food),t}) = \alpha + \sum_{c(food)} \beta_{c(food),c(food)} * \log\left(\frac{CP_{r,c(food),t}}{CPI_{r,t}}\right) + \beta_2$$
$$* \log\left(\frac{GDPI_{r,t}}{POP_{r,t}/POP_{r,2005}}\right) + \log(POP_{r,t}) + \beta_2 * TRD + \log(R)$$

(57)

Where:

FO =	Food consumption (in kt)
c(food)=	Sub index indicating that the measure is for the 'food commodities'
$\beta_{c(food),c(food)}$	Food own- and cross-price elasticities[1]
CP =	Consumer price (in local currency/t)
CPI =	Consumer price index (2010 =1)
GDPI =	Gross domestic product index (2010 =1)
POP =	Population (in thousands)
TRD	Trend

1. The own and cross-price elasticities are estimated in according with microeconomic theory: (i) own-price elasticity should be negative; (ii) the sum of all cross- and own-price elasticities per product should be zero (homogeneity of degree 0: if all product prices change by the same percentage the food demand mix does not change, a different value can be assumed if changes in the food demand mix are expected); (iii) substitutes should have a positive cross-price elasticity; and (iv) the mirror elasticities (e.g. β_(c1,c2) and β_(c2,c1)) should be such that the quantity response of a product to a price change of another product is the same as the quantity response of the other product to a price change of the first product (the symmetry condition) (Jechlitschka, Kirschke and Schwarz, 2007[1]).

2.4.5. Feed module

The feed module is structured in a similar way as the food demand module. It contains a link to: (i) own and cross-prices (of the different feed types); (ii) the feed users: through animal production (beef and veal, sheep and goat meat, and milk) and through the feed requirements of fish from aquaculture and non-ruminants; and (iii) a trend. Aglink-Cosimo covers a wide range of feed types: cereal brans, corn gluten feed, dried beet pulp, distillers dried grains, fish meal, maize, meat and bone meal, molasses, other coarse grains, protein meal, pulses, rice, root and tubers, skimmed milk powder, wheat, and whey powder. These are all part of the set 'c(feed)'.

$$\log(FE_{r,c(feed),t}) = \alpha + \beta_1 * \log(QP_{r,SH,t}) + \beta_2 * \log(QP_{r,BV,t}) + \beta_3 * \log(QP_{r,MK,t}) + \beta_4$$
$$* \log(FD_{r,FHA,t}) + (1 - \beta_1 - \beta_2 - \beta_3 - \beta_4) * \log(FD_{r,NR,t})$$
$$+ \sum_{c(feed)} \beta_{c(feed),c(feed)} * \log\left(\frac{PP_{r,c(feed),t}}{GDPD_{r,t}}\right) + \beta_6 * TRD + \log(R)$$

(58)

Where:

FE =	Feed use (in kt)
c(feed)=	Sub index indicating that the measure is for the 'feed commodities'
QP_{SH}, QP_{BV}, QP_{MK} =	Quantities produced of sheep and goat meat (SH), beef and veal (BV), and milk (MK) (in kt)
FD_{FHA}, FD_{NR} =	Total feed use of fish from aquaculture and from non-ruminants (in kt)
$\beta_{c(feed),c(feed)}$	Feed own and cross-price elasticities
$PP_{c(feed)}$ =	Producer prices of the feed commodities (local currency/t)
GDPD =	Deflator of the gross domestic product (2010=1)
TRD	Trend

In the same way as explained in a footnote in the food use section, the own and cross price elasticities are estimated considering the corresponding microeconomic foundations.

The above feed commodities are grouped into three categories in the model: low protein (LPF), medium protein (MPF), and high protein (HPF). The feed use of these three groups is aggregated to obtain the variable feed use of 'all protein feed' (APF).

$$FE_{r,APF,t} = FE_{r,LPF,t} + FE_{r,MPF,t} + FE_{r,HPF,t} \tag{59}$$

The elements of the feed groups are as follows:

- Low protein feed (LPF): maize, other coarse grains, wheat, cereal bran, dried beet pulp, molasses, rice, and roots and tubers.
- Medium protein feed (MPF): corn gluten feed, dried distillers grains (DDG), pulses, and whey powder.
- High protein feed (HPF): protein meal, fish meal, meat and bone meal (MBM), and skim milk powder (SMP).

For all categories, production-weighted prices are calculated (PP_{LPF}, PP_{MPF}, PP_{HPF}, and PP_{APF}). In this way a country specific feed cost per tonne ($FECI_r$) is estimated, which is currently assumed to be the same for ruminants (RU) and non-ruminants (NR). Thus, for a determined country, the same FECI for all livestock categories is used.

$$FECI_{r,c(RU),t} = PP_{r,APF,t} \tag{60}$$

$$FECI_{r,c(NR),t} = PP_{r,APF,t} \tag{61}$$

Note that the system allows for variations in the feed intensity, since it responds to feed prices as shown in Equation (58). The balance between supply and demand is obtained by setting the production (FE_{APF}) equal to the use by ruminants (FD_{RU}), non-ruminants (FD_{NR}), and fish from aquaculture (FD_{FHA}), whereby some countries separate ruminants into 'beef and veal' and 'milk'.

$$FD_{r,RU,t} = FE_{r,APF,t} - (FD_{r,NR,t} + FD_{r,FHA,t}) \tag{62}$$

or $$FD_{r,BV,t} = FE_{r,APF,t} - (FD_{r,MK,t} + FD_{r,NR,t} + FD_{r,FHA,t}) \tag{63}$$

The feed use of ruminants or of beef and veal, depending on which template is used, are obtained as the residuals of the above equations. The use of agricultural feed in aquaculture is exogenous and comes from a separate fish and aquaculture model. Feed use for non-ruminants and milk if defined separately are based on feed conversion rates.

$$FD_{r,NR,t} = \frac{QP_{r,PK,t}}{CY_{r,PK,t}} * FCR_{r,PK,t} + \frac{QP_{r,PT,t}}{CY_{r,PT,t}} * FCR_{r,PT,t} + QP_{r,EG,t} * FCR_{r,EG,t} \tag{64}$$

Where:

FD =	Feed use (in kt)
QP_{PK}, QP_{PT}, QP_{EG} =	Quantities produced of pig meat (PK), poultry (PT), and eggs (EG) (in kt)
CY =	Conversion between carcass and live weight
FCR =	Feed conversion ratio

Feed conversion ratios are also computed for ruminants respective for beef and veal (depending on the approach). These are used as control variables to check the plausibility of the solutions generated by the model.

Finally, due to the use of other feed (e.g. grazing, silage, and food waste) and the use of animals for other purposes than meat, milk or eggs, it is not possible to derive the actual total requirements of feed. Thus, bear in mind that although the system is complete, some elements of feed use are not covered.

Crushing

Crushing is specific to oilseeds (soybean, rapeseed, sunflower seed, groundnut, and other oilseeds) and means the conversion of these into vegetable oil and protein meal. The main driver of crushing in all countries/regions is the crush margin, which is depicted as the ratio between the income for the protein meal and vegetable oil over the price for oilseeds.

$$\log(CR_{r,c(OS),t}) = \alpha + \beta_1 * \log(CRMAR_{r,c(OS),t}) + \beta_2 * \log(CR_{r,c(OS),(t-1)}) + log(GDPI_{r,t}) \\ + \log(R) \tag{65}$$

$$CRMAR_{r,c(OS),t} = \frac{PP_{r,c(OM),t} * YLD_{r,c(OM),t} + PP_{r,c(OL),t} * YLD_{r,c(OL),t}}{PP_{r,c(OS),t}} \tag{66}$$

Where:

CR =	Quantity of oilseed for crushing into meal and oil (in kt)
c(OS) =	Set of oilseed commodities: soybean (SB), rapeseed (RP), sunflower seed (SF), groundnut (GN), and other oilseeds (OOS)
CRMAR =	Crush margin
GDPI	Gross domestic product index (2010 = 1)
PP =	Producer price (local currency/t)
c(OM) =	Set of oilseed meal commodities: soybean meal (SM), rapeseed meal (RM), sunflower meal (SFM), groundnut meal (GM), and other oilseeds meal (OOM)
c(OL) =	Set of oilseed oil commodities: soybean oil (SL), rapeseed oil (RL), sunflower oil (SFL), groundnut oil (GL), and other oilseeds oil (OOL)

Note the equations for the European Union regions (E14 and NMS) include links to the crushing margins of 'other oilseeds' (OOS).

Processing of grains into sweetener (SWG)

This component of demand refers mainly to the use of maize to produce High Fructose Corn Syrup (isoglucose) (HFCS), which is mainly produced in the United States, China, Japan, the European Union, Argentina, Mexico, Korea, and Canada. Other countries produce either small or no quantities.

The production of HFCS depends, in a similar way as for the crushing of oilseeds, on a processing margin. However, in this case an additional link to the lagged (t-1) production is also established. In countries which produce rather small quantities, a simpler formula is used where HFCS production is assumed to change proportionally to the production of maize.

$$\log(QP_{r,HFCS,t}) = \alpha + \beta_1 * \log\left(\frac{ProMAR_{r,HFCS,t}}{GDPD_{r,t}}\right) + \beta_2 * \log(QP_{r,HFCS,(t-1)}) \\ + \log(R) \tag{67}$$

or

$$QP_{r,HFCS,t} = QP_{r,HFCS,(t-1)} * \frac{QP_{r,MA,t}}{QP_{r,MA,(t-1)}} * R \tag{68}$$

Where:

QP =		Quantity produced domestically (in kt)
HFCS =		Sub index indicating that the measure is for 'high fructose corn syrup'
ProMAR =		Processing margin (processing of maize into HFCS)
GDPD =		Deflator of the gross domestic product (2010=1)
MA =		Sub index indicating that the measure is for 'maize'

In a second step, the quantity of maize required to produce HFCS is computed with a conversion factor (γ = 0.6). The factor of 0.6 implies that 0.6 tonnes of HFCS are obtained from each tonne of maize.

$$SWG_{r,MA,t} = \frac{QP_{r,HFCS,t}}{\gamma} \tag{69}$$

Where:

SWG =		Quantity of maize used to produce HFCS (in kt)
QP =		Quantity produced domestically (in kt)
HFCS =		Sub index indicating that the measure is for 'high fructose corn syrup'
MA =		Sub index indicating that the measure is for 'maize'
γ =		Constant technical factor for the conversion of feedstock into HFCS (γ = 0.6)

Other uses

The use of agricultural commodities for 'other uses' contains a number of different components. In short, it includes all uses not covered in any of the other consumption items, e.g. seed use, or processing not covered elsewhere.

The importance of 'other uses' as a component of total consumption (QC) defines how much emphasis is allocated to the estimation of the parameters in the equation.

$$\log(OU_{r,c,t}) = \alpha + \beta_1 * \log\left(\frac{PP_{r,c,t}}{CPI_{r,t}}\right) + \beta_2 * \log(GDPI_{r,t}) + \beta_3 * TRD + \log(R) \tag{70}$$

Where:

OU =		Quantity of ag. commodities used for 'other uses' (in kt)
PP =		Producer price (local currency/t)
CPI =		Consumer price index (2010 =1)
GDPI =		Gross domestic product index (2010 = 1)
TRD =		Trend

Food loss and waste

Food loss and waste represent economic losses for all actors along the food supply chain. In addition to representing an inefficient use of resources, it could significantly impact food availability and level of nutrition. As such, food lost along the value chain and wasted at the retail and household levels must be considered to accurately measure food consumption and nutrition.

Food loss and waste that are taken into consideration in Aglink Cosimo when computing historical values of food consumed and other uses variables including the following.

Value chain losses account for all losses between the level at which production is recorded and delivered to retail outlets (i.e. up to but not including retail), i.e. losses occurred during the transformation of primary commodities into processed products, storage, and transportation. Losses occurring before and during

harvest are excluded. A simple formula calculates the share of losses along the value chain, where the percentage is assumed to change according to income (approximated with per capita GDP using the ratio of GDPI and a population index) and to own producer prices.

$$\log(LO..VC..SHR_{r,c(food),t}) = \alpha + \beta_1 * \log\left(\frac{GDPI_{r,t}}{POP_{r,t}/POP_{r,2010}}\right) + \beta_2 * \left(\frac{PP_{r,c(food),t}}{CPI_{r,(t-1)}}\right) + \log(R) \quad (71)$$

Where:

LO..VC..SHR =	Share of value chain losses (in %)
PP =	Producer price (local currency/t)
CPI =	Consumer price index (2010 =1)
GDPI =	Gross domestic product index (2010 = 1)
c(food)=	Sub index indicating that the measure is for the 'food commodities'
POP =	Population (in thousands)

The share of value chain losses is defined relative to supply, including domestic production, imports, and supply from stocks, to compute the total amount lost along the value chain.

$$LO..VC_{r,c(food),t} = LO..VC..SHR_{r,c(food),t} * (QP_{r,c(food),t} + IM_{r,c(food),t} + ST_{r,c(food),(t-1)}) \quad (72)$$

Where:

LO..VC =	Quantity lost in the value chain (in kt)
LO..VC..SHR =	Share of value chain losses (in %)
IM =	Quantity imported (in kt)
c(food) =	Sub index indicating that the measure is for the 'food commodities'
QP =	Quantity produced domestically (in kt)
ST =	Year-end stocks (in kt)

Distribution waste accounts for all food wasted at the retail distribution level. The calculation of the distribution waste shares is derived using the FAOSTAT Food Security Indicators which includes a percentage of calories wasted of all food per country annually (https://www.fao.org/faostat/en/#data/FBS item "Incidence of caloric losses at retail distribution level").[2] Waste shares are applied to food consumption variables in the model, decreasing available food. Equation (73) calculates the percentage of waste at the retail level, where the share is assumed to change according to income (approximated with per capita GDP using the ratio of GDPI and a population index) and to own consumer prices.

$$\log(WST..DIST..SHR_{r,c(food),t}) = \alpha + \beta_1 * \log\left(\frac{GDPI_{r,t}}{POP_{r,t}/POP_{r,2010}}\right) + \beta_2 * \left(\frac{CP_{r,c(food),t}}{CPI_{r,(t-1)}}\right) + \log(R) \quad (73)$$

---

[2] First, the percentage of caloric waste at the distribution level is divided into shares of calories wasted per food group for each region or country. The study conducted by (Oelofse et al., 2021[6]) was utilised to break down the total calorie waste by food group. Secondly, a subsequent calculation breaks down the food group calorie waste percentage into individual food item waste percentages at the country level to account for the specific composition of each country's food basket. The caloric proportion of each individual food item within the total calorie share of the respective food group is used to disaggregate the calorie waste percentages. Finally, the individual calories wasted for each food item can be computed. By employing conversion factors that relate food calories to quantities, these calorie figures are transformed into volumes wasted..

Where:

WST..DIST..SHR =	Share of food wasted at the retail distribution level (in %)
CPI =	Consumer price index (2010 =1)
GDPI =	Gross domestic product index (2010 = 1)
CP =	Consumer price (in local currency/t)
c(food)=	Sub index indicating that the measure is for the 'food commodities'
POP =	Population (in thousands)

To compute the food quantity wasted at the retail level, the waste share is multiplied by the food availability (total supply).

$$WST..DIST_{r,c(food),t} = WST..DIST..SHR_{r,c(food),t} * FOA_{r,c(food),t}$$

(74)

Where:

FOA =	Food availability (in kt)
c(food) =	Sub index indicating that the measure is for the 'food commodities'
WST..DIST..SHR =	Share of food wasted at the retail distribution level (in %)
WST..DIST =	Quantity of food wasted at the retail distribution level (in kt)

To compute food availability, distribution waste must be added to food consumption as represented in equation (75).

$$FOA_{r,c(food),t} = (FO_{r,c(food),t})/(1 - WST..DIST..SHR_{r,c(food),t}) \quad \frac{((1 + WST..DIST..SHR_{r,c(food),t}}{- WST..DIST..SHR_{r,c(food),t})) * (FO_{r,c(food),t})} (1$$

(75)

Where:

FO =	Food consumption (in kt)
FOA =	Food availability (in kt)
c(food)=	Sub index indicating that the measure is for the 'food commodities'
WST..DIST..SHR =	Share of food wasted at the retail distribution level (in %)

Household waste is defined as food waste occurring at the household level. It is computed as a share of the food consumed; percentages are calculated using The Post-Harvest Loss Information System (SIPPOC) data and FAO Food loss index database (https://www.fao.org/platform-food-loss-waste/flw-data/en/). Food intake is, therefore, total food available less distribution and household level waste. The percentage of waste at the household level is defined in Equation (76), where the share is assumed to change according to income (approximated with per capita GDP using the ratio of GDPI and a population index) and to own consumer prices.

$$\log(WST..HHLD..SHR_{r,c(food),t}) = \alpha + \beta_1 * \log\left(\frac{GDPI_{r,t}}{POP_{r,t}/POP_{r,2010}}\right) + \beta_2 * \left(\frac{CP_{r,c(food),t}}{CPI_{r,(t-1)}}\right) + \log(R)$$

(76)

Where:

WST..HHLD..SHR =	Quantity of food wasted at the household level (in %)
CPI =	Consumer price index (2010 =1)
CP =	Consumer price (in local currency/t)

GDPI =   Gross domestic product index (2010 = 1)
c(food)=   Sub index indicating that the measure is for the 'food commodities'
POP =   Population (in thousands)

To compute the food quantity wasted at the household level, the household waste share is multiplied by the food consumption (food available minus the distribution waste).

$$WST..HHLD_{r,c(food),t} = WST..HHLD..SHR_{r,c(food),t} * (FO_{r,c(food),t}) \tag{77}$$

Where:

FO =   Food consumption (in kt)
c(food) =   Sub index indicating that the measure is for the 'food commodities'
WST..HHLD..SHR =   Share of food wasted at the household level (in %)
WST..HHLD =   Quantity of food wasted at the household level (in kt)

To compute food intake, the amount of household waste is subtracted from food consumed at retail level.

$$FOI_{r,c(food),t} = FO_{r,c(food),t} - WST..HHLD_{r,c(food),t} \tag{78}$$

Where:

FO =   Food consumption (in kt)
c(food) =   Sub index indicating that the measure is for the 'food commodities'
FOI =   Food intake (in kt)
WST..HHLD =   Quantity of food wasted at the household level (in kt)

2.4.6. Trade

In Aglink-Cosimo, countries trade with a common world market (not with a bilateral partner). At the world market, export and import quantities find their equilibrium through clearing world market prices (Section 3.2). The import and export prices ($IMP_{r,c,t}$ and $EXP_{r,c,t}$) are derived from those world market prices ($XP_{WLD,c,t}$). The quantities imported and exported respond to the relative prices between domestic producer and the trading prices. Import and export prices include an *ad valorem* factor (TAVI and TAVE respectively) to account for trade policies.

$$\log(IM_{r,c,t}) = \alpha + \beta * \log\left(\frac{PP_{r,c,t}}{IMP_{r,c,t} * \left(1 + TAVI_{r,c,t}/100\right)}\right) + \log(R) \tag{79}$$

$$\log(EX_{r,c,t}) = \alpha + \beta * \log\left(\frac{PP_{r,c,t}}{EXP_{r,c,t} * \left(1 - TAVE_{r,c,t}/100\right)}\right) + \log(R) \tag{80}$$

Where:

IM =   Quantity imported (in kt)
EX =   Quantity exported (in kt)
PP =   Producer price (local currency/t)
IMP =   Import price (local currency/t)
EMP =   Export price (local currency/t)
TAVI =   Import tariff (or subsidy) in *ad valorem* equivalent
TAVE =   Export tax (or subsidy) in *ad valorem* equivalent

The β parameters (trade elasticities) of the equations are negative for exports and positive for imports. A larger absolute value of these elasticities results in stronger integration of local markets into the world market, and thus a stronger link between domestic and world market prices.

In some cases, alternative approaches are used for the modelling of imports and exports. For example, in the case of no or very small trade volumes, the respective trade flow is treated as an exogenous variable. For beet pulp, milling by-products, corn gluten feed, and other individual cases where prices are derived via price transmission equations, trade is residual and closes the balance.

In the case of sugar, trade is separated into raw and white sugar even though all quantities of the domestic balance (production, consumption, trade, and stocks) are given in raw sugar equivalent, making it possible for the balance to clear.

For pig meat, sheep and goat meat, as well as for beef and veal, a separation is made between trade in live animals and meat. Generally, the trade of meat is calculated using the standard format and the trade of live animals is exogenous. Subsidised exports, food aid, and selected import quotas are modelled on an *ad hoc* basis.

Export taxes (TAVE) are generally exogenous, while import tariffs are computed using an equation considering *ad valorem* and specific import tariffs.

$$TAVI_{r,c,t} = TAV_{r,c,t} + \frac{TSP_{r,c,t}}{IMP_{r,c,t}} * 100 \tag{81}$$

Where:

TAVI =	Import tariff (or subsidy) in *ad valorem* equivalent (in %)
TAV =	*Ad valorem* import tariff (in %)
TSP =	Specific import tariff (local currency/t)
IMP =	Import price (local currency/t)

An alteration of this equation occurs in the case of tariff rate quotas (TRQs).

$$TAVI_{r,c,t} = TAVI_{r,c,t}^{IQS} + \frac{\max\left(0, TAVI_{r,c,t}^{OQS} - TAVI_{r,c,t}^{IQS}\right)}{1 + exp\left\{\max\left[-50, \min\left(50, \ \gamma * \left(1 - \frac{IM_{r,c,t} + 1}{TRQ_{r,c,t} + 1}\right)\right)\right]\right\}} \tag{82}$$

Where:

TAVI^IQS =	In-quota import tariff in *ad valorem* equivalent (in %)
TAVI^OQS =	Out of quota import tariff in *ad valorem* equivalent (in %)
exp =	Exponential function ($f(x) = e^x$)
γ =	Transition factor between in-quota and out of quota tariff
IM =	Quantity of imports (in kt)
TRQ =	Tariff rate quota (in kt)

With TRQs, the TAVI is a function of the import level itself. Theoretically, the effective import tariff is either (i) equal to the in-quota tariff as long as imports are equal or below the TRQ level, or (ii) equal to the over-quota tariff if imports are above the TRQ level. However, this relation only holds for individual tariff lines, which is not the case here (there is only one TAVI in the import equation above). As such, the relationship between import levels and the tariff rate is approximated using the transition factor (γ), whose values range between 0.1 and 200 (with the majority being around 100). With relatively high transition factors and import levels well above the TRQ (e.g. 25% or more above it), the approximated TAVI will practically be at the out-of-quota level. With relatively low transition factors and import levels at less than 25% above the TRQ,

the estimated TAVI will be somewhere between the in-quota and the out-of-quota levels. Hence, the choice of γ depends on the properties of the trade measures in place for the modelled commodity.

2.4.7. Stocks

In the standard form, stocks (ST) are a function of the supply (quantity produced + stocks available from the previous year), consumption (QC), relative prices (current prices with the prices of previous periods), and a trend.

$$
\log(ST_{r,c,t}) = \alpha + \beta_1 * \log(QP_{r,c,t} + ST_{r,c,(t-1)}) + \beta_2 \\
* \log(QC_{r,c,t}) + \beta_3 * \frac{3 * PP_{r,c,t}}{PP_{r,c,(t-1)} + PP_{r,c,(t-2)} + PP_{r,c,(t-3)}} + \beta_4 * TRD + \log(R) \quad (83)
$$

Where:

ST =	Year-end stocks (in kt)
QP =	Quantity produced domestically (in kt)
QC =	Quantity consumed domestically (in kt)
PP =	Producer price (local currency/t)
TRD	Trend

Note that depending on the commodity (e.g. meat products or sugar) or the country, the above standard form might be slightly adapted to match the specific conditions.

In addition to private stocks, state stocks need to be considered in some cases (e.g. intervention stocks in the European Union, Indian, and Chinese cereal markets).

In contrast to all other commodities, stock changes rather than absolute stocks are used for dairy products in the market clearing balance.

3 The modelling of biofuels

3.1. Introduction

Biofuels (ethanol and biodiesel), similar to other processed commodities (e.g. vegetable oil or sugar), use agricultural commodities as feedstocks in their production process and are an important consumption component for several markets. Their modelling is more complex than the other processed commodities, since the market drivers are numerous. In most cases, the level of consumption is policy driven via biofuel mandates. However, relative prices (biofuels vs. pure traditional fuels, i.e. gasoline and diesel) play a role in production and consumption. Furthermore, biofuel mandates are often stipulated as shares of total transport fuel consumption, another important element in the modelling of biofuels. The production of low and high biofuel blends (currently existent mainly for bioethanol in Brazil) also adds to the complexity since the possibility of production of high blends is added to most countries.

The modelling of the different biofuel elements of this complex module is described in this section, which focusses on the approach taken for the most relevant biofuel-producing countries. Some market elements (the clearing of world and domestic markets, trade, and stocks) are modelled in the same way as the other agricultural commodities and are thus not included here. For details on the modelling of those elements, see Sections 3.2, 3.3.1, 3.3.4 and 3.3.5. Countries with smaller production quantities follow a similar but less differentiated approach.

3.2. Production

Biofuels are produced from various feedstocks. For ethanol, the agricultural feedstocks are Maize (MA), Molasses (MOL), Other coarse grain (OCG), Rice (RI), Root and tubers (RT), Wheat (WT), Sugar beet (SBE), Sugar cane (SCA) and Dedicated energy crops (ECR). Biodiesel is produced from Vegetable oil (VL); to be more precise Vegetable oil is separated into Soybean oil (SL), Rapeseed oil (RL), Palm oil (PL), Sunflower oil (SFL) for selected modules. As mentioned above, the approach for the modelling of production is like that of the production of protein meal and vegetable oil (from the crushing of oilseeds), or to the production of HFCS based on maize. The production of biofuels, from a determined feedstock, is a function of current and lagged margin revenues. The quantity of biofuels produced is then linked to the corresponding feedstock through a conversion coefficient. Note that in the case of biofuels, the production is computed directly, and the quantity of feedstock required is computed in a second step (for protein meals, vegetable oils, and HFCS the sequence is the other way around, first the calculation of the feedstock use for processing and then the processed output).

As mentioned above, the first step in the production of biofuels is computed directly, making use of the following equation.

$$
\begin{aligned}
\log\left(QP^{BF}_{r,feedstock,t}\right) \\
= \alpha + \beta_1 * \log\left(RM^{BF}_{r,feedstock,t}\right) + \beta_2 * \log\left(RM^{BF}_{r,feedstock,t-1}\right) + \beta_3 \\
* \log\left(RM^{BF}_{r,feedstock,t-2}\right) + \beta_4 * \log\left(RM^{BF}_{r,feedstock,t-3}\right) + \log\left(R\right)
\end{aligned}
\tag{84}
$$

Where:

$QP^{BF}_{r,feedstock,t} =$	Quantity of a determined biofuel produced from a determined feedstock (in million litres)
BF =	Super index indicating that the measure is for the set of biofuels: 'ethanol and biodiesel'
Feedstock =	Sub index indicating that the measure is for one of the biofuel feedstocks (e.g. for maize, sugar cane, palm oil, etc.)
$RM^{BF}_{r,feedstock,t} =$	Marginal revenue of feedstocks used to produce biofuels. The revenue is specific for a determined feedstock used in the production of either ethanol or biodiesel.

As part of Equation (85), the marginal revenue of the feedstocks used in the production of biofuels is obtained from:

$$RM^{BF}_{r,feedstock,t} = \frac{PP^{BF}_{r,t} + DP^{BF}_{r,feedstock,t} + QP^{BBP..VAL}_{r,feedstock,t}}{CPCI^{BF}_{r,feedstock,t}} \tag{85}$$

Where:

$PP^{BF}_{r,t} =$	Producer price of biofuels (either ethanol or biodiesel) (in local currency/l)
$DP^{BF}_{r,feedstock,t} =$	Direct payment for the use of a determined feedstock in the production of biofuels (in local currency/hectolitre of biofuel)
$QP^{BBP..VAL}_{r,feedstock,t} =$	Production of biofuel by-products (produced from a determined feedstock) in value terms (in local currency/hectolitre of biofuel)
$CPCI^{BF}_{r,feedstock,t} =$	Cost of production index of biofuels (produced with a determined feedstock)

Following the instructions from above, in a second step the feedstock use is computed based on the quantity of biofuel produced with the help of a conversion factor:

$$BF_{r,feedstock,t} = \frac{QP^{BF}_{r,feedstock,t}}{BF^{CONV}_{r,feedstock}} \tag{86}$$

Where:

$BF_{r,feedstock,t} =$	Use of an agricultural commodity as feedstock to produce biofuels (in kt)
$QP^{BF}_{r,feedstock,t} =$	Quantity of a determined biofuel produced from a determined feedstock (in million litres)
$BF^{CONV}_{r,feedstock} =$	Conversion factor from a determined feedstock to a determined biofuel

Note that the use of agricultural commodities for the production of biofuels ($BF_{r,feedstock,t}$) is one of the elements of domestic disappearance of agricultural commodities (Equation (54)). This stablishes the link between biofuels and agricultural commodities.

3.3. Domestic disappearance

For biofuels, the domestic disappearance (QC) is simpler than for the agricultural commodities. The different uses of biofuels are fuels (FL) and other uses (OU).

$$QC_{r,BF,t} = FL_{r,BF,t} + OU_{r,BF,t} \tag{87}$$

Other uses currently exist only for ethanol and contain for example ethanol used in the alcohol industry. These are generally rather small values that are handled as exogenous variables in the model.

The modelling of the use of biofuels as fuels is the core piece of the biofuel module. It considers the total fuel used for transport in a country (gasoline and diesel) and it computes low and high-blend biofuel volumes by using estimated shares from the total transport fuels. The total fuels use for transport are endogenous equations dependent on gasoline and diesel prices, income, a trend, and population growth (Equation (88)).

The low-blend biofuel share is modelled as the maximum between a mandate-driven estimated share and a non-mandate driven estimated share, which considers other rather market oriented elements as the use of biofuels (ethanol) as additive in fossil fuels (gasoline), or relative prices (ethanol or biodiesel vs. gasoline and diesel correspondingly).

The high-blend biofuel shares (summer 2022) only apply for ethanol in Brazil and the United States as these two countries have the necessary infrastructure for the vehicles' modified engines. However, only Brazil has a significant high-blend biofuel share (slightly above 20%). In the United States, this share is limited, and accordingly the share used in the model is very small (0.01%). The share of high-blend ethanol in Brazil is estimated by using an equation that considers relative prices (ethanol/gasoline).

Total biofuel use is obtained as the sum of the low and high-blend biofuel use.

The main equations linked to the computation of the use of biofuels as fuels (total fuel use for transport, quantity consumed of biofuels, and the steps to obtain the effective low-blend biofuel share) are presented below.

For the total fuel use (gasoline and diesel), Equation (88) is used.

$$
\begin{aligned}
\log\big(QC^{TRAN}_{r,FossilFuel,t}\big) \\
= \alpha + \beta_1 * \log\left(\frac{CP_{r,FossilFuel,t}}{GDPD_r}\right) + \beta_2 * \log\left(\frac{CP_{r,BF,t}}{GDPD_r}\right) + \beta_3 * \log\left(\frac{GDPI_{r,BF,t}}{POP_r}\right) \\
+ \beta_4 * TRD + \log * (POP) + R
\end{aligned}
\tag{88}
$$

Where:

$QC^{TRAN}_{r,FossilFuel,t} =$	Total fossil fuel (either gasoline or diesel) use for transport (in million litres)
CP =	Consumer price (in local currency/hectolitre)
BF =	Sub index indicating that the measure is for "biofuels" (either ethanol or biodiesel)
GDPI =	Gross domestic product index (2010 = 1)
POP =	Population (in thousands)
TRD =	Trend

The use of biofuels as fuels is then computed by multiplying the total use of gasoline or diesel with the corresponding effective shares. The equation below for low-blend biofuels is an example. However, this procedure applies for the operation of both low- and high-blend biofuels. Note that gasoline or diesel is converted into the corresponding biofuel energy equivalent, since the effective biofuel shares are also estimated in energy equivalent terms.

$$
FL^{LBLD}_{r,BF,t} = QCS^{Eff}_{r,BF,t} * \frac{QC^{TRAN}_{r,FossilFuel,t}}{ERAT_{WLD,BF}}
\tag{89}
$$

Where:

$FL_{r,BF,t}^{LBLD} =$	Total low-blend biofuel use as fuel (in million litres)
BF =	Sub index indicating that the measure is for "biofuels" (either ethanol or biodiesel)
$QCS_{r,BF,t}^{Eff} =$	Effective biofuel share in gasoline or diesel (in energy equivalent terms)
$QC_{r,FossilFuel,t}^{TRAN} =$	Total fossil fuel (either gasoline or diesel) use for transport (in million litres)
$ERAT_{WLD,BF} =$	Energy equivalent of the biofuels with the corresponding fossil fuel substitute (for ethanol: 0.67, for biodiesel: 0.92)

For the computation of the effective low-blend shares for biofuels, the following sequence of equations (Equations (90), (91), (92), (93), and (94)) are applied.

For the effective biofuel share:

$$QCS_{r,BF,t}^{Eff} = max\left(QCS_{r,BF,t}^{OBL..AD}, QCS_{r,BF,t}\right) \tag{90}$$

Where:

$QCS_{r,BF,t}^{Eff} =$	Effective biofuel share in gasoline or diesel (in energy equivalent terms)
BF =	Sub index indicating that the measure is for "biofuels" (either ethanol or biodiesel)
$QCS_{r,BF,t}^{OBL} =$	Adjusted obligatory share (mandate-driven)
$QCS_{r,BF,t} =$	Non-mandate driven share that considers other, rather market-oriented, elements

In the following equation, the obligatory share (mandate-driven) is adjusted to account for the conversion of the total fossil fuel use for transport from Equation (85). In that conversion, the fossil fuel is transformed into the biofuel equivalent required to give the same amount of energy. In practical terms, the adjustment reduces the mandate-driven share. The reduction is larger for ethanol since the energy equivalent factor is smaller than the biodiesel factor (0.67 for ethanol vs 0.92 for biodiesel). The closer the energy equivalent is to 1, the smaller the adjustment.

$$QCS_{r,BF,t}^{OBL..AD} = \frac{ERAT_{WLD,BF} * QCS_{r,BF}^{OBL..VAD}}{\left(1 - \left(1 - ERAT_{WLD,BF}\right) * QCS_{r,BF}^{OBL..VAD}\right)} \tag{91}$$

Where:

$QCS_{r,BF,t}^{OBL..AD} =$	Adjusted obligatory share in energy equivalents
BF =	Sub index indicating that the measure is for "biofuels" (either ethanol or biodiesel)
$ERAT_{WLD,BF} =$	Energy equivalent of the biofuels with the corresponding fossil fuel substitute (for ethanol: 0.67, for biodiesel: 0.92)
$QCS_{r,BF}^{OBL..VAD} =$	Obligatory volume share as stipulated in the mandate

For the non-mandate shares, the following is applied (Equations (88), (89), and (90)).

$$QCS_{r,BF,t} = QCS_{r,BF,t}^{ADD} + QCS_{r,BF,t}^{LBLD} \tag{92}$$

Where:

$QCS_{r,BF,t} =$	Non-mandate driven share that considers other, rather market-oriented, elements
BF =	Sub index indicating that the measure is for "biofuels" (either ethanol or biodiesel)
$QCS_{r,BF,t}^{ADD} =$	The share of biofuel used as additive in fossil fuels
$QCS_{r,BF,t}^{LBLD} =$	The share of biofuel obtained considering infrastructure limits and relative prices (biofuel/fossil fuel)

The $QCS_{r,BF,t}^{LBLD}$ is obtained from the minimum between (i) the share corresponding to the infrastructure limit or "blend wall" minus the share used as additive, and (ii) the share obtained considering relative prices (biofuel/fossil fuel). The infrastructure limit or "blend wall" is a blending boundary set in accordance with the available engine technologies in a country (higher blends require adapted engines). In point (i), the share of biofuels use as additives is subtracted since the blending wall applies to low blend plus additives and the latter are exogenous in the model.

$$QCS_{r,BF,t}^{LBLD} = min\left(QCS_{r,BF,t}^{Limit} - QCS_{r,BF,t}^{ADD}, \left(QCS_{r,BF,t}^{LBLD..EQ}\right)\right) \qquad (93)$$

Where:

$QCS_{r,BF,t}^{LBLD} =$ The share of biofuel obtained considering infrastructure limits and relative prices (biofuel/fossil fuel)

BF =   Sub index indicating that the measure is for "biofuels" (either ethanol or biodiesel)

$QCS_{r,BF,t}^{Limit} =$ The share of biofuel corresponding to the infrastructure limit or "blend wall"

$QCS_{r,BF,t}^{ADD} =$ The share of biofuel used as additive in fossil fuels

$QCS_{r,BF,t}^{LBLD..EQ} =$ The share of biofuel (either ethanol or biodiesel) obtained considering the relative prices (biofuel/fossil fuel)

Finally, the share of biofuels obtained considering relative prices is computed as a fraction of a maximum low blend share with a sigmoid function. This function derives a market driven use of biofuels and evaluates at the maximum low blend share if biofuels become competitive.

$$QCS_{r,BF,t}^{LBLD..EQ} = \frac{QCS_{r,BF,t}^{LBLD..MAX}}{\left[1 + e^{\left(4*(PREM_{BF}^{FossilFuel}-\gamma)*(PR_{BF}-\gamma)\right)}\right]} \qquad (94)$$

Where:

$QCS_{r,BF,t}^{LBLD..EQ} =$ The share of biofuel (either ethanol or biodiesel) obtained considering the relative prices (biofuel/fossil fuel)

$QCS_{r,BF,t}^{LBLD..MAX} =$ Maximum share of biofuels in fuel mixture (also known as "blend wall")

BF =   Sub index indicating that the measure is for "biofuels" (either ethanol or biodiesel)

$PREM_{BF}^{FossilFuel}$ Maximum premium price of the biofuel relative to fossil fuel (either gasoline or diesel) prices

$PR_{BF} =$ Price ration between the biofuel and the corresponding fossil fuel

$\gamma =$ Energy equivalent of the biofuels with the corresponding fossil fuel substitute (for ethanol: 0.67, for biodiesel: 0.92)

4 Land markets

4.1. Introduction

An understanding of land use is essential for shedding light on a range of important policy issues. First, food availability depends on land use outcomes (including land use expansion or contraction) and their interaction with yields (considering intensive and extensive production systems). Second, on-going land use changes, such as conversion of tropical forest to agricultural land, have an impact on climate change (e.g. Harvey and Pilgrim (2011[2])). Third, important policy instruments such as the decoupled payments under the EU Common Agricultural Policy, the Agricultural Risk Coverage of the US Farm Bill, or the biofuel promoting policies implemented around the globe have a significant impact on land use, and thus also on food availability and climate change.

Aglink-Cosimo uses a Positive Mathematical Programming (PMP)-based approach for the modelling of land use. This approach reflects physical land constraints, allows to properly calibrate the response to incentives (price, subsidies, and costs), and maintains a desirable level of simplicity. It also accounts for a country's complete land balance, taking into consideration the competition of arable land with other land uses (pasture lands, set aside, forests, and an aggregate of other land uses), making the analysis of the impact of land use changes possible (e.g. on climate change).

4.2. The approach

4.2.1. Theoretical background

In theory (although not in Aglink-Cosimo), the original PMP approach (Howitt, 1995[3]) proposed adding a quadratic cost function to the explicitly specified elements of the gross margin of a crop definition in a linear programming model. Thus, the farmers' optimisation problem led to:

$$\max \pi(LU_c) = \sum_c \frac{IP_c - ECHA_c}{PCST_c} * LU_c - (\alpha * LU_c + 0.5 * \beta * LU_c^2) \tag{95}$$

Such that:

$$\sum_c LU_c = L \ [SHP_{AGR}]$$
$$LU_c \geq 0 \ [\gamma]$$

Where:

$\pi(LU) =$	Profit obtained from the land use
c =	Sub index indicating that the measure is for the set of agricultural commodities with land use

IP =   Production incentive
PCST =   Production cost index
ECHA   Expected fertiliser costs per ha
LU =   Land use quantity
L =   Total available land that can be allocated to the agricultural commodities with land use
SHP_{AGR} =   Total agricultural area shadow price (land rent)
γ =   Shadow price of the non-negativity restriction

Note that the fraction of the production incentive IP net of fertiliser costs and the production cost index PCST is not equal to an explicit specified gross margin as used in programming models, but it can be used as proxy without losing the properties of the approach. To be applicable to an equilibrium model, the lagrangian dual formulation of first order conditions of this primal model is necessary.

This formulation can be obtained by: (i) including the constraints into the objective function

$$\max \pi(LU_c) = \sum_c \frac{IP_c - ECHA_c}{PCST_c} * LU_c - (\alpha * LU_c + 0.5 * \beta * LU_c^2)$$

$$+ SHP_{AGR} * \left(L - \sum_c LU_c\right) + \gamma * LU_c \tag{96}$$

and then, (ii) taking the first derivatives with respect to all crop allocations, SHP_{AGR} (land rent), and γ (shadow price of the non-negativity restriction):

$$0 = \frac{IP_c - ECHA_c}{PCST_c} - (\alpha + \beta * LU_c) - SHP_{AGR} + \gamma \tag{97}$$

Subject to:

$$\sum_c LU_c = L \; [SHP_{AGR}]$$
$$LU_c \geq 0 \; [\gamma]$$
$$LU_c \gamma_c = 0$$

4.2.2. Practical application

The land use equations in Aglink-Cosimo are based on the above theoretical principles with a few adjustments. The main difference is that the non-negativity constraint is not represented as shown in Equation (97), but with a "max" condition. The second difference is that it is not the land use that enters the system, but the land use share.

In practical terms, the complete land use system in Aglink-Cosimo is realised as presented in the following steps.

The harvested area (AH) of a crop is equal to the land use variable (LU) (which contains the first harvest on a certain land area) and the harvested areas that potentially follow within one year (AH2), e.g. the production of soybean and maize within one year on the same land. To control for crops that need more than one season to grow, the land use variable is divided the maximum of 1 and a crop production index (CRPI). The CRPI is greater than 1 if the crop needs more than one season to grow, meaning that to harvest one ha of that crop, it needs more than one hectar of land; e.g. in some regions the maturing of sugar cane exceeds twelve months.

$$AH_{r,c,t} = \frac{LU_{r,c,t}}{\max(1, CRPI_{r,c,t})} + AH2_{r,c,t} \tag{98}$$

The AH2 variable is a simple double log equation with an own price effect in countries where multi-cropping is important.

$$\log(AH2_{r,c,t}) = \alpha + \beta * \log\left(\frac{IP_{r,c,t} - ECHA_{r,c,t}}{PCST_{r,c,t}}\right) + \log(R) \tag{99}$$

Where:

AH2 =	Areas harvested not as first crop (harvested areas that potentially follow within one year) (in ha)	
IP =	Production incentive (prices and subsidies) (in local currency/t)	
ECHA	Expected fertiliser costs per ha	
PCST =	Production cost index	

The land use of specific crops is equal to the land use share ($LU_{r,c,t}^{shr}$), multiplied by the total agricultural area ($LU_{r,AGR,t}$). The total agricultural area is divided by 100 to set it in the corresponding units.

$$LU_{r,c,t} = LU_{r,c,t}^{shr} * \frac{LU_{r,AGR,t}}{100} \tag{100}$$

The land use share variable ($LU_{r,c,t}^{shr}$) is equal to the maximum between the land use share equation ($LU_{r,c,t}^{shr..eq}$) and an exogenous minimum land use ($LU_{r,c,t}^{min}$). This layer is necessary to render the land use share always positive, since as mentioned before, the non-negativity constraint of Equation (95) has been abandoned:

$$LU_{r,c,t}^{shr} = \max\left(\frac{LU_{r,c,t}^{min} * 100}{LU_{AGR}}, LU_{r,c,t}^{shr..eq}\right) \tag{101}$$

The land use share equation ($LU_{r,c,t}^{shr..eq}$) is the first equation in the Equation (97) but solved for the land use share. Note that the coefficients in that equation are set to the following: δ=α/β and γ =1/β in the land use share equation below.

$$LU_{r,c,t}^{shr..eq} = \delta + \gamma\left(\frac{IP_{r,c,t} - ECHA_{r,c,t}}{PCST_{r,c,t}} - SHP_{r,AGR,t}\right) \tag{102}$$

Two adding up restrictions guarantee that the total land balances hold. The first one defines total land ($LU_{r,LND,t}$) as the sum over total agricultural land ($LU_{r,AGR,t}$), forest ($LU_{r,FST,t}$) and other land ($LU_{r,OLN,t}$). The second one defines the total agricultural land as sum over all crop land uses, an aggregate of pasture and fodder ($LU_{r,PAF,t}$) and set aside land ($LU_{r,SET,t}$). Note that the set of crops also considers a rest category (Agricultural Crops Other = AGO), to account for the crops not considered explicitly in Aglink-Cosimo.

$$LU_{r,LND,t} = LU_{r,AGR,t} + LU_{r,FST,t} + LU_{r,OLN,t} \tag{103}$$

$$LU_{r,AGR,t} = \sum_{c(crops)} LU_{r,c(crops),t} + LU_{r,PAF,t} + LU_{r,SET,t} \tag{104}$$

Land allocated to pasture and fodder follows the traditional double log approach including a lagged dependant variable on the right-hand side to acknowledge less flexibility between crops and the fodder pasture aggregate.

$$\log(LU_{r,PAF,t}) = \alpha + \beta_1 * \log\left(\frac{IP_{r,PAF,t} - ECHA_{r,PAF,t}}{PCST_{r,PAF,t}} * \frac{1}{SHP_{r,AGR,t}}\right) + \beta_2 * \log(LU_{r,PAF,t-1}) \tag{105}$$

The land allocated to set aside is treated exogenously and its projection is based on historical trends and expert judgement.

The land allocated to forest also applies the double log approach.

$$\log\left(\frac{LU_{r,FST,t}}{LU_{r,FST,t}^{BAS}}\right) = \alpha + \beta_1 * \log\left(\frac{SHP_{r,AGR,t}}{\left(1 + e^{\left(-10*(SHP_{r,AGR,t}-5)\right)}\right)} + 1\right) + \beta_2 * \log(TRD) + R \tag{106}$$

Where:

$LU_{r,FST,t}$ = Total land use for forest (in kha)
$LU_{r,FST,t}^{BAS}$ = Total land use for forest in the base year (in kha)
$SHP_{r,AGR,t}$ = Total agricultural area shadow price (land rent)
TRD = Trend

Like set aside, the land allocated to the aggregate "other land" ($LU_{r,OLN,t}$) is treated exogenously and its projection is based historical data and expert judgement.

For crops, the production incentive considers the lagged expected revenue per hectare (RH) and area payments (effective support payments – EPA) (Equation (107)). For pasture and fodder areas, the incentive is an estimate of the revenues from ruminant production (BV=beef, MK=Milk, SH=sheep meat) that considers producer prices, effective support payments (EPQ) the quantities produced in the base year ($QP_{r,MK,t}^{BAS}$, $QP_{r,BV,t}^{BAS}$, $QP_{r,SH,t}^{BAS}$, $LU_{r,PAF,t}^{BAS}$), and the effective support payment for pasture and fodder lands ($EPA_{r,PAF,t}$) (Equation (108)).

$$IP_{r,c(crops),t} = RH_{r,c,t-1} + EPA_{r,c,t} \tag{107}$$

$$IP_{r,PAF,t} = \frac{\begin{bmatrix} \left(0.5PP_{r,MK,t-1} + 0.3PP_{r,MK,t-2} + 0.2PP_{r,MK,t-3} + EPY_{r,MK,t} * YLD_{r,MK,t} + EPQ_{r,MK,t}\right) \\ * QP_{r,MK,t}^{BAS} \\ + \left(0.5PP_{r,BV,t-1} + 0.3PP_{r,BV,t-2} + 0.2PP_{r,BV,t-3} + EPQ_{r,BV,t}\right) * QP_{r,BV,t}^{BAS} \\ + \left(0.5PP_{r,SH,t-1} + 0.3PP_{r,SH,t-2} + 0.2PP_{r,SH,t-3} + EPQ_{r,SH,t}\right) * QP_{r,SH,t}^{BAS} \\ + 1 \end{bmatrix}}{LU_{r,PAF,t}^{BAS}}$$
$$+ EPA_{r,PAF,t} \tag{108}$$

The expected fertiliser costs are defined as

$$\begin{aligned} ECHA_{r,c,t} = {}& 0.5\big(QCHA..c_{r,N,t-1}CP_{r,N,t-1} + QCHA..c_{r,P,t-1}CP_{r,P,t-1} + QCHA..c_{r,K,t-1}CP_{r,K,t-1}\big) \\ & + 0.3\big(QCHA..c_{r,N,t-2}CP_{r,N,t-2} + QCHA..c_{r,P,t-2}CP_{r,P,t-2} \\ & + QCHA..c_{r,K,t-2}CP_{r,K,t-2}\big) \\ & + 0.2\big(QCHA..c_{r,N,t-3}CP_{r,N,t-3} + QCHA..c_{r,P,t-3}CP_{r,P,t-3} \\ & + QCHA..c_{r,K,t-3}CP_{r,K,t-3}\big) \end{aligned} \tag{109}$$

Finally, the production cost index PCST, for crops, is a weighted average of the cost of production indices (CPCI) in two periods of time (current (t) and the past (t-1)). For the pasture and fodder aggregate, the PCST is a function of past CPCIs for meat and dairy (MD), and past ruminant (RU) feed expenditure indices (FECIs).

$$PCST_{r,c(crops),t} = 0.5 * CPCI_{r,c(crops),t} + 0.5 * CPCI_{r,c(crops),(t-1)} \tag{110}$$

$$\log(PCST_{r,PAF,t}) = \beta_1 * \log(CPCI_{r,MD,(t-1)} + CPCI_{r,MD,(t-2)} + CPCI_{r,MD,(t-3)}) + \beta_2 \\ * \log(FECI_{r,RU,(t-1)} + FECI_{r,RU,(t-2)} + FECI_{r,RU,(t-3)}) \tag{111}$$

Note the IP and the PCST of the non-modelled crop areas of the 'other agricultural crops – AGO' – are computed using different equations than above (Equations (110) and (111)) since the corresponding variables (RH, EPA, and CPCI) are not available for the AGO category. The IP and PCST variables for this category are estimated as functions of past land rents of the total agricultural area (SHP_AGR) and of the past PCSTs for wheat, correspondingly.

5 Post-model indicators

5.1. Introduction

The *OECD-FAO Agriculture Outlook* includes a wide range of indicators that help to monitor and assess current and projected outcomes for agriculture and fish commodity markets. These indicators map commodity projections to well-recognized measures of sectoral performance, as well as to those that are also used in wider contexts such as the Sustainable Development Goals (SDGs).

Indicators currently produced are of two basic types, the primary and the secondary indicators. The "primary indicators" use variables that are fully internal to the projections database. A good example are real commodity prices, for which indicators are computed based on the generated internal prices divided by the internal GDP deflator. The "secondary indicators" draw from databases that are external to the *Outlook* process but may be projected consistently and reliably based on these databases. A good example of such an indicator is calorie availability per capita, which draws from FAO's Food Balance Sheet estimates, and extrapolates these using the projections of per-capita food use that are included in the *Outlook*. In most cases, extrapolation is straightforward, but can be more complex where these indicators are not completely within the commodity scope of the *Outlook*. In case of secondary indicators, the mathematical form is not represented here as the focus is on the narrative.

The primary and secondary indicators are discussed separately, but aggregation – which is another element of the post-model calculations – is discussed first.

5.2. Aggregation

Many variables that exist for Aglink-Cosimo country modules can be aggregated into regional clusters and commodity aggregates. Commodity aggregation follows the principal hierarchy shown in Figure 1.

Figure 1. Standard product aggregates in Aglink-Cosimo
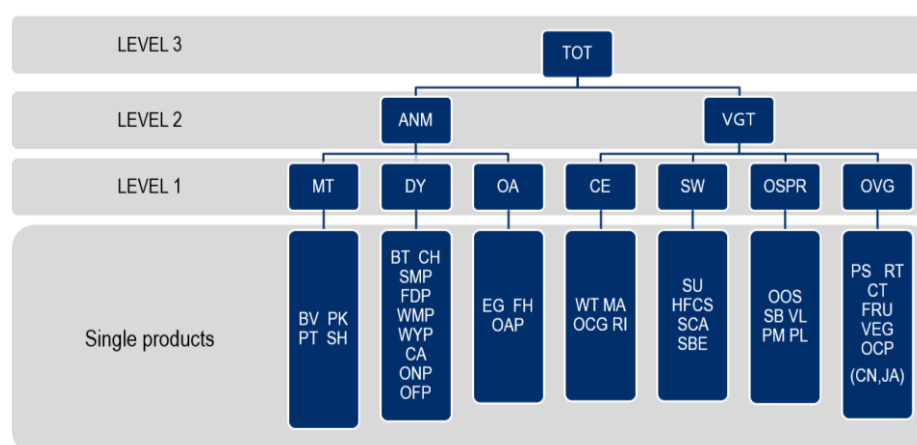
Regional clusters are based either on geographical similarities or on economic characteristics. Table 1 gives an overview on the standard regional aggregates in Aglink-Cosimo

Table 1. Standard regional Aggregates in Aglink-Cosimo

Geographical aggregates	Economic aggregates
North America	Low-income countries
Europe	Lower-middle income countries
Latin America & the Caribbean	Upper-middle income countries
Africa	High income countries
Asia Pacific	OECD countries
Oceania	G20 countries
Near East and North Africa	G20 + OECD countries
Sub-Saharan Africa	BRICs
South America	Developed countries
South-East Asia	Developing countries
Asia Without China India	Least developed countries

Regional and commodity aggregations are often simple sums as for quantity variables like production, consumption, etc. In other cases, they are weighted averages. Both aggregation types are not only applied to core model variables, but to the indicators discussed below. A few exceptions to the commodity hierarchy exist for certain indicators and are mentioned in the respective sections below.

5.3. Primary indicators

Primary indicators provide the simplest and most immediate means to assess the consistency of the *Outlook* with respect to its internal economic logic. The main primary indicators are listed below, which also gives a brief description and the basic formulas of each.

Indicator	Unit	Formula
Per capita food consumption	Kg/cap/year	$FO..PC_{r,c,t} = \dfrac{FO_{r,c,t}}{POP_{r,t}} * 100 * CW_c$ With CW=1 except BV(0.7), PK(0.78), PT and SH (0.88)
Moving three-year average of per capita food consumption	Kg/cap/year (Calendar year)	$FO..APC_{r,c,t} = \big[w_c^1 * FO..PC_{r,c,t} + w_c^2 * FO..PC_{r,c,t-1} + w_c^3 * FO..PC_{r,c,t-2}\big]/3$ With w being commodity specific weights to convert marketing years to calendar years.
Market balance positions in calorie equivalents	Bln calories	$MbalPos..AES..TOT_{r,c,t} = MbalPos_{r,c,t} * calcont_c/1000$ With MbalPos containing QP, QC, OU, FE ,FO, SWG, BF, CR, EX, IM and calcont being the global average calorie content per commodity on kcal/kg
Market balance positions in protein equivalents	1000t	$MbalPos..AQS..PROT_{r,c,t} = MbalPos_{r,c,t} * protcont_c/100$ With MbalPos containing QP, QC, OU, FE ,FO, SWG, BF, CR, EX, IM and protcont being the percentage of protein in one unit of commodity weight
Market balance positions in fat equivalents	1000t	$MbalPos..AQS..FAT_{r,c,t} = MbalPos_{r,c,t} * fatcont_c/100$ With MbalPos containing QP, QC, OU, FE ,FO, SWG, BF, CR, EX, IM and fatcont being the percentage of fat in one unit of commodity weight

Indicator	Unit	Formula
Dairy products in milk solid equivalents	1000t	$$MbalPos..MSD_{r,c(dairy),t} = MbalPos_{r,c(dairy),t} * [fat_{c(dairy)} + NFS_{c(dairy)}]$$ With MbalPos containing QP, QC, OU, FE ,FO, EX, IM and fat being the share of fat and NFS the share of non-fat solids in one unit of commodity weight.
Food expenditures (for Aglink-Cosimo commodities)	Mn USD (real)	$$FO..EXP..USD_{r,c,t} = \frac{FO_{r,c,t} * CP_{r,c,t}}{XR_{r,t} * GDPD_{r,t}} / 1000$$
Food expenditures per capita (for Aglink-Cosimo commodities)	USD (real)	$$FO..EXP..USD..PC_{r,c,t} = \frac{FO..EXP..USD_{r,c,t} * 1000}{POP_{r,t}}$$
Food expenditure share in GDP (for Aglink-Cosimo commodities)	%	$$FOEXP..GDPUS_{r,c,t} = \frac{FO..EXP..USD..PC_{r,c,t}}{GDPUS..PC_{r,t}} * 100$$
Meat output per livestock unit	t/head	$$YLD_{r,c(meat),t} = \frac{QP_{r,c(meat),t}}{LI_{r,c(meat),t}}$$
Crop aggregate yields	t/ha	$$YLD_{r,c(meat),t} = \frac{QP_{r,c(cAgg),t}}{AH_{r,c(cAgg),t}}$$
Stock to use ratio	%	$$ST..QC_{r,c,t} = \frac{ST_{r,c,t}}{QC_{r,c,t}} * 100$$
Stock to disappearance ratio	%	$$ST..QCEX_{r,c,t} = \frac{ST_{r,c,t}}{QC_{r,c,t} + EX_{r,c,t}} * 100$$
Share of single feed items in total feed protein	%	$$FE..SHR..APF_{r,c,t} = \frac{FE..AQS..PROT_{r,c,t}}{FE..AQS..PROT_{r,APF,t}} * 100$$
Energy and Protein losses in animal production Partial indicator as it does only include bulk feed. Difference between energy in total feed used and energy	Bln calories for energy 1000t for protein	$$FO..EMT_{r,t} = FE..AES..TOT_{r,t} - QP..AES..TOT_{r,ANM,t} + QP..AES..TOT_{r,FHC,t}$$ The formula for protein follows the same principle
Value of trade at world reference prices (for Aglink-Cosimo commodities)	USD 1000	$$EX..VAL_{r,c,t} = EX_{r,c,t} * XP_{c,t}$$ $$IM..VAL_{r,c,t} = IM_{r,c,t} * XP_{c,t}$$ $$NT..VAL_{r,c,t} = NT_{r,c,t} * XP_{c,t}$$
Value of trade at constant world reference prices (2014-2016) (for Aglink-Cosimo commodities)	%	$$EX..CVAL_{r,c,t} = EX_{r,c,t} * [XP_{c,2014} + XP_{c,2015} + XP_{c,2016}]/3$$ $$IM..CVAL_{r,c,t} = IM_{r,c,t} * [XP_{c,2014} + XP_{c,2015} + XP_{c,2016}]/3$$ $$NT..CVAL_{r,c,t} = NT_{r,c,t} * [XP_{c,2014} + XP_{c,2015} + XP_{c,2016}]/3$$
Share of imported protein/calories in domestic use	%	$$IM..QC..PROT_{r,c,t} = \frac{IM..AQS..PROT_{r,c,t}}{QC..AQS..PROT_{r,c,t}} * 100$$ $$IM..QC..ENE_{r,c,t} = \frac{IM..AES..TOT_{r,c,t}}{QC..AES..TOT_{r,c,t}} * 100$$
Share of exported protein/calories in domestic production	%	$$EX..QC..PROT_{r,c,t} = \frac{EX..AQS..PROT_{r,c,t}}{QP..AQS..PROT_{r,c,t}} * 100$$ $$EX..QC..ENE_{r,c,t} = \frac{EX..AES..TOT_{r,c,t}}{QP..AES..TOT_{r,c,t}} * 100$$

5.4. Secondary indicators

The rich and detailed coverage of agricultural and fish markets within the *Outlook* offers the possibility to generate indicators that can be linked with high profile political agendas and goals (e.g. the Sustainable Development Goals or alternative strategic goals formulated by the OECD and/or FAO). The main secondary indicators computed based on the *Outlook* projections are:

- Food balance sheets – availability of calories, protein and fat
- Greenhouse gas emissions
- Net value of agriculture and fish production
- FAO's food price index

These indicators are discussed below, with particular attention to the data sources and the formulae or approaches used. A common procedure for all secondary indicators is to first aggregate the original historical data bases so that they match the Aglink-Cosimo definitions and extend those series by a suitable variable from the Aglink-Cosimo projections.

5.4.1. Food balance sheets: Availability of calories, protein, and fat

Overview

FAO produces food balance sheets that provide detailed estimates of commodity supply including calorie, protein and fat availability per person per day. These estimates are the foundation for the further calculations used by FAO to measure the number of people who are undernourished. These indicators are also used to measure dietary differences in different countries and how these change over time.

Data sources

Data for these indicators are taken from bulk downloads from FAOSTAT, in the Food Balance domain. FAO recently updated its primary food supply estimates for crops, and livestock/fish. The methodology changed and data have been revised from 2014-2018, with implications for continuity of these indicators over time. The coverage and definitions of commodities included can be found in historical data from the older dataset, which have been matched/bridged as closely possible with the new dataset, to assure a continuous coverage of data. Three-year moving averages of these data series have been used.

Projection method

The three variables – calorie, protein and fat availability (FO..DES..TOT, FO..DFS..PROT, FO..DFS..FAT) per capita – are projected using the annual year-on-year changes of the three-year average food per capita food consumption described above (FO..APC). Commodities not covered in the *Outlook* database (fruits, vegetables, other animal and other vegetal products) are extended using an elasticity on total GDP.

5.4.2. Greenhouse gas emissions

Overview

Climate change is closely linked with the production of greenhouse gases (GHG). As estimated by FAO, agriculture's share of direct GHG emissions is 22% (2017) and remains an important component due to the growing livestock and crop production. The *Outlook* projections provide the opportunity of linking these to GHG outcomes and to evaluate the implications of, for example, production growth as diets change (e.g. the projected increase in the demand for livestock products), or of land use changes (e.g. the projected increase in land use devoted to crops).

Data sources

FAO's Emissions – Agriculture and land use databases provide a highly detailed and rich source of data on the complete range of emissions and their sources (FAOSTAT). These databases include aggregations on a carbon dioxide basis from the various types and sources, thus enabling a simplified and useful means to monitor GHG emissions. The focus of the indicators at this point are the CO2 equivalence of the following categories:[3]

- Burning of biomass
- Burning of crop residues.
- Burning of savannahs
- Crop residues.
- Enteric fermentation.
- Net forest emissions
- Manure applied to soils
- Manure left on pastures
- Manure management
- Organic soils
- Cultivation of organic soils
- Rice cultivation
- Application of synthetic fertilisers

Projection method

The projection of the CO2 equivalence indicators follows the pattern of other secondary indicators: linking the indicator to the appropriate variables from the *Outlook* and to change them accordingly as the projected variables change. The detail varies considerably but the formulae follow the general pattern by type:

- *Enteric fermentation, manure applied to soils, manure left on pastures and manure management:* These emissions inventories exist for animal production systems. Assuming that emissions per animal unit stay at their last available level, these series are extended with the livestock inventory of each product in Aglink-Cosimo. For eggs, where the livestock units are not included in the model, production quantities are used as extension variable.

- *Application of synthetic fertilisers:* FAOSTAT only features total fertilizer emissions per country that are not allocated to single crop areas. Using data from the International Fertilizer Association, crop specific synthetic fertilizer application quantities have been estimated to generate a historical database of emissions per crop activity. This database is then extended using harvested areas from Aglink-Cosimo

- *Rice cultivation:* Emissions from rice cultivation are extended by the harvested areas of rice.

- *Burning of crop residues, crop residues:* This position exists for several crop activities. The series are extended in proportion to the harvested area of each crop in Aglink-Cosimo.

- *Burning of biomass, burning of savannah, organic soils and cultivation of organic soils:* As there is no corresponding variable in Aglink-Cosimo these positions are kept constant on their last available observation.

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[3] These categories refer to the definition in FAOSTAT before 2021, when several names and the allocation of some to land use or agriculture changed.

- *Net forest emissions:* These emissions are closely related to the annual change in carbon stock in living biomass (trees). A historical 'yield' of carbon stock per total forest area is calculated and kept on trend for the projections. This yield is then multiplied with the forest land use variable from Aglink-Cosimo to obtain carbon stock projections. Net emissions from forest are then calculated using IPCC guidelines to convert carbon mass to carbon dioxide.

Each of the components are added linearly for all agriculture (AGR), and for all land use (LLCF), including forestry, to provide the aggregate production of GHG emissions on a CO_2 equivalent basis. Both, AGR and LLCF emissions are then aggregated to the total AFOLU emissions (AFOL)

5.4.3. Net value of agriculture and fish production

Overview

Measuring aggregate economic activity traditionally uses a real "net-value added" approach, such as that provided by the gross domestic product measures of the system of national accounts. The GDP measure is a final demand measure that deducts all intermediate input costs, valued at constant price weights to derive an estimate of the real returns to labour and capital. FAO produces a more modest estimate of the net value added of agricultural production, from which the costs that are internal to the national agricultural sector are deducted. Internal costs considered are those for seed and feed. This measure is a practical one for summarizing the aggregate movement in the "volume" of net production and integrates well with the projections of the *OECD-FAO Agricultural Outlook*.

Data sources

The main source of the data is the value of production dataset found in FAOSTAT. The database contains annual data on a calendar year basis. The bulk download contains various estimates of the value of production in different currency units, and at constant 2014-16 reference prices. The element code used to consistently measure values across countries is code 152 "international dollars". Unfortunately, the code is not currently available for several commodities, specifically the individual crop and livestock commodities. However, it is available at the national aggregate level, as well as at the total crop and livestock levels. At present, where international dollar estimates are missing, USD estimates (code 58) are used.

The value of production dataset currently does not include estimates for the "net-value" of production. Nor does it have estimates for the value of seed or feed. To estimate these, quantity data must be obtained from the crops supply/utilization data in the Food Balance Sheets, which contain estimates only for 2014-18, and the estimate for feed does not include DDG. The data also do not include values for gross indigenous production. Hence data from the trade in live animals database must be used, along with carcass weight assumptions taken from the FAOSTAT livestock products production data.

Projection method

The projection equations used to extrapolate the gross values of production, the values of seed production and feed use are listed below. These equations follow the approach used to project external indicators, assuming that the growth in main projection variables is applied to the detail of the indicator. One complication is that the original database is on a calendar year basis, while many of the projection data – such as certain crop production, seed use, and feed use – are on a crop year basis that may vary from feed to feed. No adjustment has yet been made for this issue.

- *Gross value (GVA) by commodity:* As this measure is in constant prices, production quantities of Aglink-Cosimo are used to extrapolate these series which exist per commodity. Categories with no matching Aglink-Cosimo variable are trend extrapolated.

- *Gross value of crop seed by product:* Those are extrapolated using the harvested area of each crop.
- *Gross value of feed:* Feed values are extrapolated with Average Protein Feed variable (APF_FE)
- *Net value crop and livestock production:* The aggregate gross value of crop production is then calculated as the sum of all crops of the GVA and then the sum of all crops of the seed values is subtracted. Similarly, to obtain the Net Value of livestock production is the sum over all animal products of their Gross values minus their feed values.

This indicator is one example where the commodity aggregation differs from the standard. The ANM (animal) aggregate does here not include fish production. Crop and Animal net values are added up to total agriculture (AGR) and the grand total (TOT) is then Agriculture + Fish.

5.4.4. FAO's food price index

Overview

The FAO Food Price Index FAOFPI, has become a high-profile indicator of monthly movements in internationally traded food commodities. Published monthly, the Laspeyres price indicator combines over 100 price quotes into a composite measure of price changes. The index was revised in 2020, with updates made to the base period used to calculate price weights and to certain series used to derive its component.

Data sources

The FAOFPI is produced monthly, and monthly price index data are provided online for various commodities on the Markets and Trade Division website. Price weights for each commodity are also published.

Projection method

Reference prices used in the *OECD-FAO Agricultural Outlook* move in very similar directions as the key commodity prices used in the formula of the FAOFPI. Consequently, the projection method is to extend the individual price components of the FAOFPI using the world price developments of the corresponding commodities, and weight those indexes with the same trade weights as used in the original calculation. As the *Outlook* reference prices for wheat, maize, rice, other coarse grain, vegetable oils, and meals are annual marketing year estimates they cannot track the effect of monthly movements of the original estimates, wherefore only the annual averages can be reported.

6 Outlook process and partial stochastic application

6.1. Producing the *OECD-FAO Agricultural Outlook*

The projections presented and analysed in the *OECD-FAO Agricultural Outlook* (e.g. OECD-FAO (2021[4]), are the result of a process that brings together information from many sources. The projections rely on input from country and commodity experts, and from the OECD-FAO Aglink-Cosimo model of global agricultural markets. Aglink-Cosimo is also used to ensure the consistency of baseline projections. A large amount of expert judgement, however, is applied at various stages of the *Outlook* process. The *Agricultural Outlook* presents a unified assessment judged by the OECD and FAO to be plausible given the underlying assumptions and the information available at the time of writing.

6.1.1. The starting point: Creation of an initial baseline

The data series for the historic values are drawn from OECD and FAO databases. For the most part, information in these databases has been taken from national statistical sources. Starting values for the likely future development of agricultural markets are developed separately by OECD for its member countries and some non-member countries, and by FAO for all remaining countries.

On the OECD side, an annual questionnaire is circulated in November to national administrations. Through these questionnaires, the OECD obtains information on how countries expect their agricultural sector to develop for the various commodities covered in the *Outlook*, as well as on the evolution of agricultural policies.

On the FAO side, the starting projections for the country modules are developed through model-based projections and consultations with FAO commodity specialists.

External sources, such as the International Monetary Fund (IMF), the World Bank and the United Nations (UN), are also used to complete the view of the main economic forces determining market developments (Box 2).

This part of the process seeks to create a first insight into possible market developments and at establishing the key assumptions that condition the *Outlook*. The main economic and policy assumptions are summarised in the overview chapter and in specific commodity tables. The sources for the assumptions are discussed in more detail further below.

As a next step, the OECD-FAO Aglink-Cosimo modelling framework is used to facilitate a consistent integration of the initial data and to derive an initial baseline of global market projections. The modelling framework ensures that at a global level, projected levels of consumption match with projected levels of production for the different commodities. The model is discussed in Section 6.3.

In addition to quantities produced, consumed and traded, the baseline also includes projections for nominal prices (in local currency units) for the commodities concerned.4

The initial baseline results are then reviewed:

- For countries under the OECD's responsibility, the initial baseline results are compared with the questionnaire replies. Any issues are discussed in bilateral exchanges with country experts.
- For country and regional modules developed by the FAO, initial baseline results are reviewed by a wider circle of in-house and international experts.

6.1.2. Final baseline

At this stage, the global projection picture starts to emerge, and refinements are made according to a consensus view of both Secretariats and external advisors. Based on these discussions and updated information, a second baseline is produced. The information generated is used to prepare market assessments for cereals, oilseeds, sugar, meats, dairy products, fish, biofuels and cotton over the course of the *Outlook* period.

These results are discussed at the annual meetings of the Group on Commodity Markets of the OECD Committee for Agriculture, which brings together experts from national administrations of OECD countries as well as experts from commodity organisations. Following comments by this group, and data revisions, the baseline projections are finalised.

The *Outlook* process implies that the baseline projections presented in this report are a combination of projections and expert knowledge. The use of a formal modelling framework reconciles inconsistencies between individual country projections and forms a global equilibrium for all commodity markets. The review process ensures that judgement of country experts is brought to bear on the projections and related analyses. However, the final responsibility for the projections and their interpretation rests with the OECD and FAO Secretariats.

The revised projections form the basis for the writing of the *Agricultural Outlook*, which is discussed by the Senior Management Committee of FAO's Department of Economic and Social Development and the OECD's Working Party on Agricultural Policies and Markets of the Committee for Agriculture in May, prior to publication. In addition, the *Outlook* will be used as a basis for analyses presented to the FAO's Committee on Commodity Problems and its various Intergovernmental Commodity Groups.

Box 2. Sources and assumptions for the macroeconomic projections

Population estimates from the United Nations Population Prospects database provide the population data used for all countries and regional aggregates. For the projection period, the medium variant set of estimates is selected from the four alternative projection variants (low, medium, high, and constant fertility). The UN Population Prospects database was chosen because it represents a benchmark source which includes data and estimates for all countries reflected in the model. For reasons of consistency, the same source is used for both the historical population estimates and the projection data.

The other macroeconomic series used in Aglink-Cosimo are real GDP, the GDP deflator, the private consumption expenditure (PCE) deflator and exchange rates expressed as the local currency value of one USD. Historical data for these series in OECD countries as well as Brazil, Argentina, China, and

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4 Trade data for regions, e.g. the European Union or regional aggregates of developing countries, refer only to extra-regional trade. This approach results in a smaller overall trade figure than cumulated national statistics. For further details on particular series, enquiries should be directed to the OECD and FAO.

the Russian Federation are consistent with those published in the latest *OECD Economic Outlook* (www.oecd.org/eco/economicoutlook.htm). For other economies, historical macroeconomic data were obtained from the *World Economic Outlook* database of the International Monetary Fund (IMF). Assumptions for future years are based on the recent medium-term macroeconomic projections of the OECD Economics Department, projections of the *OECD Economic Outlook* and projections of the IMF.

The model uses indices for real GDP development, consumer prices (PCE deflator) and producer prices (GDP deflator) which are constructed with the base year 2005 normalized to 1. When no information is available, it is assumed that real exchange rates remain constant, which implies that a country with higher (lower) inflation relative to the United States (as measured by the US GDP deflator) will have a depreciating (appreciating) currency and therefore an increasing (decreasing) exchange rate over the projection period, since the exchange rate is measured as the local currency value of USD 1. The calculation of the nominal exchange rate uses the percentage growth of the ratio "country-GDP deflator/US GDP deflator".

The oil price (Brent crude oil price in US dollars per barrel) used to generate the *Outlook* is taken for the historic years from the short-term update of the *OECD Economic Outlook* in December. The reference oil price used in the projections is assumed to follow the growth rate of the World Bank average oil price.

6.2. Partial stochastic use of Aglink-Cosimo

The partial stochastic analysis highlights how alternative scenarios diverge from the baseline by treating several variables stochastically. The selection of those variables aims at identifying the major sources of uncertainty for agricultural markets. In particular, country specific macroeconomic variables, the crude oil price, and country- and product-specific yields are treated as uncertain within this partial stochastic framework. Apart from the international oil price, four macroeconomic variables are considered in all countries: the consumer price index (CPI), the gross domestic product index (GDPI), the gross domestic product deflator (GDPD) and the US-Dollar exchange rate (XR). The yield variables considered contain crop and milk yields in all model regions.

The approach applied to determine the stochastic draws of these variables is based on a simple process which captures the historical variance of each single variable. The three main steps of the partial stochastic process are briefly explained below.

The quantification of the past variability around the trend for each macroeconomic and yield variable separately.

Step 1 is to define the historical trend of stochastic variables. Often a linear trend does not represent adequately observed dynamics. Consequently, a non-linear trend is estimated by applying a Hodrick-Prescott filter, which seeks to separate short-term fluctuations from long-term movements.[5] The filter is applied to the yield time series directly and to year-on-year changes for macro variables.

Step 2 involves generating 1 000 sets of possible values for the stochastic variables. For each year of the 2021-2030 projection period, one year of the historical period 1995-2020 is drawn. The relative deviation between the actual variable value of that year and the respective trend value estimated in Step 1 is then applied to the value of the variable in the actual projection year. All variables thereby receive the value of the same historical year. The process, however, handles macro variables separated from yields, as neither are strongly correlated.

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[5] The filter was popularised in the field of economics in the 1990s by Hodrick and Prescott (1997[5]).

Step 3 involves running the Aglink-Cosimo model for each of the 1 000 alternative "uncertainty" scenarios generated in Step 2. When both macroeconomic and yield uncertainty were included, this procedure yielded 98% successful simulations. The model does not usually solve all stochastic simulations as the complex system of equations and policies may lead to solutions that are not feasible when exposed to extreme shocks in one or several stochastic variables. However, the success rate of the 1 000 model runs is usually above 95%.

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Annex A. World market clearing prices in Aglink-Cosimo

Cereals	
Wheat	No.2 hard red winter wheat, ordinary protein, United States f.o.b. Gulf Ports (June/May), less EEP payments where applicable
Maize	No.2 yellow corn, United States f.o.b. Gulf Ports (September/August)
Other coarse grains	Feed barley, Europe, FOB Rouen (July/June)
Rice	Milled, 100%, grade b, Nominal Price Quote, NPQ, f.o.b. Bangkok (January/December)
Oilseeds	
Soybeans	Soybean, U.S., CIF Rotterdam (October/September)
Other oilseeds	Rapeseed, Europe, CIF Hamburg (October/September)
Protein meals	Weighted average price of soybean, rapeseed and sunflower meal, European port (October/September)
Vegetable oils	Weighted average price of soybean, rapeseed, sunflower and palm oil, European port (October/September)
Fibre crops	
Cotton	Cotlook A index, Middling 1 3/32", c.f.r. far Eastern ports (August/July)
Other crops and feed products	
Dried distillers grains	Wholesale price, Central Illinois(September/August)
Dried beet pulp	Beet pulp price, United States
Cereal brans	Wheat middlings in Buffalo, NY
Meat and bone meal	Ruminant meat and bone meal, Central United States (R-T)
Corn gluten feed	Corn gluten feed, 21% protein, Midwest
Roots and tubers	Thailand, Bangkok, Cassava (flour), Wholesale
Pulses	Canadian field pea producer price (August/July)
Sweeteners	
Raw sugar	Raw sugar world price, ICE contract No11 nearby (October/September)
White sugar	Refined sugar price, Euronext,Liffe, Contract No. 407 London, Europe, (October/September)
High fructose corn syrup	United States wholesale list price HFCS-55, October/September
Molasses	Unit import price, Europe, October/September
Meats	
Beef and veal, Pacific	US Choice steers, 1100-1300 lb lw, Nebraska - lw to dw conversion factor 0.63
Beef and veal, Atlantic	Brazil: frozen beef, export unit value, product weight
Pig meat, Pacific	US Barrows and gilts, No1-3, 230-250 lb lw, Iowa/South Minnesota - lw to dw conversion factor 0.74
Pig meat, Atlantic	Brazil: frozen pig meat, export unit value, product weight
Poultry	Brazil: export unit value for chicken (FOB), product weight
Sheep meat	New Zealand lamb schedule price, all grade average
Fish and seafood	
Fish	World unit value of trade (sum of exports and imports)
Fish from aquaculture	World unit value of aquaculture fisheries production (live weight basis)
Fish from capture	FAO estimated value of world ex vessel value of capture fisheries production excluding for reduction
Fish meal	Fish meal, 64-65% protein, Hamburg, Germany
Fish oil	Fish oil any origin, N.W. Europe
Dairy products	

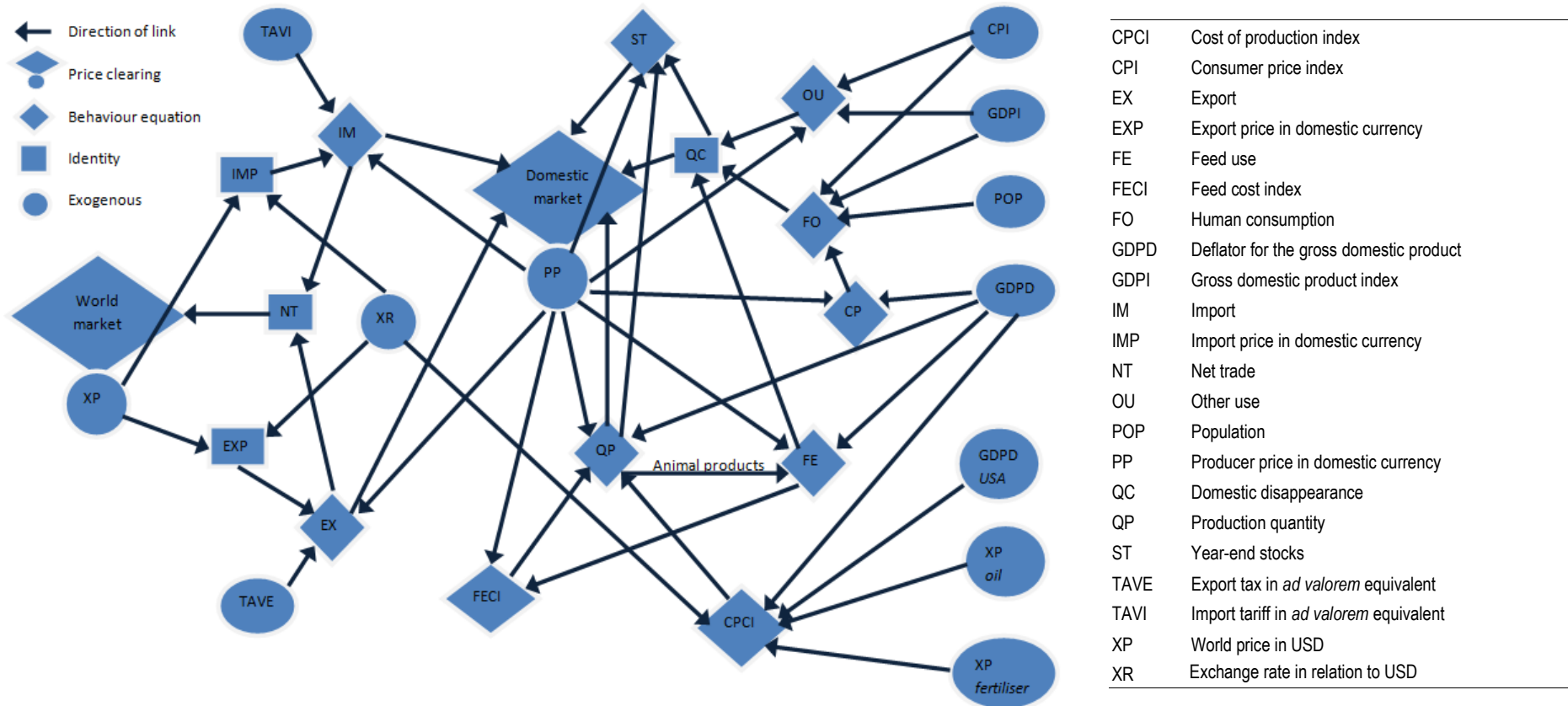|	
Butter	F.o.b. export price, butter, 82% butterfat, Oceania
Cheese	F.o.b. export price, cheddar cheese, 39% moisture, Oceania
Skim milk powder	F.o.b. export price, non-fat dry milk, 1.25% butterfat, Oceania
Whole milk powder	F.o.b. export price, WMP 26% butterfat, Oceania
Whey powder	F.o.b. export price, sweet whey non-hygroscopic, Western Europe
Casein	Export price, New Zealand
Biofuels	
Ethanol	Wholesale price, United States, Omaha
Biodiesel	Producer price Germany net of biodiesel tariff and energy tax

Annex B. List of commodities in Aglink-Cosimo

Cereals		Sugars and sweeteners		Dairy products	
Wheat	WT	Sugar beet	SBE	Milk	MK
- Durum wheat	WTD	Sugarcane	SCA	Other fat products	OFP
- Soft wheat	WTS	Sugar and molasses	SUMOL	Other non-fat solid prod.	ONP
Maize	MA	Sugar	SU	Butter	BT
Other coarse grains	OCG	Raw sugar	SUR	Cheese	CH
- Barley	BA	White sugar	SUW	Whole milk powder	WMP
- Oats	OT	Molasses	MOL	Skim milk powder	SMP
- Sorghum	SO	High fructose corn syrup (isoglucose)	HFCS	Fresh dairy products	FDP
- Rye	RY	Sweetener	SW	Other dairy products	ODP
- Millet	MT			Whey powder	WYP
- Other cereals	OC			Casein	CA
Rice	RI				

Oilseeds & products		Other crops		Animal products	
Soybean	SB	Cotton	CT	Beef and Veal	BV
Other oilseeds	OOS	Cotton seed	CSE	Pig meat	PK
- Rapeseed	RP	Roots and tubers	RT	Poultry meat	PT
- Sunflower seed	SF	Pulses	PS	- Other poultry	OP
- Groundnuts	GN	- Beans	BN	- Chicken	CK
Protein meals	PM	- Field peas	FP	-- Chicken white	CKW
- Palm kernel meal	KM	Jatropha	JA	-- Chicken brown	CKB
-Copra meal(coconut)	CM	Cereal brans	CEB	Sheep meat	SH
- Cotton seed meal	CSM	Corn Gluten Feed	CGF	- Mutton	MU
- Oil meals	OM	Dried distillers grains	DDG	- Lambs	LA
-- Groundnut meal	GM	Dried beet pulp	BP	Wool	WL
-- Soybean meal	SM			Eggs	EG
-- Rapeseed meal	RM	**Energy products**		Fish and aquaculture	FHA
-- Sunflower meal	SFM	Biofuels	BF	Meat and bone meal	MBM
Vegetable oils	VL	Ethanol	ET	Fish meal	FM
- Palm oil	PL	Biodiesel	BD	Fish oil	FL
- Palm kernel oil	KL	Crude oil	OIL		
-Copra (coconut) oil	CL	Diesel	DIE		
- Cotton seed oil	CSL	Gasoline	GAS		
- Oilseed oils	OL	Fertilizer	FT		
-- Soybean oil	SL				
-- Rapeseed oil	RL				
-- Sunflower oil	SFL				
-- Groundnut oil	GL				

Annex C. Regions and countries covered by Aglink-Cosimo

Countries in AGLINK			
OECD countries		**OECD aggregates**	
Australia	AUS	European Union	EUN
Canada	CAN	- 14 older Member States	E14
Japan	JPN	- New Member States after 2004	NMS
Korea	KOR		
Mexico	MEX	**Non-OECD countries**	
New Zealand	NZL	Argentina	ARG
Norway	NOR	Brazil	BRA
Switzerland	CHE	People's Republic of China	CHN
United Kingdom	GBR	Russian Federation	RUS
United States	USA	Argentina	ARG
Countries in COSIMO			
OECD countries			
Chile	CHL		
Colombia	COL		
Israel	ISR		
Türkiye	TUR		
Non-OECD countries		**Cosimo aggregates**	
Egypt	EGY	LDC Sub-Saharan Africa	AFL
Ethiopia	ETH	Other Sub-Saharan Africa	AFS
India	IND	Least Developed North Africa	ANL
Indonesia	IDN	Other North Africa	AFN
Iran (Islamic Republic of)	IRN	LDC Southern Asia	ASL
Kazakhstan	KAZ	Central Asia	ASC
Malaysia	MYS	Other Asia	ASA
Nigeria	NGA	Other Europe	EUE
Pakistan	PAK	Other Near East	NEO
Peru	PER	Other Oceania	OCE
Philippines	PHL	Other South America and Caribbean	SAC
Paraguay	PRY		
Saudi Arabia	SAU		
South Africa	ZAF		
Thailand	THA		
Ukraine	UKR		
Viet Nam	VNM		

Annex D. An overview of Aglink-Cosimo

CPCI	Cost of production index
CPI	Consumer price index
EX	Export
EXP	Export price in domestic currency
FE	Feed use
FECI	Feed cost index
FO	Human consumption
GDPD	Deflator for the gross domestic product
GDPI	Gross domestic product index
IM	Import
IMP	Import price in domestic currency
NT	Net trade
OU	Other use
POP	Population
PP	Producer price in domestic currency
QC	Domestic disappearance
QP	Production quantity
ST	Year-end stocks
TAVE	Export tax in *ad valorem* equivalent
TAVI	Import tariff in *ad valorem* equivalent
XP	World price in USD
XR	Exchange rate in relation to USD