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Documentation of the European Commission's EU module of the Aglink-Cosimo model: 2021 version

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EXECUTIVE SUMMARY

This report documents the EU module of the European Commission's version of the Aglink-Cosimo model. Aglink-Cosimo is a recursive-dynamic, partial equilibrium, multi-commodity market model of world agriculture developed by the Organisation for Economic Cooperation and Development (OECD) and the Food and Agriculture Organization of the United Nations (FAO) Secretariats in collaboration with some OECD member countries. The model is used to simulate the development of annual supply, demand and prices for the main agricultural commodities produced, consumed, and traded worldwide. Aglink-Cosimo covers 35 individual countries, 12 regional aggregates, and 29 market-clearing prices at the world level. At the EU level, the model is used to produce the report "EU agricultural outlook for markets, income and environment" (henceforth, EU Outlook). This is a yearly exercise that provides a detailed overview of the main EU agricultural markets over the medium term (typically 10 years ahead). It incorporates information from policy makers and market experts in the European Commission (EC), as well as from stakeholders, researchers, and modellers. It serves as a reference baseline for scenario-based policy and market analysis. This report presents the structure and specific features of the model by commodity group along with theoretical underpinnings. It also describes how the model is calibrated to medium-term projections of agricultural markets and how it is used for scenario simulations. Applications around uncertainty, policy evaluation and climate change are also mentioned.

Keywords: partial equilibrium model, recursive-dynamic, trade, multi-commodity markets, agriculture, global model, baseline, medium-term outlook

1 INTRODUCTION TO THE AGLINK-COSIMO MODEL

Aglink-Cosimo is a recursive-dynamic, partial equilibrium, multi-commodity market model of world agriculture. The model integrates the Organisation for Economic Cooperation and Development's (OECD's) Aglink and the Food and Agriculture Organization of the United Nation's (FAO's) Cosimo modules. It is managed by the OECD and FAO Secretariats. The model is used to simulate the development of annual supply, demand and prices for the main agricultural commodities produced, consumed and traded worldwide. The 2021 version of the Aglink-Cosimo model is composed of around 33,600 equations. It covers 35 individual countries and 12 regional aggregates, over 90 commodities and 29 world-market clearing prices (see Annex). Country and regional modules and projections are developed and maintained by the OECD and FAO Secretariats in conjunction with country experts in national administrations. For an overview flow-chart of the model see figure 1.

The Aglink component of the model consists of 15 country modules: 11 OECD countries/regions (Australia, Canada, EU-27, UK, Switzerland, Norway, Japan, Korea, Mexico, New Zealand, and the USA) and four non-OECD countries (Argentina, Brazil, China and Russia). The Cosimo component of the model consists of 32 endogenous modules: four OECD members (Chile, Colombia, Israel and Turkey), 17 non-OECD countries and 11 regional aggregates (see Annex).

The purpose of this report is to document the EU module that is divided into two separate modules: one covering the first 14 Member States[1] (E14; excluding the UK) and another for the 13 newer Member States (NMS). Trade, stocks and biofuel use are determined endogenously for EUN. Everything else relates to the two sub-regions, E14 and NMS.

There have been several updates after the previous documentation (Araujo-Enciso et al. 2015; OECD 2015). Major changes include a new land-use system with full area allocation, a new biofuels module with endogenous gasoline and diesel consumption, changes related to the end of sugar and milk quota system in the EU and changes to

[1] The E14 aggregate is composed of: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, and Sweden. The NMS aggregate is composed of: Bulgaria, Croatia, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovakia, and Slovenia.

the Common Agricultural Policy. In addition, a new partial stochastic analysis methodology has been developed (Araujo-Enciso et al. 2020).[2]

This documentation proceeds as follows. In the remainder of this chapter the building blocks of the model (variables, parameters, constants, and residuals) are presented together with peer-reviewed publications and the partial stochastic analysis methodology. Commodities or commodity groups are treated separately in the corresponding chapters to help the reader obtain a comprehensive overview of the markets modelled. Finally, the yearly baseline construction procedure is explained.

1.1 Regions, commodities, and items

As mentioned above, the EU module covers two regional aggregates: E14 and NMS. EUN is the aggregate of these sub-regions but, as mentioned above, trade, stocks and biofuels are specific to EUN rather than E14 and NMS. Usually, the model does not include bilateral links between regions. However, in a few markets such links are particularly important and are modelled specifically. For example, the EU module includes bilateral meat trade between the EUN and the Pacific (PAC), Atlantic (ATL) and China's (CHN) markets. Bilateral flows may also be introduced conditionally when simulating specific scenarios (e.g., EC 2018:15). A full list of modelled regions and countries is included in the Annex (table A.1).

The Aglink EU module covers 99 commodities ranging from crops (e.g., soft wheat, soybeans) to processed goods (e.g., whole milk powder) and by-products (e.g., distiller's dried grains). Additionally, two world prices of non-agricultural commodities are included in the cost of production commodity index of the EU module: crude oil and fertiliser. While the crude oil (Brent) price is exogenous, the world fertiliser price is positively associated with world prices of key crops. A full list of commodities from the EU module can be found in the Annex (table A.2).

The Aglink EU module covers 118 items captured in behavioural equations. Items represent different objects used in the model in generic equations, such as yield (YLD) and returns per hectare (RH), or in specific equations, such as gasoline quantity consumed (QC..GAS). The modelling of specific items in templated equations allows for incorporating policies in the model. Tariffs or coupled support, for example, apply to

[2] The OECD and FAO secretariats published a revised version of their model documentation shortly before this report was published (see OECD/FAO 2022).

specific commodity groups in the EU. A full list of all the items included in the EU module can be found in the Annex (table A.3).

1.2 Medium-Term baseline process

An important activity of the European Commission's market analysis is the annual production of medium-term baseline projections for agricultural commodity markets. The EU Outlook is published annually by the European Commission's Directorate General for Agriculture and Rural Development (DG AGRI) in the second half of the year. Aglink-Cosimo is the key model for building these baseline projections and for performing partial stochastic uncertainty analysis around them. The outlook exercise serves as an input to the annual OECD-FAO Agricultural Outlook that is carried out annually in the first half of the year and has a broader scope than the EU Outlook.

The process of obtaining the yearly EU Outlook starts with the release of the latest OECD-FAO medium-term baseline, corresponding model, and data in June. Four steps summarise the procedure from the OECD-FAO baseline to the publication of the EU Outlook:

1. The first step consists in recalibrating the EU component of the OECD-FAO baseline by taking into account the following information: an updated and consistent set of medium-term macroeconomic projections and additional information coming from the short-term EU Outlook[3].
2. The second step is a review of the preliminary medium-term baseline obtained in the first step by interacting with commodity experts (i.e., market experts on arable crops, sugar and biofuels, meat, milk and dairy products). A key input into the baseline projections is the up-to-date input of market experts. The inputs collected are incorporated into the EU baseline and then serve as a starting point for the calibration of other models used in the Commission (e.g., CAPRI, MAGNET, AGMEMOD) as well as for scenario analyses.
3. The preliminary baseline produced in the previous step is the basis of the EU Outlook workshop that brings together policymakers, modellers, market experts and stakeholders. The workshop (usually carried out in October) offers an opportunity to verify the reliability of the results obtained and to discuss how

[3] The short-term EU Outlook is a six- to 18-month forecast of EU agricultural market developments generated by the market units at DG AGRI, based on the latest knowledge and expectations.

different settings and assumptions regarding macroeconomic factors and other uncertainties may influence the projections of individual commodity markets. As part of this validation procedure, suggestions and comments made during the workshop are taken into account in order to improve the baseline projections.

4. The last step consists of a high-level Outlook Conference where the final EU Outlook projections are presented. At the same time, the projections are released to the public. The released baseline is then used as the European Commission's input to the following year's OECD-FAO Agricultural Outlook.

1.3 Peer-reviewed model applications

Apart from the yearly publication of the EU Outlook, the Aglink-Cosimo model has been used in a series of model applications involving either expansions of the model or scenario analyses. Kavallari et al. (2014) demonstrated the unintended consequences of economic growth and downturns on food security. Fellmann et al. (2014) and Araujo-Enciso and Fellmann (2020) showed the importance of harvest failure in Russia, Ukraine and Kazakhstan for global world markets and the negative impact of export restrictions on food security, especially of grain net importing countries. More recent analyses include a wide variety of topics, such as: biofuel policies (Araujo-Enciso et al. 2016); dietary changes (Santini et al. 2017); greenhouse gas emissions (Jensen et al. 2019); the impact of Covid-19 (Elleby et al. 2020); uncertainty in agricultural markets (Araujo-Enciso, Pieralli, and Pérez Domínguez 2020); extreme weather events (Chatzopoulos et al. 2020; 2021); insect-based food production (Jensen et al. 2021); risk management policies (Pieralli et al. 2021); and cumulated effects of free-trade agreements (Ferrari et al. 2021).

1.4 Variables, constants, and parameters

Equations in the model are either identities or behavioural. Identities are equations that force variables to satisfy an equality. Behavioural equations model a relationship between variables including the possibility for residual error. Most behavioural equations in are "double-log", which is a convenient linearization of a Cobb-Douglas in exponential form such that both the left- and right-hand side variables are expressed in logarithmic terms: $\log(Y) = \alpha + \beta \log(X) + \log(R)$. This functional form is very tractable and represents well first-order approximations to arbitrary functional forms.

The constant (α) shifts the linear relationship between $\log(X)$ and $\log(Y)$ up and down. The elasticity (β) represents the percentage change in Y to a one-percent change in X.

Depending on the size and sign of β, the relationship between the underlying Y and X can change shape. If β is lower than 1 but still positive, the underlying relationship between Y and X is concave (i.e., Y experiences diminishing marginal returns with respect to increasing X). Assuming $R = 1, \alpha = 0,$ and $\beta = 0.5$, if $X = 4$, then $Y = 2$. If X increases 4 times ($X = 16$), then Y doubles $(Y = 4)$. If β is negative, Y decreases with increases in X. If $\beta = -0.5$, when X increases 4 times ($X = 16$), Y diminishes $(Y = 1/4)$.

Lastly, in all subsequent equations, α and β are region- and commodity-specific even if the notation is kept the same in this report, for simplicity.

1.4.1 Model variables

Variables are determined within the model (endogenously) or outside the model (exogenously). The model consists of a square system -i.e. the same number of endogenous variables and linearly independent equations. This ensures the existence of a single solution to the model. The EU module has 1,968 endogenous variables in the 2021 OECD-FAO model version. For the equations to model appropriately the behaviour of agricultural markets, all parameters have to be specified.

1.4.2 Model parameters

The Aglink-Cosimo model is elasticity driven. As mentioned above, two attractive properties of the "double-log" function pertain to tractability and the interpretation of β parameters as elasticities. Most of the behavioural equations include elasticities, for example yield-to-price elasticities and price elasticities of demand.

Additional parameters in the model are attached to time trends to reflect, for example, the increment in yield thanks to technological change or change in demand due to changes in consumer preferences. Time trends vary by equation and, when they exist, they are parameterised with a linear trend.

1.4.3 Model constants

Constants in Aglink-Cosimo are used as scaling parameters and are typically re-calculated during calibration of the baseline process. Calibration aligns the linear relationship between $\log(Y)$ and $\log(X)$ along the projection period. The calculation of the constants is described below.

1.5 Model calibration and simulation

Calibrating a model implies finding the values for a set of model variables that reproduce a specific historical or projected state of the economy, often called a baseline. During the EU Outlook elaboration, the EU module is calibrated following the approach taken by the OECD and FAO Secretariats in the yearly elaboration of their agricultural outlook. After having included historical market trends and new market expert information on EU agricultural markets, the model is calibrated to reproduce the projected baseline. Calibration is done through the so-called calibration-factors: the residual errors (or R-factors) and the constants. These terms are endogenous during calibration but exogenous (i.e., fixed) during simulation.

An example of a simple equation is: $\log(Y) = \alpha + \beta \ \log(X) + \log(R)$. In the following, we will use typical notation to represent a calculated parameter with a hat on top. The first phase of calibration involves calculating the constants ($\hat{\alpha}$). Constants are chosen such that the average of the residuals is zero in the calibration period. In the second step of calibration, residuals are calculated to match the other variable levels in every year: $\log(R) = \hat{\alpha} + \beta \ \log(X) - \log(Y)$, where elasticities remain fixed. If the model is well calibrated, log-transformed R-factors should be near 0 at least for the period used to estimate the constants. Once the R-factors have been calculated during calibration, $\widehat{\log(R)}$, they remain fixed during simulation, where only X and Y vary to satisfy the calibrated behavioural equation: $\log(Y) = \hat{\alpha} + \beta \ \log(X) + \widehat{\log(R)}$. During simulation, X and Y may differ from their calibration values. Exogenous changes to X represent shocks to variables that will result in endogenous changes in Y. In modelling jargon, the exogenous shocks and the resulting impacts are part of a simulation scenario.

Constants and residuals come from the same calibration process: both terms are calculated so that the right-hand side equals the left-hand side (Y) of each equation. The left-hand side variables (Y) are commodity market items related to domestic supply (e.g., land use shares, yields), domestic demand (e.g., feed, food, fuel consumption) and trade (i.e., imports and exports). Left-hand side variables are typically exogenous during calibration and endogenous during simulation.

1.6 Partial stochastic analysis

The stochastic analysis is based on a selection of variables that are deemed to be the major sources of uncertainty for EU agricultural markets. In total, 39 country-specific macroeconomic variables from main commercial EU partners, the crude oil price and 85 country/product-specific yields, shown in the Annex, are treated as uncertain within this framework. More details on the partial stochastic analysis methodology can be found in Araujo-Enciso, Pieralli, and Pérez Domínguez (2020).

The procedure for producing partial stochastic simulations consists of three steps:

- fitting a time series model for each stochastic variable in order to separate a signal from unexplained variability (noise);
- the generation of a large number of sets of possible alternative values for the stochastic variables[4]; and
- the execution of the Aglink-Cosimo model for each set of alternative values of the stochastic variables.

The first step quantifies past variability around the modelled variables for each group of macroeconomic and yield variables separately. For macroeconomic variables, the estimation is based on vector autoregressive (VAR) models. In each year, for the different variables, the unexplained portion of variability is retained. Next, the joint distribution of the unexplained parts of the time series (the VAR residuals) is modelled through a copula approach.

Yields are fitted with a cubic trend time series model. Regional blocks of correlation matrices are calculated between empirical distributions of yield residuals for the main commodities using a copula approach like in the macro case. However, between regional blocks, correlations are assumed to be zero. Regional blocks are shown in the shaded areas in the Annex (table A 1).

The second step involves creating sets of alternative values by multiplying the stochastic variables with simulated errors, thus reproducing the covariance determined in the first step for each year of the medium-term outlook period. Macroeconomic and yield errors are simulated with a copula approach to reproduce the correlation between country specific macroeconomic time series and yield regional blocks.

The third step involves running the Aglink-Cosimo model for each of the alternative "uncertainty" scenarios generated in the second step and solving the model for the whole outlook period. In order to understand how much each source of uncertainty affects the results of the model, this step can be performed three times: once accounting only for yield uncertainty, another accounting only for macroeconomic uncertainty, and a third accounting for both. Occasionally, the model may not solve. The model is a

[4] The number of alternative sets is large enough to simulate with sufficient statistical precision the tails of the distributions estimated. For example, as a rule of thumb, if one wanted statistical evidence on the last 5% of the distribution tails, one should have around 1,000 alternative sets of values, depending on the estimated precision needed (Efron, 1987).

complex system of equations, and extreme shocks in one or many stochastic variables may lead to infeasible solutions.

1.7 Stochastic scenario analyses

Aglink-Cosimo is also used to assess what would happen under different assumptions concerning policy contexts, macroeconomic conditions, and yield estimates. This can be done either with deterministic scenario analysis (i.e., analysing one or a few alternative baselines) or stochastic scenario analysis (i.e., analysing hundreds or thousands of alternative baselines through subsets).

Analysis of a scenario implies assessing the model results when some specific assumptions are changed and comparing the alternative results with the initial baseline. In this case, the model is simulated for some or all projection years with the new assumptions and potential adjustments. Adjustments to the baseline can come in different forms: in some cases, they are just manipulations of the parameters; in others, the model may also be modified to reflect a particular policy or problem. In a recent example that combines changes in data, equations and parameters, the Aglink-Cosimo model was extended with an explicit representation of climate-stress events (Chatzopoulos et al. 2021). Such events were then stochastically simulated to identify distortions in market equilibria stemming from extreme-climate anomalies.

Analyses of subsets of stochastic uncertainty scenarios (i.e., where the model is solved as many times as the number of stochastic replications) focus on selecting conditional replications. In contrast to a scenario analysis, the model is run for each of the stochastic draws to compose a set of replications, where main macroeconomic or yield assumptions are varied but parameters and/or equations are not necessarily changed in the model. Several examples looking at low or high oil prices or low and high yields have been published recently. More details can be found directly in Araujo-Enciso, Pieralli, and Pérez Domínguez (2020) or in Araujo-Enciso and Fellmann (2020).

1.8 Market-clearing mechanism

Markets clear when a certain quantity of supplied products are demanded at the market clearing price. All commodities traded internationally have a net trade to equal exports (EX) minus imports (IM):

$$NT_{c,r,t} = EX_{c,r,t} - IM_{c,r,t}. \tag{1}$$

In the EU module, exports and imports are modelled at the EU-27 level. EU production of commodities consumed outside the EU (EU export supply/foreign import demand) and EU consumption of commodities produced outside the EU (EU import demand/foreign export supply) simultaneously affect and are affected by domestic and foreign producer prices.

Producer prices are modelled as closing variables ensuring a market balance for each country/region between production, consumption, exports, imports, and stocks. The following equation defines implicitly the producer price as the variable that balances the market:

$$PP^{*}_{c,r,t} = PP_{c,r,t} > 0$$

such that

$$QP_{c,r,t}(PP_{c,r}) - QC_{c,r,t}(PP_{c,r}) + IM_{c,r,t}(PP_{c,r}) - EX_{c,r,t}(PP_{c,r}) + \Delta ST_{c,r,t}(PP_{c,r}) = 0 \qquad (2)$$

In the above equation, $QP_{c,r,t}$ is the quantity produced of a commodity c in a country/region r in year t. $QC_{c,r,t}$ is the quantity consumed, $IM_{c,r,t}$ is quantity of imports from abroad, $EX_{c,r,t}$ is quantity of exports towards the international market, and $\Delta ST_{c,r,t}$ is the difference between current (ending) and lagged (opening) stocks. All these variables depend on producer prices.

This is true for most arable commodities, dairy, and meats. However, in some cases, market clearing occurs at the level of disaggregated components of certain commodities. For example, milk-fat and non-fat solids are clearing variables for the milk market. That means that there will be weighted average price aggregates that represent the domestic market price. For example, a weighted average of the milk-fat and non-fat solids represents the EU milk price.

The sum of all regional net trade positions represents world net trade and determines the world market equilibrium. International-reference prices of selected commodities ($XP_{c,t}$) clear markets at the world level by equating total exports and total imports, subject to statistical differences ($SD_{c,t}$):

$$XP_{c,t}: 0 = NT_{c,t} - SD_{c,t}. \qquad (3)$$

The international price of commodity c in year t ($XP_{c,t}$) is used to calculate import ($IMP_{c,r,t}$) and export ($EXP_{c,r,t}$) prices in each country. These prices, expressed in domestic currencies (e.g., EU maize import price equals world price times exchange rate:

$IMP_{MA,EUN,t} = XP_{MA,t}XR_{EUN,t}$), convert international-reference prices into domestic-price equivalents.

The remainder of this report analyses how most agricultural markets are modelled in the EU module of Aglink-Cosimo, after presenting the land-use system. For each group of commodities, first production, then consumption (i.e., what are their main uses), trade (exports, imports), and stocks are presented.

2 LAND-USE SYSTEM

Agricultural production in the model is based on a profit-maximization framework where each commodity is treated as if it were produced by a single composite input (Varian 1992). Main supply components (yield, cost of production commodity index, land area harvested, and inventories) will be introduced, together with the consumption uses of agricultural products, starting from the land-use allocation system.

Producers are assumed to maximize profits (π) by changing land uses, subject to land being fully utilised and subject to land areas chosen being all non-negative:

$$\max \pi\left(LU_{c,r,t}\right) = \sum_{c=1}^{C} \frac{IP_{c,r,t}}{PCST_{c,r,t}} LU_{c,r,t} - \left(\alpha_{c,r} LU_{c,r,t} + \frac{1}{2\beta_{c,r} LU_{c,r,t}^{2}}\right) \tag{4}$$

$$\text{s.t.} \sum_{c=1}^{C} L\,U_{c,r,t} = LU_{r,t}$$

$$LU_{c,r,t} \geq 0.$$

The first equation above is the objective function of the problem: it is a profit maximization equation recognizing that profit depends on land use, and land utilization depends on the ratio of a production incentive ($IP_{c,r,t}$) to a production-cost index ($PCST_{c,r,t}$). It is the dual formulation of the calibrated positive mathematical programming problem used to reproduce an observed situation (Howitt 1995). Nonlinear (‘perturbation’) terms are added to ensure that the problem is calibrated to the observed situation in the second step. More on these quantities is in the explanation of the specific equations introduced in the model but, beforehand, the rest of the maximization model will be explained. The second equation above is the first constraint that ensures that the total land area is used in every period and region. The third equation is a non-negativity constraint ensuring that all land uses are non-negative.

To solve this optimization problem under the assumption that all solutions are interior, the Lagrangian problem is formulated as follows:

$$\mathcal{L}(LU_{c,r,t}) = \sum_{c=1}^{C} \frac{IP_{c,r,t}}{PCST_{c,r,t}} LU_{c,r,t} - \left(\alpha_{c,r} LU_{c,r,t} + \frac{1}{2\beta_{c,r} LU_{c,r,t}^{2}}\right) + \lambda\left(LU_{r,t} - \sum_{c=1}^{C} L\,U_{c,r,t}\right) + \gamma_c LU_{c,r,t}, \quad (5)$$

where λ and γ are Lagrangian multipliers added to solve the problem.

Taking first derivatives with respect to the crop allocations and shadow prices of land (λ, land rent) and γ_c (shadow price of the non-negative land use restrictions) obtains the following set of first-order conditions:

$$0 = \frac{IP_{c,r,t}}{PCST_{c,r,t}} - \left(\alpha_{c,r} + \beta_{c,r} LU_{c,r,t}\right) - \lambda + \gamma_c \quad (6)$$

$$\sum_{c=1}^{C} L\,U_{c,r,t} = LU_{r,t}$$

$$LU_{c,r,t} \geq 0.$$

This maximization problem solution follows in essence a positive mathematical programming approach. However, for ease of modelling, the non-negativity constraint is obeyed in practice by including a minimum boundary (close to zero). Moreover, and more importantly for the model, the actual variables included in the model are not actual area variables as in Eq. (6) but are land use shares of a total land area available as in Eq. (7).

For the main crops grown in the EU (cotton, maize, other coarse grains, other oilseeds, pulses, rice, roots and tubers, sugar beet, soybeans, wheat, and other agricultural crops) land use shares are determined by a land-use-share equation:

$$LU..SHR..EQ_{c,r,t} = \beta_1\left(\frac{IP_{c,r,t}}{PCST_{c,r,t}} - SHP_{AGR,t}\right) + R_{c,r,t}, \quad (7)$$

where $IP_{c,r,t}$ denotes incentives to production and where $PCST_{c,r,t}$ is a production-cost index. These first-order conditions define the equilibrium land-use shares and the equilibrium implicit price -the shadow price or opportunity cost of agricultural land, $SHP_{AGR,t}$- such that the land market is in equilibrium.

In Eq. (7), a higher incentive to production would induce more land to enter that crop agricultural use. Three variables modify the value of Eq. (7): the production-cost index, production incentives, and the shadow price. The production-cost index $PCST_{c,r,t}$ is defined as a simple average of lagged and current cost indexes:

$$PCST_{c,r,t} = \frac{1}{2}\sum_{p=0}^{1} CPCI_{c,r,t-p}. \tag{8}$$

A higher shadow price, which is not crop specific, incentivizes non-agricultural land use (e.g., forestry). The shifts between crops and pasture, on one hand, and forestry are dictated by a margin difference between commodity production incentives, commodity production costs, and the shadow price of agricultural land. More land will shift to agriculture if the marginal incentives to agricultural production are in favour of agricultural over non-agricultural land use. In practice, however, agricultural land use is very inelastic.

The third variable affecting Eq. (7) is the production incentive, $IP_{c,r,t}$, which represents total expected returns per hectare of a given crop. It is defined as the sum of expected market returns and subsidies per hectare of area harvested ($EPA_{c,r,t}$). Specifically, the $IP_{c,r,t}$ variable is defined as

$$IP_{c,r,t} = RH_{c,r,t-1} + EPA_{c,r,t}, \tag{9}$$

where $RH_{c,r,t-1}$ denotes lagged revenue per hectare. The revenue per hectare ($RH_{c,r,t}$) in a period t is defined as a weighted average of the contemporaneous and lagged returns per hectare (w_t =0.5, w_{t-1} =0.3, and w_{t-2}=0.2):

$$RH_{c,r,t} = \sum_{p=0}^{2} w_{t-p} PP_{c,r,t-p} \times YLD_{c,r,t-p}. \tag{10}$$

In this way, the weighted average attenuates the importance of lagged revenues. Expected incentives to production ($IP_{c,r,t}$) are thus assumed to be adaptive with most of the revenue signal coming from previous year revenue per hectare (half), with lower importance on the previous two years. Being a weighted average of past years' revenues per hectare smooths out strong variabilities in price ($PP_{c,r,t}$) and yield ($YLD_{c,r,t}$). Moreover, in the production incentive (IP), the model only includes past years' revenues per hectare to mimic that the decision on the land-use shares depends on expectations based on past returns.

In the EU module, $EPA_{c,r,t}$, or effective support payments per ha, are given by

$$EPA_{c,r,t} = EPA_{AGR,t} + EPA..DP_{c,r,t}, \tag{11}$$

where the first term ($EPA_{AGR,t}$) on the right-hand side of Eq. (11) is a policy variable showing payment per hectare of agricultural land and the second term ($EPA..DP_{c,r,t}$) represents the coupled subsidies of the EU Common Agricultural Policy (CAP). It is assumed that decoupled payments (Single Farm Payment or SFP[5]) have a small coupling effect on production ($SFP..CF_{AGR,r,t}$), currently set at 6%. Only this share (coupling factor) of the single farm payment $SFP_{AGR,r,t}$, is added in the production incentive:

$$EPA_{AGR,r,t} = SFP..CF_{AGR,r,t} \times SFP_{AGR,r,t}, \tag{12}$$

where the single farm payment for agricultural use in each region $SFP_{AGR,r,t}$ is set at 246 EUR for E14 and 165 EUR for NMS. Updates of these numbers are envisaged to incorporate the new CAP. More information on the modelling of the CAP is provided in chapter 12 of this report.

Since most crop support was fully decoupled in 2005, coupled subsidies $EPA..DP_{c,r,t}$ are only used for few products. Only a few Member States used Article 68 of Council Regulation 73/2009[6] or Complementary National Direct Payments to grant coupled payments to some products or crops. In 2013, suckler cow, sheep and goat, and cotton were the only coupled payments permitted. However, the 2013 CAP reform reintroduced voluntary coupled support as an option for the Member States to distribute up to 8% (or 13% if the Single Area Payment Scheme is used) of the national direct payments' envelope, with some exceptions possible. Most Member States have decided to support protein crops and sugar beet, in addition to the previously supported sectors (cow, sheep and goat, and cotton). In E14, barley, cotton, maize, oats, rice, rapeseed, rye, soybeans, sugar beet, sunflower, soft and durum wheat, pasture, forestry, and other cereals are supported through coupled support. In NMS only sugar beet and durum wheat are supported. Coupled support, $EPA..DP_{c,r,t}$, is determined as the envelope of the

[5] The Single Area Payment Scheme (SAPS), which applies in several Member States of the NMS, is modelled as a Single Farm Payment.

[6] Article 68 of EU Council Regulation 73/2009 can be found here: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:030:0016:0099:en:PDF

voluntary coupled support $EPA..BUDGET_{c,r,t}$ divided by the area harvested $AH_{c,r,t}$. More on this in chapter 12.

Actual land use shares resulting from Eq. (7) are forced not to go lower than a set of fixed minima ($LU..MIN_{c,r,t}$). Land use shares are thus given as the maximum between minimum fixed shares and the result of the behavioural land-use share equations (7) ($LU..SHR..EQ_{c,r,t}$):

$$LU..SHR_{c,r,t} = \max\left(\frac{LU..MIN_{c,r,t}}{LU_{AGR,t}}, LU..SHR..EQ_{c,r,t}\right). \quad (13)$$

Total land use by crop c in region r at time t is given by

$$LU_{c,r,t} = \max\left(LU..MIN_{c,r,t}, LU..SHR_{c,r,t} \times LU_{AGR,t}\right). \quad (14)$$

In order to account for land-use substitution among crops, the following sets of arable crops are modelled separately: the ones included in the other coarse grains aggregate (barley, other cereals, oats, rye), the ones in the other oilseeds aggregate (including rapeseed and sunflower), and the ones in the wheat aggregate (soft and durum). The land-use shares of the individual crops in the three aggregates are determined by sets of more complicated land-use share equations including elasticity parameters (β and γ) to allow for substitution between crop land uses within aggregates (e.g., between barley and oats in the OCG aggregate):

$$LU..SHR..EQ_{c,r,t} = \left(\alpha + \frac{(IP_{c,r,t}/PCST_{c,r,t})^{\beta}}{\sum_{c\in C}\left(\frac{IP_{c,r,t}}{PCST_{c,r,t}}\right)^{\gamma}}\right) \times R_{c,r,t}, \quad (15)$$

where β and γ represent the elasticities of substitution between competitive ratios $\frac{IP_{c,r,t}}{PCST_{c,r,t}}$ for different commodities inside each set of equations. Similar to the crops included in Eq. (7), the shares determine the commodity-specific land uses within each aggregate C. Land-use shares are allocated to different crops according to their relative competitiveness, given by how their ratios between production incentives ($IP_{c,r,t}$) and the production cost index ($PCST_{c,r,t}$) compare with the ones of the other crops.

Forestry land use $FST_{LU_{r,t}}$ in region E14 or NMS is modelled with the following equation:

$$\log\left(\frac{FST_{LU_{r,t}}}{FST_{LU}..BAS_{r,t}}\right) = \alpha + \beta\log\left(\frac{SHP_{r,t}}{1+\exp\left(-10\times\left(SHP_{r,t}-5\right)\right)} + 1\right) + \gamma\log(T) + \log\left(R_{FST_{LU},r,t}\right), \quad (16)$$

where β is an elasticity between forestry land use deviations from a baseline value ($FST_{LU}..BAS_{r,t}$) and a deflated shadow price of agricultural land use and γ is an elasticity of forestry land use deviations from the baseline value with respect to a time trend T.

Pasture and fodder land use ($LU_{PAF,r,t}$) in E14 and NMS are modelled through the following equation:

$$\log\left(LU_{PAF,r,t}\right) = \alpha + \beta\log\left(\frac{IP_{c,r,t}}{SHP_{r,t} \times PCST_{c,r,t}}\right) + \gamma\log\left(LU_{PAF,r,t-1}\right) + \log\left(R_{LU_{PAF,r,t}}\right), \tag{17}$$

where β is an elasticity between pasture and fodder land use and the margin incentive to production $\frac{IP_{c,r,t}}{PCST_{c,r,t}}$, γ is an elasticity of pasture and fodder land use with respect to the pasture and fodder land use in the previous period $t-1$ and $SHP_{r,t}$ is strictly positive. This elasticity measures the persistence in pasture and fodder land use over time: how much of the previous time period land use is maintained under the same use in this time period. This approach is chosen because use of land for pasture and fodder is quite persistent over time.

The incentive price for pasture and fodder is relative to the returns per hectare in beef (BV), sheep (SH), and milk production (MK):

$$IP_{PAF,r,t} = \begin{bmatrix} \left(\sum_{p=0}^{2} w_{t-p}PP_{MK,r,t-p} + EPQ_{MK,r,t} + EPY_{MK,r,t} \times YLD_{MK,r,t}\right) \times QP_{MK,r,t} \\ +\left(\sum_{p=0}^{2} w_{t-p}PP_{BV,r,t-p} + EPQ_{BV,r,t}\right) \times QP_{BV,r,t} \\ +\left(\sum_{p=0}^{2} w_{t-p}PP_{MK,r,t-p} + EPQ_{SH,r,t}\right) \times QP_{SH,r,t} \end{bmatrix} / LU_{PAF,r,t} \tag{18}$$

where the weights used are the same for different products but differ over time: w_t =0.5, w_{t-1} =0.3, and w_{t-2}=0.2. In this equation, all the potential products from pasture and fodder are considered, as part of the weighted averages of the product prices. All land uses under pasture and fodder are considered in the weighted average in Eq. (18).

The production cost index for pasture and fodder is an increasing function of the input price index for meat and dairy (MD) in the last three years and a decreasing function of the bulk feed-cost index (FECI) in the last three years:

$$PCST_{PAF,r,t} = \alpha + \log\left(\sum_{p=1}^{3} CPCI_{MD,r,t-p}\right) + \beta\log\left(\sum_{p=1}^{3} FECI_{RU,r,t-p}\right) + \log\left(R_{PCST_{PAF,r,t}}\right) \tag{19}$$

The semi-elasticity[7] β in the equation above shows how much the production cost index $PCST$ changes, in percentage terms, relative to the feed-cost index, which represents feed substitution.

Groundnut land use for E14 and NMS and cotton land use for NMS are defined as follows:

$$LU_{c,r,t} = \frac{AH_{c,r,t}}{CRPI_{c,r,t}}, \tag{20}$$

where $CRPI_{c,r,t}$ denotes the "Crop production index". Finally, compulsory set-aside land use has been abolished since 2008 and is now voluntary. In the model, the land set-aside is set exogenously: $LU_{SET,r,t}$ for E14 and NMS.

3 ARABLE CROPS

The arable crops module covers grains, oilseeds, roots and tubers, pulses and sugar beet. The grains include coarse grains (i.e., maize, barley, oats, rye and other cereals), wheat (i.e., soft and durum), and rice. Oilseeds include rapeseed, soybean, and sunflower seed. Other crops, such as fruit and vegetables, are included in the model exogenously.

This section introduces how arable crop costs are modelled: production equations, yield equations, and land uses. This chapter then analyses arable crop consumption and arable crop trade. In the treatment of subsequent agricultural products (e.g., dairy products) in other chapters only differences with the arable crop case will be mentioned.

3.1 Costs of production commodity index

The Aglink-Cosimo model represents costs through a univariate cost of production commodity index (or $CPCI$). That means that costs are represented by an index of the costs per unit of a composite input. In other words, $CPCI$ represents a unitary cost of all the inputs used to produce a certain commodity in a country. The cost index is constructed for arable crops as a weighted average of five sub-indices representing

[7] The term semi-elasticity in this case is used to refer to a parameter that measures the relationship between a dependent variable (on the left-hand side of the equation) and the logarithm of an independent variable (on the right-hand side of the equation). Semi-elasticities (when multiplied by 100) approximate percentage changes in the dependent variable when a change in one unit of the independent variable occurs.

important input-cost categories: seed, fertilizers, energy, tradable, and other non-tradable inputs. These are indexed by the subscript s below.

The main equation for the cost index for arable crops (barley, soft wheat, durum wheat, cotton, maize, oats, pulses, rice, rapeseed, roots and tubers, rye, soybeans, sugar beet, sunflower, other cereals) is the following:

$$CPCI_{c,r,t} = \sum_{s \in S} w_{s,c,r,t} \times PI\left(P_{s,c,r,t}\right), \tag{21}$$

where

- $CPCI_{c,r,t}$ is commodity production cost index for commodity c, in region r, in year t;
- the weights w_s are: a weight of seed inputs in total base commodity production costs, a weight of energy inputs, a weight of fertiliser inputs, a weight of tradable inputs, and a weight of non-tradable inputs;
- the price indexes $PI(P_s)$ are deflated indexes (with respect to a base year) of prices representative of the respective different cost categories: the crop producer price $PP_{c,r,t-1}$ (for seed costs), the world crude oil price $XP_{OIL,WLD,t}$ (for energy costs), the world fertiliser price $XP_{FT,WLD,t}$ (for fertiliser costs), the Gross Domestic Product Deflator in the US (for tradable costs) and the Gross Domestic Product Deflator in each country (for non-tradable costs).

For future reference, a similar cost index is available for livestock (beef, milk, pigmeat, poultry, sheep). The only difference is that it does not contain the seed and fertiliser components. The explanation of each of the three cost sub-indices is similar to the case of the crops. These cost indexes are further multiplied by a factor introducing an adjustment for cost-reducing total factor productivity change.

All weights of the various cost categories w_s are country specific. They are estimated based on historical cost structures in individual countries. They are weights to aggregate, from different cost sub-indices, a univariate commodity-specific input cost index. These cost indexes vary depending on the price movement of each input and on country- and commodity-specific weights.

The list of cost categories considered in each sub-index can be found in Table 1. Feed costs are endogenous to the model and, therefore, are not considered in these weights. The total cost of labour is included. Thus, own labour is accounted for at its opportunity cost. Land and capital costs are not included except for depreciation.

The current (2021 model version) cost weights for the EU module were revised in 2017 and are based on FADN (Farm Accountancy Data Network). At the time of this update, the latest year for which data were available was 2014 (along with estimates for 2015 and 2016). Historic values have been introduced in the model for all years between 2005 and 2015. Beyond 2015, the average for 2005–2015 is used (see Table 2).

3.2 Arable crop production

For the crops that are modelled, total quantity produced for crop c in region r at time t, $QP_{c,r,t}$, is obtained by multiplying the area harvested ($AH_{c,r,t}$) with the yield ($YLD_{c,r,t}$):

$$QP_{c,r,t} = AH_{c,r,t} \times YLD_{c,r,t}. \tag{22}$$

In Aglink-Cosimo, countries (in aggregate) adjust the quantity of input used on the basis of a (production) profit margin per unit of product. Yields are assumed to increase with farmers' expected profit margin at the time of making production decisions. This margin is composed of output return per unit (past-year producer price $PP_{i,t-1}$, as a signal for the profitability of the crop, plus present-year support payments EPY_{it}) divided by the average cost of production commodity index ($CPCI$) during the growing period of a certain commodity. Standard yield equations for arable crops (specific for region r and year t) are modelled as follows:

$$\log YLD_{c,r,t} = \alpha + \beta \log\left(\frac{PP_{c,r,t-1} + EPY_{c,r,t}}{\zeta \times CPCI_{c,r,t-1} + (1-\zeta) \times CPCI_t}\right) + \gamma\, T + \log\left(R_{c,r,t},\right), \tag{23}$$

where α is a constant, β is the profit margin to yield elasticity, and R is a residual (R factor). Apart from the profit (return/cost) margin $\left(\frac{PP_{c,r,t-1}+EPY_{c,r,t}}{\zeta\times CPCI_{c,r,t-1}+(1-\zeta)\times CPCI_t}\right)$, in the yield equation there is a time-trend component (T) that approximates disembodied Hicks-neutral technological change. Attached to this component, there is an associated γ coefficient approximating the yearly percentage change of crop-specific yield technological progress.

In an addition, which is not part of the core model (Thompson et al. 2017), an endogenous productivity component was designed, for ad-hoc analyses. That component models cost-reducing technological progress (through the $CPCI$ indexes) and transfers the changes in those variables, in part, to an endogenous time-trend coefficient.

The $EPY_{c,r,t}$ variable represents coupled production subsidies. The variable is usually 0 in major arable crops in the EU, but it can be used to represent ad-hoc scenarios in which subsidies are directed to a specific crop. For example, in recent modelling (Pieralli et al. 2021), the $EPY_{c,r,t}$ variable has been used to model the effect of additional risk-management schemes on production.

The effective agricultural area harvested is usually determined by the agricultural land use (LU) in Europe:

$$AH_{c,r,t} = \frac{LU_{c,r,t}}{\max(1, CRPI_{c,r,t})} + AH2_{c,r,t}, \tag{24}$$

where $CRPI_{c,r,t}$ denotes the "Crop production index" and $AH2_{it}$ denotes "Second and later harvested area". The equation therefore allows for multiple harvests of the same agricultural land in a year.

Total land use (LU_{LND}) is the sum of agricultural use (LU_{AGR}), including the pasture and fodder area, forestry (LU_{FST}) and other land uses (LU_{OLN}). Agricultural land use (LU_{AGR}) is determined as the total land available minus other land uses and forestry as $LU_{AGR} = LU_{LND} - LU_{OLN} - LU_{FST}$.

Once determined, agricultural land use (LU_{AGR}) is allocated through land use shares (e.g., for maize, $LU..SHR..EQ_{MA}$) to the arable crop land uses (cotton, maize, other coarse grains, soybeans, other oilseeds, pulses, roots and tubers, rice, sugar beet, wheat, and other agricultural uses). The land-use system is treated in more detail in Chapter 3.

3.3 Arable crop consumption

Most arable crops are consumed domestically (QC) as food (FO), feed (FE), biofuels (BF), crushing (CR) for vegetable oil, sweetener (SW), high-fructose corn syrup (*HFCS*), or other uses (OU).

$$QC_{c,r,t} = FO_{c,r,t} + FE_{c,r,t} + BF_{c,r,t} + CR_{c,r,t} + SW_{c,r,t} + HFCS_{c,r,t} + OU_{c,r,t}. \tag{25}$$

Arable crops used as biofuel is calculated by multiplying the biofuel use at the EU level by an exogenous share ($BF..SHR_{c,t}$): $BF_{c,t} = BF_{EUN,t} \times BF..SHR_{c,t}$.

Oilseeds use for crushing $CR_{v,r,t}$ depends on the crushing margins of all the oilseed crops ($CRMAR_{v,r,t}$), their respective elasticities β_v, and a time trend:

$$\log\left(CR_{v,r,t}\right) = \alpha + \sum_{v\in OL} \beta_v \log\left(CRMAR_{v,r,t}\right) + \gamma\, T + \log\left(R_{CR,v,r,t}\right), \tag{26}$$

where $OL = \{SB, RP, SF\}$, i.e., the arable crops v in the OL group are soybeans (SB), rapeseed (RP), and sunflower (SF).

In the model, food use of wheat, coarse grains, oilseeds, vegetable oils and rice is a function of consumer prices (CP) of other competing commodities deflated by the consumer price index (CPI), the per capita Gross Domestic Product index, population, and a time trend T. I.e.,

$$\log\left(FO_{c,r,t}\right) = \sum_{s\in S} \alpha_s \log\left(\frac{CP_{s,r,t}}{CPI_{r,t}}\right) + \beta \log\left(\frac{GDPI_{r,t}}{POP_{r,t}}\right) + \log\left(POP_{r,t}\right) + \delta\, T + \log\left(R_{FO,s,r,t}\right), \tag{27}$$

where S denotes the set of food commodities included in the food demand equations. The coefficients β are largely positive for arable crops and for most goods implying an increase in food consumption with an increase in per capita GDP (these are normal goods). Some goods (coarse grains, rice, and roots and tubers), however, have negative (albeit very small) elasticities mimicking the behaviour of an inferior good. These are goods whose demand decreases if wealth (proxied by per capita GDP) increases. The coefficients α_s represent own- and cross-price elasticities with the first being negative and the latter being positive. Intuitively, food demand for a good decreases with increases in its own consumer price and, vice-versa, increases with increases in other products' prices. As the population term has a coefficient of 1, it could implicitly be brought to the left-hand side turning the equation into a per-capita food-demand function. Food demand functions in Aglink-Cosimo are homogenous of degree zero.

Other uses of arable crops are directly modelled as a function of how expensive the commodity is (PP) with respect to a consumer price inflation index (CPI) and a time trend (T):

$$\log\left(OU_{c,r,t}\right) = \alpha + \beta \log\left(\frac{PP_{c,r,t}}{CPI}\right) + \gamma \log\left(GDPI_{c,r,t}\right) + \delta\, T + \log\left(R_{OU,c,r,t}\right) \tag{28}$$

For barley, other cereals, oats, and rye, the food consumption of a crop is obtained by multiplying an aggregate "other coarse grains" food use by a share proportional to the ratio of the producer price of the crop and that of maize:

$$\log(FO..SHR_{c,r,t}) = \alpha + \beta \log\left(\frac{PP_{c,r,t}}{PP_{MA,r,t}}\right) + \log(R_{FO..SHR,c,r,t}). \quad (29)$$

The parameters β can be interpreted as own-price elasticities of demand and, for that reason, they are negative.

Arable crop stocks are composed of private and public intervention stocks. For the crops in which the stocks are not differentiated (all but barley, maize, rice, soft wheat and sugar), stocks are modelled similarly to private stocks:

$$\log(ST_{c,t}) = \alpha + \beta\log(QP_{c,t} + ST_{c,t-1}) + \gamma\log(QC_{c,t}) + \delta\log\left(\frac{PP_{c,t}}{\frac{1}{3}\sum_{p=1}^{3} P\,P_{c,t-p}}\right) + \eta\,T + \log(R_{ST,c,t}). \quad (30)$$

The equation shows stocks to depend positively on the quantity produced and stored in the past (β>0), negatively on the quantity consumed (γ<0) and negatively on the difference in producer price between present and past years (δ<0). The expression also includes a time trend. Intervention stocks are exogenous. While the first term $QP_{c,t} + ST_{c,t-1}$ represents the "transactional motive" of storage, the term $\frac{PP_{c,t}}{\frac{1}{3}\sum_{p=1}^{3} PP_{c,t-p}}$ represents the "speculative motive".

In each of the regions (E14 and NMS), consumer prices (CP) differ from producer prices (PP) by ad valorem taxes (TAX), retail margins (MAR), and additional specific taxes ($ADDTAX$):

$$CP_{c,r,t} = (PP_{c,r,t} + MAR_{c,r,t}) \times \left(1 + \frac{TAX_{c,r,t}}{100}\right) + ADDTAX_{c,r,t}. \quad (31)$$

Consumer prices at the EU level are a population weighted average of the regional ones: $CP_{EUN} = \sum_{r=\{E14,NMS\}} w_{r,POP} CP_{r,t}$, where the weights are the population shares of each EU regional aggregate $w_{E14,POP} = \frac{POP_{E14}}{POP_{E14}+POP_{NMS}}$ and $w_{NMS,POP} = \frac{POP_{NMS}}{POP_{E14}+POP_{NMS}}$.

3.4 Arable crops trade

Part of the domestic production is exported. The quantities exported are a function of the ratio of domestic producer prices $PP_{c,t}$ to international prices (expressed in domestic currency). Exports of different arable commodities are potentially divided into subsidised and unsubsidised exports. Subsidised exports are only present for few crops, such as barley and soft wheat among arable crops. These are only triggered if the domestic producer price is lower than fixed support prices. Subsidised exports are proportional to the difference in price between the domestic producer prices and support prices set by legislation, subject to ceilings.

Unsubsidised exports are usually modelled as follows:

$$\log(EX_{c,t}) = \alpha + \beta \log\left(\frac{PP_{c,t}}{XP_{c,t}XR_{c,t}\left(1 - \frac{TAVE_{c,t}}{100}\right)}\right) + \log(R_{EX,c,t}). \quad (32)$$

Log-exports depend negatively ($\beta < 0$) on the logarithmic difference between the prices described above. The negativity of β implies that a domestic price increasing more than international price -or an international price decreasing more than the domestic price- discourages exports. Very rarely, international export prices at the denominator of the ratio are subtracted of any export tax ($TAVE$).

In a similar manner, imports are given by:

$$\log(IM_{c,t}) = \alpha + \beta\log\left(\frac{PP_{c,t}}{XP_{c,t}XR_{c,t}\left(1 + \frac{TAVI_{c,t}}{100}\right)}\right) + \log(R_{IM,c,t}). \quad (33)$$

Similarly to Eq. (32), log-imports depend on a wedge between local and international prices denominated in domestic currency ($XP_{c,t}\,XR_{c,t}$), but elasticity β is positive. This implies that imports increase when domestic prices increase more than international prices or when the latter decrease more than the former. International import prices in domestic currency at the denominator are augmented by an ad valorem import tariff. Therefore, import tariffs decrease the competitiveness of foreign products by lowering the price difference with domestic products. More on import tariffs in Chapter 11.

4 VEGETABLE OILS AND PROTEIN MEALS

Some arable crops are used as intermediate products to produce vegetable oils and protein meals. The vegetable oils included in the model are oilseed oils (rapeseed oil, sunflower oil, soybean oil and groundnut oil), coconut oil, palm kernel oil, palm oil, and cottonseed oil. In the EU module, palm oil production is assumed to be zero, while cottonseed oil is only -and in small amounts- produced in E14. Groundnut production is exogenous, while coconut is only imported.

Vegetable oil production depends on the quantity of oilseed crops crushed ($CR_{c,r,t}$) and the oil yield ($YLD_{L,c,r,t}$: i.e., the quantity of oil (L) that can be obtained from a certain quantity of crop crushed):

$$QP_{L,c,r,t} = YLD_{L,c,r,t} \times CR_{c,r,t}. \tag{34}$$

The quantity crushed for every crop $CR_{c,r,t}$ is dependent on the crushing margins of all the oilseed crops ($CRMAR_{c,r,t}$), their respective elasticities β_v, and a time trend T:

$$\log(CR_{v,r,t}) = \alpha + \sum_{v \in OL} \beta_v \log(CRMAR_{v,r,t}) + \gamma\, T + \log(R_{CR,v,r,t}), \tag{35}$$

where the crops v in the OL set are soybeans, rapeseed, and sunflower.

The crushing margin is calculated as an average of the yields obtained from the production of oilseed oils (L) and protein meals (M) for each of the oilseeds (sum of revenues per tonne of oilseed oil or protein meal divided by the price of the crushed crop):

$$CRMAR_{v,r,t} = \frac{PP_{L,v,r,t} \times YLD_{L,v,r,t} + PP_{M,v,r,t} \times YLD_{M,v,r,t}}{PP_{v,r,t}} \tag{36}$$

where $PP_{L,v,r,t}$ represents the prices of soybean, sunflower and rapeseed oils, $PP_{M,v,r,t}$ represent the prices of soybean, sunflower or rapeseed meals, while $YLD_{L,v,r,t}$ and $YLD_{M,v,r,t}$ represent, respectively, the yields of oilseed oils and protein meals for the three oilseed crops considered (see Table 3).

Oilseed meal is an aggregate of soybean, rapeseed, sunflower, and groundnut meals. The total production of protein meals is an aggregate of oilseed meal plus coconut, cottonseed, and palm kernel meals. The production of oilseed meal in the model is similar to the above description for oilseed oils. In this case, the production comes from multiplication of oilseed crop crushed ($CR_{c,r,t}$) and meal yield ($YLD_{M,c,r,t}$, i.e. the quantity of meal obtainable from a certain quantity of crop crushed):

$$QP_{M,c,r,t} = YLD_{M,c,r,t} \times CR_{c,r,t}. \tag{37}$$

All yields of protein meals are reported in Table 3. All oilseeds utilised are reported in Table 4. A representation of how the aggregates are formed is in Figure 2. Consumption, trade, and stocks of vegetable oils and protein meals are modelled in a similar fashion as the arable crops.

5 SUGAR

The European sugar market in Aglink-Cosimo is modelled considering the use of sugar beet for both biofuels and sugar. Sugar production is calculated as a function of sugar beet production only, meaning that domestic sugar cane production is assumed to be zero:

$$QP_{SU,r,t} = YLD_{SBE..SU,r,t} \times \left(QP_{SBE,r,t} - BF_{SBE,r,t}\right). \tag{38}$$

In the above equation $YLD_{SBE..SU,r,t}$ is the extraction rate of sugar beet to sugar (i.e., how much sugar can be produced with one tonne of sugar beet) while $BF_{SBE,r,t}$ is the quantity of sugar beet used for biofuels production. Eq. (38) shows that the production quantity of sugar is obtained by multiplying the extraction rate by the amount of sugar beet that is not used for biofuels.

Sugar beet production and land allocation follows the same method as for other arable crops. Following the EU reforms in 2017, there is no longer a quota for sugar nor support prices in the EU. Quantity consumed and food demand are modelled in the same way as in the arable crops' case. Private stocks of sugar are modelled as in Eq. (30). Intervention stocks of sugar are modelled as the maximum between zero and the amount $(Support\ Price - Levy - Producer\ Price) * 1000$, which is the difference between support price, levy, and producer price.

Exports of white sugar until 2016 were supported but this is not the case anymore: only unsubsidized exports of white sugar remain, and they are treated the same as exports in Eq. (32). European sugar imports are modelled as in Eq. (33). One part of European sugar imports comes from the "Everything but Arms" countries, least developed countries for whom all import tariffs are removed except for arms and ammunitions. In this case there are no import tariffs $(TAVI = 0)$.

6 MILK AND DAIRY PRODUCTS

In the following two subsections, modelling of milk and dairy products is shown after considering the important reforms occurred with the end of the EU milk quota in 2015.

6.1 Milk

After the expiry of the EU quota regime, milk production $QP_{MK,r,t}$ is now given by the dairy cow inventory ($CI_{MK,r,t}$) times the milk yield ($YLD_{MK,r,t}$), representing how much milk can be produced by a dairy cow, plus the production of milk from other cows (non-dairy or buffalo, $QP_{MK..OTH,r,t}$):

$$QP_{MK,r,t} = CI_{MK,r,t} \times YLD_{MK,r,t} + QP_{MK..OTH,r,t}. \tag{39}$$

The production of milk from dairy cows is therefore a function of two endogenous variables: the milk yield ($YLD_{MK,r,t}$) per cow and the number of dairy cows - i.e., the dairy-cow inventory ($CI_{MK,r,t}$).

Following a similar specification as in the case of arable cropping yields, milk yields in the EU module are modelled as functions of the gross margin per tonne of output[8], of the ruminant feed cost margin[9], and of a time trend T:

$$\log\left(YLD_{MK,r,t}\right) = \alpha + \beta \log\left(\frac{PP_{MK,r,t} + EPY_{MK,r,t}}{CPCI_{MK,r,t}}\right) + \gamma \log\left(\frac{FECI_{RU,r,t}}{CPCI_{MK,r,t}}\right) + \delta\ \mathrm{T} + \log\left(R_{MK,r,t}\right). \tag{40}$$

In the above equation, $PP_{MK,r,t}$ is the producer price of milk, $EPY_{MK,r,t}$ is the milk coupled support payments, $CPCI_{MK,r,t}$ is the cost of milk production, $FECI_{RU,r,t}$ is the cost of an average protein feed for ruminants, and δ is the disembodied level of technological progress per year in milk production.

The number of dairy cows producing milk (i.e., the dairy-cow inventory) depends on the present and past profit margin for milk, on the present and past cost margins for feeding a ruminant, and on the potential profit margin of producing beef meat:

$$\log\left(CI_{MK,r,t}\right) = \alpha + \sum_{p=0}^{1} \beta_p \log\left(\frac{PP_{MK,r,t-p} + EPI_{MK,r,t-p}}{CPCI_{MK,r,t-p}}\right) + \gamma_p \log\left(\frac{FECI_{RU,r,t-p}}{CPCI_{MK,r,t-p}}\right)$$
$$+ \delta_p \log\left(\frac{PP_{BV,r,t} + EPQ_{BV,r,t-p}}{CPCI_{MK,r,t-p}}\right) + \eta \log(CI_{MK,r,t-1}) + \log\left(R_{CI..MK,r,t}\right). \tag{41}$$

where $PP_{MK,r,t}$ is the producer price of milk, $PP_{BV,r,t}$ is the producer price of beef meat, $EPI_{MK,r,t}$ and $EPQ_{BV,r,t}$ are the milk and beef coupled support payments. The cost of average protein feed for ruminants is equal to the price of average protein feed, which is discussed in the feed demand module discussion.

[8] Milk producer price plus voluntary coupled support divided by the cost of production commodity index.
[9] Cost of an average protein feed for ruminants $FECI_{RU,r,t}$ divided by the cost of milk index $CPCI_{MK,r,t}$.

Fat and non-fat milk solids supply from milk is obtained in EUN as a weighted average of the fat ($FAT_{MK,r,t}$) and non-fat solids ($NFS_{MK,r,t}$) average contents in the E14 and NMS regions:

$$FAT_{MK,EUN,t} = \frac{\sum_{r\in\{E14,NMS\}} Q\,P_{MK,r,t} \times FAT_{MK,r,t}}{QP_{MK,EUN,t}} \tag{42}$$

and

$$NFS_{MK,EUN,t} = \frac{\sum_{r\in\{E14,NMS\}} Q\,P_{MK,r,t} \times NFS_{MK,r,t}}{QP_{MK,EUN,t}}. \tag{43}$$

A common (EUN) milk price is calculated as a weighted average of E14 and NMS milk supplies $PP_{MK,EUN,t} = \frac{\sum_{r\in\{E14,NMS\}} QP_{MK,r,t} \times PP_{MK,r,t}}{QP_{MK,EUN,t}}$. The regional milk prices are linear functions of the fat and non-fat solids prices in each of the two regional aggregates (weighted by the fat and non-fat solid content of milk, respectively). The clearing equations for fat and non-fat solids include the fat components not only from milk (subtracting farm use, FU) but also from all other dairy products (fresh dairy products FDP, other fat products OFP, butter BT, cheese CH, whole milk powder WMP, skimmed milk powder SMP, casein CA, and whey powder WYP), which are introduced in the following subsection. By multiplying all quantities of single dairy products by the average percentage of fat content, the model clears the milk fat quantity market:

$$PP..FAT^{*}_{MK,r,t} \;=\; PP..FAT_{MK,r,t} > 0$$

$$such\ that$$

$$\begin{aligned}&(QP_{MK} - FU_{MK}) \times FAT_{MK} - QP_{FDP} \times FAT_{FDP} - QP_{BT} \times FAT_{BT} - QP_{CH} \times FAT_{CH} \\ &-QP_{SMP} \times FAT_{SMP} - QP_{WMP} \times FAT_{WMP} - QP_{CA} \times FAT_{CA} - QP_{WYP} \times FAT_{WYP} - QP_{OFP} = 0.\end{aligned} \tag{44}$$

Similarly, the model clears the non-fat solids market:

$$PP..NFS^{*}_{MK,r,t} \;=\; PP..NFS_{MK,r,t} > 0$$

$$such\ that$$

$$\begin{aligned}&(QP_{MK} - FU_{MK}) \times NFS_{MK} - QP_{FDP} \times NFS_{FDP} - QP_{BT} \times NFS_{BT} - QP_{CH} \times NFS_{CH} \\ &-QP_{SMP} \times NFS_{SMP} - QP_{WMP} \times NFS_{WMP} - QP_{CA} \times NFS_{CA} - QP_{WYP} \times NFS_{WYP} - QP_{OFP} = 0.\end{aligned} \tag{45}$$

All products in Eq. (44) and (45) are functions of fat and non-fat prices, respectively. Fresh milk is not traded as such but in the form of dairy products obtained from milk. These are introduced in the next section.

6.2 Dairy products

Dairy products modelled in Aglink-Cosimo include fresh dairy products (FDP), other fat products (OFP), butter (BT), cheese (CH), whole milk powder (WMP), skimmed milk powder (SMP), casein (CA), and whey powder (WYP).

All dairy products have a similar clearing equation as Eq. (2). The exception is other dairy product containing fat solids (OFP) that clear the market by simply equating quantity produced and quantity consumed: $QP_{OFP} = QC_{OFP}$.

Cheese production is given by the sum of dairy ($QP_{CH..DY,r,t}$ from fresh dairy cow milk) and non-dairy ($QP_{CH..ND,r,t}$ from other milk) cheese production:

$$QP_{CH,r,t} = QP_{CH..DY,r,t} + QP_{CH..ND,r,t}. \tag{46}$$

Production of butter, fresh dairy products, other fat products, skimmed milk powder, whole milk powder, casein, and dairy cheese production is given by equations of the following form:

$$\log(QP_{d,r,t}) = \alpha + \beta\log\left(\frac{PP_{d,r,t}}{PP_{MK..FAT,r,t} \times FAT_{d,r,t} + PP_{MK..NFS,r,t} \times NFS_{d,r,t}}\right) + \log(R_{d,r,t}), \tag{47}$$

where d is a dairy product element of the set $DP = \{BT, FDP, OFP, SMP, WMP, CA, CH\}$. The quantity produced of each dairy product $QP_{d,r,t}$ is linked to the gross margin, defined as the ratio between producer price and a weighted average of the fat and non-fat milk solids price. Butter and skimmed milk powder prices are typically used as proxies for fat and non-fat solid prices.

Cheese production from milk other than cow milk is modelled with a simple time trend:

$$QP_{CH..ND,r,t} = (\alpha + \beta\, T) \times (R_{CH..ND,r,t}). \tag{48}$$

Finally, whey powder production is linked to the cheese production and to a time trend as follows:

$$\log QP_{WYP,r,t} = \alpha + \beta \log QP_{CH,r,t} + \gamma\, T + \log(R_{WYP,r,t}). \tag{49}$$

Quantities consumed of dairy products are modelled in a similar way as arable crops. Food demand and other uses of dairy products are also modelled similarly to arable crops. Quantities consumed of other dairy product containing fat solids are modelled similarly to the quantity demanded for food of other arable crop products:

$$\log\left(QC_{OFP,r,t}\right) = \alpha + \beta \log\left(\frac{PP_{OFP,r,t}}{CPI_{r,t}}\right) + \log\left(POP_{r,t}\right) + \gamma \log\left(\frac{GDPI_{r,t}}{POP_{r,t}}\right) + \log\left(R_{QC,c,r,t}\right). \quad (50)$$

Imports and exports of dairy products are modelled as the arable crops in Eq. (33) and (32), respectively. Consumer prices, margins and food consumption demand for dairy products are analogously modelled as in the arable crops case.

Changes in stocks for butter, skimmed milk powder and cheese are modelled at the EU aggregate level to correspond to the difference between intervention stocks in one year and previous year intervention stocks ($IST_t - IST_{t-1}$), plus variation in private stocks VST_{PRST} to obtain: $VST = IST_t - IST_{t-1} + VST_{PRST,t}$. Dairy stocks are exogenous in the model. Moreover, in the case of cheese there are no private stocks in the database.

7 MEAT AND LIVESTOCK PRODUCTS

The EU module of Aglink-Cosimo calculates endogenously the production of chicken (CK), other poultry (OP), beef and veal (BV), pork (PK), and sheep and goat meat (SH). Similarly to other products, the quantity produced of beef and veal is a function of the following elements:

(i) a weighted average of returns (present year and past two years) in the form of a gross margin: producer price ($PP_{c,r,t}$) and subsidies ($EPQ_{c,r,t}$) divided by the cost of production commodity index ($CPCI_{c,r,t}$);

(ii) a weighted average of feed costs during the last three years in the form of a feed cost index ($FECI_{c,r,t}$) divided by a cost of production commodity index;

(iii) the previous year's production quantity ($QP_{c,r,t-1}$);

(iv) the beef cow inventory from the two previous years ($CI_{BV,r,t-p}$) and the dairy cow inventory from the two previous year ($CI_{MK,r,t-p}$);

(v) a time trend (T).

The structure of the equations in the model for the production of beef and veal livestock (BV) is:

$$\begin{aligned}\log QP_{BV,r,t} = \quad & \alpha + \sum_{p=0}^{2} \beta_p \log\left(\frac{PP_{BV,r,t-p} + EPQ_{BV,r,t-p}}{CPCI_{BV,r,t-p}}\right) + \sum_{p=1}^{3} \gamma_p \log\left(\frac{FECI_{RU,r,t-p}}{CPCI_{MK,r,t-p}}\right) \\ & + \sum_{p=1}^{2} \delta_p \left(CI_{BV,r,t-p}\right) + \left(\eta CI_{MK,r,t-1} + \theta QP_{BV,r,t-1}\right) + \zeta\, T + \log\left(R_{BV,r,t}\right). \end{aligned} \tag{51}$$

In the case of sheep and goat meat (SH), the production Eq. (52) only includes two years lagged feed cost margins because their average permanence on farm is shorter than for beef and veal. In other words, producers can choose to either devote feed to sheep and goat instead of other animals during the last two years because of the sheep and goat growth cycle. For the same reason, producers choose the intensity of production looking at the past year revenue margin as shown in the following equation:

$$\begin{aligned}\log QP_{SH,r,t} = \quad & \alpha + \beta \log\left(\frac{PP_{SH,r,t-1} + EPQ_{SH,r,t-1}}{CPCI_{SH,r,t-1}}\right) + \sum_{p=1}^{2} \gamma_p \log\left(\frac{FECI_{RU,r,t-p}}{CPCI_{SH,r,t-p}}\right) \\ & + \delta QP_{SH,r,t-1} + \log\left(R_{SH,r,t}\right). \end{aligned} \tag{52}$$

In the case of chicken (CK) and other poultry (OP) the production equation is simplified, given that the influence on present production choices from past years is limited. The growth cycle of typical commercial poultry is few months. For every element l of the set $\{CK, OP\}$ quantity produced of the product is given by:

$$\log\left(QP_{l,r,t}\right) = \alpha + \beta \log\left(\frac{PP_{l,r,t} + EPQ_{l,r,t}}{CPCI_{l,r,t}}\right) + \gamma \log\left(\frac{FECI_{NR,r,t}}{CPCI_{PT,r,t}}\right) + \delta QP_{l,r,t-1} + \log\left(R_{l,r,t}\right). \tag{53}$$

In the case of pigmeat or pork (PK), the quantity produced is given by the sum of net trade in live animals (NTL) and the quantity of slaughtered animals (QPS):

$$QP_{PK,r,t} = QPS_{PK,r,t} + NTL_{PK,r,t} \tag{54}$$

The quantity slaughtered represents the net production and is endogenously calculated. Production depends on the number of animals slaughtered (SLH) and the carcass weight (CW)[10]:

$$QPS_{PK,r,t} = SLH_{PK,r,t} \times CW_{PK,r,t} \tag{55}$$

[10] Carcass weights are expressed in tonnes per animal head. A carcass weight is only a fraction of the live weight of the animal as a part of the live animal is offal (and excluded from the carcass weight).

The number of slaughtered animals (SLH) depends on revenues and the feed cost index to recognise the drivers of production decisions. Decisions on how many animals are slaughtered in a year depend on the economic returns of the previous year, and on the feed costs. In order to account for the persistence in this type of production, the number of animals slaughtered in the current year also depends on the number of slaughtered animals in the previous year:

$$\begin{aligned}\log SLH_{PK,r,t} = \quad & \alpha + \beta \log\left(\frac{PP_{PK,r,t-1} + EPQ_{PK,r,t-1}}{CPCI_{PK,r,t-1}}\right) + \gamma \log\left(\frac{FECI_{NR,r,t-1}}{GDPD_{ME,r,t-1}}\right) \\ & + \delta\, SLH_{PK,r,t-1} + \log\left(R_{PK,r,t}\right). \end{aligned} \tag{56}$$

Pork carcass weight is modelled following a similar formula used for calculating supply of other meats. Carcass weight (CW) depends on revenue gross margin and the feed cost margin of the current year to show the dependence of the final animal weight on what occurs in the present year:

$$\log CW_{PK,r,t} = \alpha + \beta \log\left(\frac{PP_{PK,r,t} + EPQ_{PK,r,t}}{CPCI_{PK,r,t}}\right) + \gamma \log\left(\frac{FECI_{NR,r,t}}{GDPD_{ME,r,t}}\right) + \delta\, T + \log\left(R_{PK,r,t}\right). \tag{57}$$

Livestock inventories for pigmeat (PK), poultry ($PT = CK + OP$) and sheep (SH) are modelled as dependent on production and a time trend for each livestock product as follows:

$$\log LI_{l,r,t} = \alpha + \beta \log\left(QP_{l,r,t}\right) + \gamma\, T + \log\left(R_{l,r,t}\right), \tag{58}$$

where $l \in \{PK,\ PT,\ SH\}$. That is, the relationship between meat production and animal numbers in Aglink-Cosimo is different than a standard production function framework.

The beef-and-veal livestock inventory is modelled as a weighted average of the present year and past two years of the dairy (CI_{MK}) and non-dairy (CI_{BV}) cow inventories:

$$LI_{BV,r,t} = \sum_{p=0}^{2} w_{BV,r,t-p} \times \left(CI_{MK,r,t-p} + CI_{BV,r,t-p}\right). \tag{59}$$

The weights $w_{BV,r,t}$ are different depending on the region and the year lag (see Table 5 for more details).

The beef and veal cow inventory depends on the present and past two years gross revenue margins (ratio of returns and production cost) and on the past three years feed margins (ratio between feed cost index and production cost index), on the one-year lagged dairy and beef cow inventories and on a time trend:

$$\begin{aligned}\log CI_{BV,r,t} = \quad & \alpha + \sum_{p=0}^{2} \beta_p \log\left(\frac{CW_{BV,r,t-p} \times \left(PP_{BV,r,t-p} + EPQ_{BV,r,t-p}\right)}{CPCI_{BV,r,t-p}}\right) + \sum_{p=1}^{3} \gamma_p \log\left(\frac{FECI_{RU,r,t-p}}{CPCI_{BV,r,t-p}}\right) \\ & + \delta \log\left(CI_{BV,r,t-1}\right) + \eta \log\left(CI_{MK,r,t-1}\right) + \theta\, T + \log\left(R_{BV,r,t}\right). \qquad (60)\end{aligned}$$

The past three years ratios of feed cost margins are present to account for the potential substitution between increasing beef cow numbers, the cost of feeding a ruminant, and the production cost. The past three years are enough to capture sudden spikes in past feed costs that might have reduced the profitability of the current-year production, such as for example a drought or a disruption to feed markets. The sum of lagged prices received by the farmers $PP_{BV,r,t-p}$ and coupled support $EPQ_{BV,r,t-p}$ times the carcass weight are called "returns" $RET_{BV,r,t-p} = \left(PP_{BV,r,t-p} + EPQ_{BV,r,t-p}\right) \times CW_{BV,r,t-p}$.

Consumer prices, consumer price margins, and food demand for all livestock products are modelled similarly to arable crops.

Beef and veal stocks are modelled similarly to arable crop stocks:

$$\log\left(ST_{BV,t}\right) = \alpha + \beta \log\left(\frac{QC_{c,t} + QC_{c,t-1}}{2}\right) + \gamma \log\left(\frac{PP_{c,t}}{\frac{1}{3}\sum_{p=1}^{3} PP_{c,t-p}}\right) + \delta\, T + \log\left(R_{ST,BV,t}\right). \qquad (61)$$

The equation models stocks depending positively on the average quantity consumed in the current and past year ($\beta = 0.1$), negatively on the difference in producer price between present and past years ($\gamma = -0.2$), and negatively ($\delta = -0.01$) on a time trend. This last negative coefficient captures the historical stock level decreases over time.

Exports of poultry is modelled through Eq. (32). Exports of beef and veal, pork and sheep are the sum of meat exports and live animals: $EX = EXM + EXL$. While live animals are exogenous, meat exports of sheep, beef and pork are endogenous. Sheep meat exports are modelled similarly to Eq. (32). Instead, beef and pigmeat are modelled as the sum of subsidised and unsubsidised exports. While subsidised exports ($EXM..SUB$) are exogenous (and set to zero since 2011), unsubsidised exports ($EXM..UNS$) are endogenous and modelled in a similar way as Eq. (32) in the case of beef and veal. The unsubsidised pigmeat portion of exports is modelled as the sum of exports to the Pacific, Atlantic and China regions. The Atlantic and Pacific market exports of pigmeat are modelled similarly to Eq. (32). Finally, exports to China are equal to the demand of pigmeat imports in China from the EU, which is a standard import equation depending on the domestic/international price ratio.

8 BIOFUELS

The quantity of diesel and gasoline consumed in transportation (incl. biofuels added to the blend) is explained in OECD (2018). We draw on that description and on the successive modifications done to the model to describe the module here. The EU module is very similar to the treatment of biofuels in other countries or regions in the model. Some of the module fundamental characteristics (OECD 2018) are that the model is non-spatial, only includes homogeneous products, and the biodiesel and ethanol products are exclusive and non-substitutable.

Demand for biofuels is mainly driven by policies (mandates) and connected to the rest of the agricultural sectors through the feedstocks used for biofuels production. Food-based feedstocks are also used for livestock feed and for food. That implies that the biofuels production is in direct competition with those other derived products.

8.1 Biofuels production

Biofuels are produced from a variety of feedstocks introduced in Chapter 4 (Arable Crops). These feedstocks (FS) differ depending on the country. In the EU, ethanol (ET) is produced by sugarcane (SCA), molasses (MOL), sugar beet (SBE), maize (MA), other coarse grains (OCG), wheat (WT), rice (RI), roots and tubers (RT), agricultural residues ($ARES$), forest residues ($FRES$), dedicated energy crops (ECR), municipal solid waste (MSW), and other waste and residues ($OTHW$). Biodiesel (BD) is produced by vegetable oils (VL), waste oils and fats (WLF), jathropa (JA), agricultural residues ($ARES$), forest residues ($FRES$), dedicated energy crops (ECR), municipal solid waste (MSW), and other waste and residues ($OTHW$). Vegetable oils (VL) includes soybean oil (SL), rapeseed oil (RL), sunflower oil (SFL), palm kernel oil (PL), and other vegetable oils (OVL).

Quantities of each biofuel (FL) are modelled as the sum of feedstocks used either for ethanol or for biodiesel. Each feedstock use (FS) for biofuels is modelled as a weighted average of present and lagged (3 lags) profits (RM) of the feedstock, separately in two different equations for the production of each biofuel (one equation for ethanol and one for biodiesel):

$$\log FS_{FL,r,t} = \quad \alpha + \sum_{p=0}^{3} \beta_p \log\left(RM_{FL,FS,r,t-p}\right) + \log FS_{FL,r,t-1} + \log\left(R_{FL,r,t}\right), \tag{62}$$

where $FL = \{ET, BD\}$ and feedstock (FS) is each of the feedstocks used for either biodiesel or ethanol. Each of the feedstock profits in producing biofuels is modelled as the sum of producer prices, coupled payments, and biofuel value of beet pulp, divided by the cost of production index of that biofuel (FL) using that feedstock (FS): $RM_{FL,FS,r,t} = \frac{PP_{FL,r,t}+DP_{FL,FS,r,t}+BPVAL_{FL,FS,r,t}}{CPCI_{FL,FS,r,t}}$.

The production cost index $CPCI$ is similar to the ones introduced in Eq. (21). It is a weighted average of deflated past prices of the feedstock, deflated world oil prices, and real GDP:

$$CPCI_{FL,FS,r,t} = \sum_{s \in S} w_{s,FL,FS,r,t} \times PI\left(P_{s,FL,FS,r,t}\right), \tag{63}$$

where $CPCI_{FL,FS,r,t}$ is the production cost index for fuel FL in region r in year t for feedstock FS and the weights w_s measure the importance of deflated past prices of feedstock, of deflated energy (identified in the world oil) prices, and of the cost of co-products (proxied with real GDP) in the total production cost index.

8.2 Biofuels consumption

Consumption of biofuels (ethanol or biodiesel) is the sum of fuel uses and other uses of biodiesel and ethanol: $QC_t = FL_t + OU_t$. Aglink-Cosimo only explicitly models domestic fuel use (FL) while other uses (OU) are exogenously determined.

Domestic total fuel (ethanol or biodiesel) consumption is composed of high and low blends: $FL_t = HBLD_t + LBLD_t$.

The majority of domestic ethanol consumed in the EU is low blend, which is mainly driven by domestic policy mandates. The low blend ethanol fuel use equals the effective share of ethanol quantity times the low blend gasoline quantity consumed, expressed in energy equivalents: $LBLD_{FL} = QCS..EFF_{FL} \times \frac{QC..TRAN_{FL}}{EE_{FL,WLD}}$. Similarly, the high blend portion of domestic biofuel (biodiesel or ethanol) consumed in Europe is the share of high blend biofuel (biodiesel or ethanol) of the fuel (diesel or gasoline, respectively) quantity consumed for transportation.

The effective share $(QCS..EFF)$ of either biofuel $\{ET, BD\}$ is the maximum of the mandate driven adjusted energy equivalent share $(QCS..OBL..AD)$ and the non-mandate driven share (QCS). The non-mandate driven uses of fuels (QCS) comprise the share of domestic fuel additive use $(QCS..ADD)$ and the market-induced share $(QCS..LBLD)$ of low blend fuels.

While the share of high blend biofuel ($QCS..HBLD$) is exogenous, the share of domestic low blend biofuel use ($QCS..LBLD$) is equal to the minimum of the share of market-driven biofuel use and the difference among the blend wall limit and the share of biofuel additive fuel use: $QCS..LBLD = \min(LBLD_{SHARE}, LIMIT - QCS..LBLD..EQ)$. The share of biofuel additive fuel use is modelled as: $QCS..LBLD..EQ = \frac{1}{1+\exp(4*\kappa_{FL})} \times R_{QCS..LBLD..EQ}$, where $\kappa_{ET} = \left(PREM..GAS - EE_{ET,WLD}\right) \times \left(\frac{CP_{ET}}{CP_{GAS}} - EE_{ET,WLD}\right)$ for the case of ethanol and $\kappa_{BD} = \left(PREM..DIE - EE_{BD,WLD}\right) \times \left(\frac{CP_{BD}}{CP_{DIE}} - EE_{BD,WLD}\right)$ for the case of biodiesel and where $EE_{BF,WLD}$ are the energy equivalents of biofuels BF to fossil fuels, equal to 0.67 for ethanol and 0.92 for biodiesel.

8.3 Fuel consumption

The total domestic quantity consumed of fossil fuel (FF, being either diesel or gasoline) for transportation is modelled as a function of own fuel (diesel, DIE, or gasoline, GAS, respectively) consumer deflated prices, alternative biofuels (BF, being either biodiesel, BD, or ethanol, ET, respectively) consumer deflated prices, GDP per capita, a time trend, and population:

$$\log\left(QC..TRAN_{FF,t}\right) = \alpha + \beta \log\left(\frac{CP_{FF,t}}{GDPD_t}\right) + \gamma \log\left(\frac{CP_{BF,t}}{GDPD_t}\right)$$
$$+\delta \log\left(\frac{GDPI_t}{POP_t}\right) + \eta\, T + \log(POP_t) + \log\left(R_{FL,t}\right). \qquad (64)$$

As the coefficient on the population is 1, if the population term is transferred to the left-hand side, the above equation is interpretable as per capita domestic quantity of transport fuel consumed. The low blend quantity consumed of fuel (diesel/gasoline) is equal to the total quantity consumed modelled as in (64) minus the high blend portion of domestic quantity consumed. These equations allow the connection between modelled conventional fuels and modelled biofuels. Diesel and gasoline consumer prices are modelled as shown for other consumer prices, with the world oil price translated into the price per 100 litres by dividing the brent price by 1.59.

8.4 Trade and stocks of biofuels

Trade of ethanol and biodiesel is modelled as in Eq. (32) and (33). Import and export prices of ethanol and biodiesel are calculated as the world prices in local currency adjusted for the quality in the EU: $EXP_{FL,t} = WP_{FL} \times XR_{EU} \times ADJ_{EU}$.

Differently from arable crops, stocks of ethanol are modelled as follows:

$$\log(ST_{ET,t}) = \alpha + \beta \log\left(\frac{PP_{ET,t}}{\frac{1}{3}\sum_{p=1}^{3} P\,P_{ET,t-p}}\right) + \log(R_{ST,ET,t}). \quad (65)$$

Eq. (65) shows ethanol stocks to be proportional to the difference in producer price between present and past three years’ average. No stocks of biodiesel are modelled.

9 FEED MODULE

The feed demand system in Aglink-Cosimo (Charlebois 2013) includes many feed products. Some products are exogenous (e.g., rice and meat and bone meal). The feed demand module characterizes cross-price effects between feed products and their dependence from livestock categories. Feedstocks used for feed are grouped into three categories depending on their protein level: low-protein feed (LPF), medium-protein feed (MPF) and high-protein feed (HPF).

Feed demand ($FE_{c,r,t}$) is a function of meat production from ruminants (i.e. sheep $QP_{SH,r,t}$ and beef and veal $QP_{BV,r,t}$), of milk production ($QP_{MK,r,t}$), feed use by non-ruminants ($FE_{NR,r,t}$), feed use by aquaculture species ($FE_{FHA,r,t}$), different commodity prices in the EU ($PP_{c,EUN,t}$) and the elasticities of feed use with respect to these commodity prices (in our notation below the γ_c). Feed demand is modelled as follows:

$$\begin{aligned}\log\left(FE_{c,r,t}\right) = \quad & \alpha + \beta_{BV}\log QP_{BV,r,t} + \beta_{SH}\log QP_{SH,r,t} + \beta_{MK}\log QP_{MK,r,t} \\ & + \beta_{FHA}\log QP_{FHA,r,t} + \left(1 - \beta_{BV} - \beta_{SH} - \beta_{MK} - \beta_{FHA}\right) \times \log FE_{NR,r,t} \\ & + \sum\gamma_c \log\left(PP_{c,r,t} \times \frac{1+\epsilon_c}{GDPD_{r,t}}\right) + \eta\,T + \log\left(R_{FE,c,r,t}\right) \end{aligned} \quad (66)$$

where β's are the (positive) elasticities of feed demand with respect to livestock production (beef and veal, sheep meat, milk, aquaculture, non-ruminant feed) and γs are the own- and cross-price elasticities of feed production with respect to producer prices of competing crops, deflated by an adjustment factor (ϵ)[11] and by the GDPD. In accordance with economic theory, the elasticities γ for the own-prices are negative and for the cross-prices are positive. These signs imply that feed demand from a certain commodity decreases if its own price increases and increases if substitutes’ prices increase.

[11] This adjustment factor is explicitly defined in the baseline variables only in the case of protein meals, and varies over time, but it is always negative.

For disaggregated commodities (BP beet pulp, CEB cereal bran, CGF corn-gluten food, DDG distiller's dried grains, MA maize, MOL molasses, PS pulses, RT roots and tubers, SMP skimmed milk powder) equation (66) is the standard way to represent the demand for feed. However, there are important agricultural commodities for which feed demand is aggregated: other coarse grains (OCG), protein meals (PM), and wheat (WT). In these latter aggregate cases, the model has equations for each of the feed product shares composing the aggregates except a commodity of reference in each of the aggregates. The feed shares of the reference goods are calculated as a residual. For the protein meals aggregate, the reference good is soybean meal and for the wheat aggregate the reference good is soft wheat. For the other coarse grains aggregate, there is no reference good per se: every commodity included in the aggregate is modelled separately.

The shares of the aggregated commodities that are not reference goods are modelled as follows:

$$\log\left(FE..SHR_{c,r,t}\right) = \alpha + \beta\log\left(\frac{PP_{c,r,t}}{PP_{REF,r,t}}\right) + \log\left(R_{FE..SHR,c,r,t}\right), \tag{67}$$

where the β for each feed share is negative implying a decrease in feed share if the price of the commodity increases more than the reference commodity in each aggregate (REF). The shares for the reference commodities are calculated as 1 minus the sum of the shares of the other commodities belonging to the same aggregate (but different from the reference good REF), except for other coarse grains:

$$FE..SHR_{REF,r,t,AGG} = 1 - \sum_{c \neq REF} FE..SHR_{c,r,t,AGG}. \tag{68}$$

Eq. (68) is repeated for each different protein meals and wheat aggregate (AGG), and the reference commodities (REF) are soybean meal and soft wheat, respectively.

Distiller's dried grains (DDG) is a by-product of ethanol production from wheat, maize, and other coarse grains. The quantity produced of DDG is modelled as the sum of quantities of feedstocks (FS) used for ethanol production multiplied by conversion factors (CV): $\sum_{FS=\{MA,WT,CG\}} CV_{FS,EUN,t} FS_{ET,EUN,t}$.

The average protein feed is the aggregate of low, medium, and high protein feed:

$$FE_{APF,r,t} = FE_{LPF,r,t} + FE_{MPF,r,t} + FE_{HPF,r,t}. \tag{69}$$

Low-, medium-, and high-protein feeds are the aggregation of feed from commodities with different feed protein content. Low-protein content feed is represented as the sum of feed from maize, other coarse grains, wheat, cereal bran, beet pulp, molasses, rice, and roots and tubers:

$$FE_{LPF,r,t} = \sum_{c \in LPF} FE_{c,r,t}\,, \tag{70}$$

where the set of low-protein feeds is defined as $LPF = \{MA, OCG, WT, CEB, BP, MOL, RI, RT\}$.

Medium-protein content feed is modelled as the sum of feed from corn-gluten feed, distillers' dried grains, pulses, and whey powder:

$$FE_{MPF,r,t} = \sum_{c \in MPF} FE_{c,r,t}\,, \tag{71}$$

where the set of medium-protein feeds is defined as $MPF = \{CGF, DDG, PS, WYP\}$.

High-protein content feed is the sum of feed from palm kernel meal, fish meal, meat and bone meal, and skimmed milk powder:

$$FE_{HPF,r,t} = \sum_{c \in HPF} FE_{c,r,t}\,, \tag{72}$$

where the set of high-protein feeds is defined as $HPF = \{PM, FM, MBM, SMP\}$.

Non-ruminant feed demand ($FD_{NR,r,t}$) is instead modelled as a function of pork, poultry, and eggs product and their feed conversion ratios (FCR), measuring the feed required from each animal to create a certain quantity of product, and the carcass yields:

$$FE_{NR,r,t} = \sum_{nr \in \{PK,PT,EG\}} QP_{nr,r,t} \times FCR_{nr,r,t} / CY_{nr,r,t}\,. \tag{73}$$

Ruminant feed requirements are modelled as the total feed required minus the feed required by non-ruminant (NR) and by the aquaculture sector (FHA):

$$FD_{RU,r,t} = FE_{APF,r,t} - FD_{NR,r,t} - FD_{FHA,r,t}, \tag{74}$$

Where FD_{FHA} is exogenous. The ruminant and non-ruminant feed cost indexes are weighted average prices of feed, equal to the average protein feed price:

$$FECI_{,r,t} = PP_{APF,r,t} = \frac{FE_{LPF,r,t} \times PP_{LPF,r,t} + FE_{MPF,r,t} \times PP_{MPF,r,t} + FE_{HPF,r,t} \times PP_{HPF,r,t}}{FE_{LPF,r,t} + FE_{MPF,r,t} + FE_{HPF,r,t}}. \quad (75)$$

Each of the producer prices of low-protein, medium-protein, and high-protein feeds are, in turn, averages of the prices of the products in each feed category and weighted for how much feed they represent in each category. For example, for the high-protein feed, the producer price is simply $PP_{HPF,r,t} = \sum_{c \in HPF} w_{c,r,t} PP_{c,r,t}$, where $w_{c,r,t} = \frac{FE_{c,r,t}}{FE_{HPF,r,t}}$.

The feed conversion ratio for ruminants is expressed as:

$$FCR_{RU,r,t} = \frac{FE_{RU,r,t}}{\frac{QP_{BV,r,t}}{0.6} + \frac{QP_{SH,r,t}}{0.25} + \frac{QP_{MK,r,t}}{4.8}}. \quad (76)$$

The feed conversion ratios for beef and veal ($FCR_{BV,r,t}$), sheep ($FCR_{SH,r,t}$) and milk ($FCR_{MK,r,t}$) are modelled as functions of the ruminant feed conversion ratio ($FCR_{RU,r,t}$) in the following way:

$$FCR_{BV,r,t} = FCR_{RU,r,t}, \quad (77)$$

$$FCR_{SH,r,t} = \frac{FCR_{RU,r,t}}{2}, \quad (78)$$

$$FCR_{MK,r,t} = \frac{FCR_{RU,r,t}}{4.8}. \quad (79)$$

All types of ruminant feed conversion ratios are related to the common feed conversion ratio for ruminants, accounting for how much feed each animal type requires to produce one unit of the respective output. The numbers at the denominators of Eq. (78) and (79) originate from these considerations. They represent the inverse of how much feed is required to produce each of the products in comparison with beef and veal (base ruminant animal). To make sure the feed conversion ratio in Eq. (76) considers the live weights of beef and veal ($QP_{BV,r,t}$) and sheep meat ($QP_{SH,r,t}$), the quantities are divided by 0.6 and 0.25 respectively.

For non-ruminants, a maximum feed conversion ratio is assumed exogenous to the model and is disaggregated for pork, eggs, and poultry in most developed countries.

10 EU AGRICULTURAL TARIFFS

Ad-valorem import tariffs ($TAVI_{c,r,t}$) depend on ad-valorem in-quota tariffs ($TAV..IQS_{c,r,t}$), endogenous ad-valorem out-of-quota tariffs ($TAVI..OQS_{c,r,t}$), tariff rate quota levels ($TRQ_{c,r,t}$), and imports ($IM_{c,r,t}$):

$$TAVI_{c,r,t} = TAVI..IQS_{c,r,t} + \frac{Max\left(0, TAVI..OQS_{c,r,t} - TAVI..IQS_{c,r,t}\right)}{1 + \exp\left(Max\left(-50, Min\left(50, TRQSL \times \left(1 - \frac{1 + IM_{c,r,t}}{1 + TRQ_{c,r,t}}\right)\right)\right)\right)}, \quad (80)$$

where the parameter $TRQSL$ is equal to either 100 (butter, cheese, rice, rye, durum wheat) or 200 (barley, beef and veal, maize, other cereals, pigmeat, poultry, sheep meat) depending on the product. The $TRQSL$ parameter influences the steepness of the curve in approximating the discrete jump between in-quota and out-of-quota import tariff. The higher is the parameter, the steeper is the jump from in-quota to out-of-quota. A more graphical explanation may be found in Araujo-Enciso et al. (2015). Main ad-valorem import tariffs for commodities are in Table 6.

Eq. (80) is composed of the sum of the ad-valorem in-quota tariff ($TAV..IQS_{c,r,t}$) and a logistic function that approximates the discontinuous behaviour of an actual ad-valorem import tariff, when imports go from lower to higher than the tariff rate quota. Depending on the relative size of imports and tariff rate quota, the logistic function is either almost zero (when the imports are much lower than the tariff-rate quota $IM_{c,r,t} \ll TRQ_{c,r,t}$) or approximating the difference between the out-of-quota and the in-quota tariff (when the imports are approaching the TRQ level or are higher than the tariff rate quota $IM_{c,r,t} > TRQ_{c,r,t}$).

The out-of-quota endogenous tariffs $TAVI..OQS_{c,r,t}$ are expressed as:

$TAVI..OQS_{c,r,t} = TAV..OQS_{c,r,t} + 100 \times \frac{TSP..OQS_{c,r,t}}{IMP_{c,r,t}}$, which equals the exogenous out-of-quota ad-valorem import tariff $TAV..OQS_{c,r,t}$ plus the percentage of import price represented by specific out-of-quota tariffs ($TSP..OQS_{c,r,t}$). In turn, while usually out-of-quota specific tariffs ($TSP..OQS_{c,r,t}$) are exogenous, in some cases (maize, soft and durum wheat, rye, and other cereals) they are endogenously modelled as:

$$TSP..OQS_{c,r,t} = \max\left(0, \min\left(1.55 \times SP_{c,r,t} - IMP_{c,r,t}, TSP..LIM_{c,r,t}\right)\right). \quad (81)$$

The above equation means that the endogenous out-of-quota specific tariff is equal to the higher between 0 and the minimum of the difference between 155% the support price and the import price ($1.55 \times SP_{c,r,t} - IMP_{c,r,t}$) and a lower threshold $TSP..LIM_{c,r,t}$, which is exogenously fixed (maize and other cereals at 94, durum wheat at 148, soft wheat at 95, and rye at 93). The support price for soft wheat is 101.31. For the other crops the support price is not present anymore in the model. Soft wheat and sugar are special cases and have more complicated equations than Eq. (80) (Araujo-Enciso et al. 2015). For some products, like skimmed milk powder, where the support price was 1,400 for incentivising subsidised exports, there are no more subsidised exports.

The ad-valorem in-quota tariff is equal to the minimum of the out-of-quota endogenous tariff $TAVI..OQS_{c,r,t}$ and the in-quota exogenous tariff $TAV..IQS_{c,r,t}$ plus the percentage of import price represented by specific in-quota tariffs ($TSP..IQS_{c,r,t}$):

$$TAVI..IQS_{c,r,t} = \min\left(TAV..IQS_{c,r,t} + 100 \times TSP..\frac{IQS_{c,r,t}}{IMP_{c,r,t}}, TAVI..OQS_{c,r,t}\right).$$

In the case of few products (cereal bran, cotton, high-fructose corn syrup, molasses, whey powder) the aggregated ad-valorem import tariff is equal to the ad-valorem import tariff plus the percentage of import price ($IMP_{c,r,t}$) represented by specific tariffs ($TSP_{c,r,t}$):

$$TAVI_{c,r,t} = TAV_{c,r,t} + 100 \times \frac{TSP_{c,r,t}}{IMP_{c,r,t}}.$$

Ad-valorem export tariffs for the following products are set to 2% in 2020 and 2021, and then at 1% thereafter: barley, biodiesel, beet pulp, cereal bran, cotton, distiller's dried grains, ethanol, high-fructose corn syrup, maize, oats, pigmeat, poultry, rice, rapeseed, roots and tubers, rye, sunflower, sheep meat, soybean oil and meal, whey powder, rapeseed oil and meal, sunflower oil, durum and soft wheat. Ad-valorem export tariffs enter the Eq. (32) in the $TAVE_{c,r,t}$ term.

11 THE COMMON AGRICULTURAL POLICY

The new Common Agricultural Policy (CAP) 2021-27 was agreed on June 25, 2021, but its entry into force has been delayed until 2023. This report considers the condition of the legislation of how the CAP is modelled at the end of November 2021.

Among the tools in the CAP, there are still some direct intervention mechanisms on the market by supporting either public or private storage of low-demanded goods of critical importance. The intervention mechanism is up to 3 million tonnes per year for soft wheat. However, these measures can only be used in case of emergency.

Maximum intervention stock quantities for butter and skimmed milk powder can be bought between March 1 and September 30 if market prices decrease below intervention prices. Helaine et al. (2016) modelled the effect of increasing EU intervention prices for butter and skimmed milk powder. Every year, 50,000 tonnes of butter and 109,000 tonnes of skimmed milk powder can be bought by private operators at fixed intervention prices. Beyond these limits, intervention is open by tender during the intervention period. Public stocks are then sold back to the market via a tendering procedure (EC 2021d). All intervention stocks for these goods are zero in the 2021 baseline.

In emergency cases, the European Commission may also decide to open intervention by tender for durum wheat, barley, maize, and paddy rice. Intervention purchases for barley, durum wheat, maize, and rice intervention stocks (IST) are exogenous and set to zero. Intervention stocks for soft wheat are modelled endogenously through the following equation:

$$IST_{WTS,EUN,t} = \max\left(0, IST_{WTS,EUN,t-1} + \min\left(13000, 500 \times \left(\frac{SP_{WTS,EUN,t}}{PP_{WTS,EUN,t}} - \frac{1}{1.05}\right)\right)\right), \qquad (82)$$

where the intervention stocks are dependent on the support price $SP_{WTS,EUN,t}$ fixed for soft wheat and whether the market price $PP_{WTS,EUN,t}$ goes below 105% of the support price. If that happens, the intervention stocks are triggered until a maximum of 13 million tonnes yearly.

The European Commission may decide to use public intervention if the beef and veal prices go below 2,224 EUR per tonne in a certain area/region for a representative period. The European Commission may grant private storage aid if average prices drop, costs increase, or other factors affect margins too strongly. Emergency measures can also be agreed if animal diseases are spread or consumers lose confidence (EC 2021a). Finally, the EU supports the beef sector through producer organisations.

Butter, skimmed milk powder, and beef intervention stocks are also all zero in the baseline. Even though the probability of reaching intervention prices is low, in some years this may happen. This can also happen in scenario and uncertainty analyses.

Exceptional market measures, such as aided private storage or export refunds, can be deployed to address severe market disturbances. These measures are not explicitly modelled, as they are taken on a case-by-case basis. Production quotas on milk were abolished in April 2015 and sugar and high-fructose corn syrup quotas were abolished in October 2017.

In addition to market interventions specific to some sectors, the CAP also supports farmers through direct payments. The report mostly follows the previous documentation (Araujo-Enciso et al. 2015). Direct payments can be decoupled or coupled:

- Decoupled payments. Following the 2013 CAP reform, intended convergence of direct payments inside the EU can sometimes lead to changes in farm subsidies and income. This convergence will lead to a gradual increase in direct payments in the NMS in parallel to a reduction in the E14. As such, decoupled payments should have no effect on agricultural production choices. However, research suggests that there is an indirect effect of decoupled subsidies on production choices. This coupling factor effect of the single farm payment (the biggest decoupled payment scheme) is currently set at 6 % ($SFP..CF_{AGR,r,t}$). Only this share of the basic payment is added to the crop revenue as detailed in chapter 3 of this report.

- Coupled payments. Further to the 2013 CAP reform, Member States can voluntarily link to production (voluntary coupled support, or VCS) up to 8 % of their direct payments up to 13 % in particular situations or over 13 % subject to the EU Commission's approval[12]. Coupled payments are added to commodity prices as a top-up to the revenue that can influence production decisions. Coupled payments are traditionally significant for beef, milk, sheep and cotton. Coupled payments can also be granted for other products.

Variables related to direct payments are defined according to the item they affect in the model:

- EPA: direct payments affecting area (in EUR/ha);
- EPY: direct payments affecting yields (in EUR/t);
- EPI: direct payments affecting animal inventories (in EUR/head);
- EPQ: subsidy based on quantity produced (in EUR/t).

The amount of EPA is determined based on the decoupled payment envelopes for the E14 or NMS, divided by the total Utilised Agricultural Area (UAA). This means that not only the budget of the basic payment scheme, but also the greening payment, is accounted for (i.e. the underlying assumption is that all farmers respect the

[12] Regulation (EU) 1307/2013, articles 52-53 explain how coupled support can be set up by Member States, text available at https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32013R1307&from=EN.

requirements and claim the payment). The use of total UAA leads to potentially underestimating the payment per hectare, as the total eligible area is smaller than the total UAA. In formulas, the total EPA payment is equivalent to the sum of the single farm payment coupled portion of direct payments $EPA_{AGR,r,t} = SFP..CF_{AGR,r,t} \times SFP_{AGR,r,t} = 6\% \times SFP_{AGR,r,t}$, plus the other coupled payments $EPA..DP_{c,r,t}$: $EPA_{c,r,t} = EPA..DP_{c,r,t} + EPA_{AGR,r,t}$.

For arable crops, the single farm payment is homogeneous in each of the two EU regions (in E14 at 246 EUR per ha and in NMS at 165 EUR per ha). However, the single farm payments for each commodity m (sheep meat, milk, and beef and veal) are calculated as the single farm payment multiplied by the hectares in pasture and fodder per unit of animal live weight ($AN_{r,t}$): $SFP_{m,r,t} = SFP_{AGR,r,t} \times (LU_{PAF,r,t}/AN_{r,t})$, where $AN_{r,t} = \left(\frac{QP_{MK,r,t}}{f_{MK}} + \frac{QP_{BV,r,t}}{f_{BV}} + \frac{QP_{SH,r,t}}{f_{SH}}\right)/f_m$, where f_m are similar to the product conversion factors used in the feed module (e.g., for beef and veal $f_{BV} = 0.6$, for milk $f_{MK} = 4.8$ and for sheep meat $f_{SH} = 1$).

The decoupled and coupled payments for beef are summed up in an EPQ variable calculated per tonne and used in the suckler cow inventory equation, where $EPI..BUDGET$ is the total amount of voluntary coupled support: $EPQ_{BV,r,t} = \frac{EPI..BUDGET_{BV,r,t}}{QP_{BV,r,t}} + (6\% \times SFP_{BV,r,t})$.

For sheep and goats, the modelling is similar to beef except that the coupled payment level is determined exogenously. For milk, the coupled and decoupled payments are aggregated in an EPI variable ($EPI_{MK,r,t}$), which is calculated per head. This variable is determined in a similar way to the total amount of voluntary coupled support for beef and veal ($EPI..BUDGET_{BV,r,t}$): $EPI_{MK,r,t} = \frac{EPI..BUDGET_{MK,r,t}}{CI_{MK,r,t}} + (6\% \times SFP_{BV,r,t})$.

Regarding greening measures, Ecological Focus Area (EFA) should be maintained at 5% of total arable land use. To meet the EFA requirement, farmers can use fallow land areas, areas under nitrogen-fixing crops, catch crops (such as mustard or green cover), and landscape features. The land area set aside is exogenously fixed.

The EU module reflects the CAP reform only in part. Given the geographical aggregation of the model, it is not possible to capture the redistribution of direct payments within Member States and regions. Similarly, the voluntary capping of payments over EUR 150,000 and specific schemes for small and young farmers are not accounted for. The effect of the redistributive payment, a top-up to the basic payment for the first hectares of the holding, as implemented by eight Member States, is also not taken into account.

12 POST-ESTIMATION MODULES

The model includes continuously expanding post-estimation modules that deal with various scientific and policy-relevant topics. Examples pertain to EU farm-income calculations, as well as calorie consumption and greenhouse gas emissions at the regional level.

This documentation treats briefly the EU income module. It is a satellite post-calculation module: a consolidated medium-term baseline and Eurostat data are combined and analysed to derive additional projections on EU agricultural income and its various components over the outlook period.

The statistical basis of the projections for agricultural income is the Economic Accounts for Agriculture (EAA). For subsidies, the data includes coupled and decoupled payments, including state aid and production-related rural development support but does not include investment subsidies. The historical value of production of Aglink products is directly taken from EAA, whereas projected values are indexed to the change in prices and production volumes of the modelled commodities. The value of non-Aglink products mainly captures the value of non-agricultural services and is assumed to follow historical trends.

Total intermediate cost is the sum of the expenditure on seed, feed, energy, fertiliser and other items. The projected expenditure on seed is based on the change in area harvested and producer prices. Feed expenditure in year t is calculated as an average of feed use and prices in previous marketing years. Expenditure on energy and fertiliser is based on the change in the quantity produced and the change in the price of on-farm energy. The size of the agricultural workforce is assumed to follow historical trends.

13 DATA SOURCES AND ASSUMPTIONS

13.1 Producer prices

Most of the prices are based on the Member States notifications to DG AGRI. The EU-27 prices correspond to the E14 average price for historical reasons to ensure longer time series without breaks (except for milk). This affects the trade patterns. Prior to EU accession in 2004, the average price for the new Member States (NMS) is estimated as the E14 price multiplied by the observed ratio between the two prices in 2004.

Oilseeds, meals and oils' prices are taken from OIL WORLD (GmbH 2021). For biodiesel and ethanol, the prices come from IHS Markit (IHS 2021).

For crops, annual averages of crop marketing year are calculated for each group as follows:

- cereals (except rice): July year_t/June year_{t+1};
- oilseeds: October year_t/September year_{t+1};
- sugar: September year_t/August year_{t+1};
- rice: September year_t/August year_{t+1}.

For the other commodities, a calendar year (January year_t/December year_t) is used.

World reference prices used in the Aglink-Cosimo model for major crop and animal products are in Tables 7 and 8 respectively. References for the EU producer prices are summarized in table 9.

13.2 Consumer prices

Historical data comes from the International Labour Organization (ILO) databases (ILO 2021). The data are available only by Member State up to 2008. From 2009 onwards, the consumer price equation in the model is used to estimate consumer prices. The choice of the commodity/country price used as reference for the EU consumers is mainly driven by the availability of the time series and the representativeness of the Member State in that market in the whole EU (see Table 10).

13.3 Balance items

EU commodity market balances (crop areas and quantities produced, meat, milk, dairy quantities produced and animal numbers) are calculated by DG AGRI and are based on Eurostat data, compiled for the EU Short Term Outlook (EC 2021e). The balance for each commodity is first established for the whole EU-27, starting with production and trade (based on external statistics of trade in ComExt database (EC 2021c)). Stocks (including intervention and private stocks) are estimated, and consumption is calculated residually to close the market balance.

For dairy products, EU aggregates are often missing from Eurostat owing to confidentiality issues at Member State level and, therefore, are estimated by DG AGRI. For the biofuel module, production figures are compiled by combining different sources: mainly Eurostat, Enerdata (2021), and IHS Markit (2021). For ethanol feedstocks, Member States have an obligation to declare to the European Commission their production of ethyl alcohol by feedstock (cereals, beet, wine) (EC 2021b). Regarding the use of waste oils, information received from DG Energy is used. Fossil fuel consumption comes from the Prospective Outlook on Long-Term Energy Systems (POLES) model.

13.4 Feed

Regarding the data used for the feed module, trade data are obtained at the Harmonized Commodity Description and Coding Systems (HS) 6-digit level from FAOSTAT, UN Comtrade and important national statistical agencies (such as the trade database of the Foreign Agricultural Service at the United States Department of Agriculture, USDA, and Statistics Canada). Production data are also obtained from FAOSTAT. In the case of cereal bran, data are available in the FAOSTAT food balance sheets. Production data for other feeds such as dried beet pulp, corn-gluten feed, distiller's dried grains and meat and bone meals (MBM) are linked to their main product and calculated using fixed conversion factors.

Production of meat and bone meals was calculated directly from beef, veal, pork, sheep meat and poultry slaughtered production, using conversion factors obtained from livestock experts.

The amount consumed as feed is assumed to be equal to the total consumption, except for molasses in all Aglink countries and cereal bran in China. Feed product prices are calculated from internationally recognised prices, as tariffs are small or equal to zero for most of these Aglink commodities.

Most prices are derived from the USA market, considering the large quantities of products in that market, the availability of data in the USDA feed database and their degree of market openness.

13.5 Macroeconomic assumptions

The assumptions for the crude oil price (Brent), the population, the GDP growth (in real terms), the GDP deflator, the consumer price index (CPI) and the exchange rate for the most relevant agricultural markets are derived from the OECD-FAO baseline and updated to reflect most recent projections (IHS Markit, 2021) and own assumptions.

14 REFERENCES

Araujo-Enciso, Sergio René, and Thomas Fellmann. 2020. "Yield Variability and Harvest Failures in Russia, Ukraine and Kazakhstan and Their Possible Impact on Food Security in the Middle East and North Africa." *Journal of Agricultural Economics* 71 (2): 493–516. https://doi.org/https://doi.org/10.1111/1477-9552.12367.

Araujo-Enciso, Sergio René, Thomas Fellmann, Ignacio Pérez Domínguez, and Fabien Santini. 2016. "Abolishing Biofuel Policies: Possible Impacts on Agricultural Price Levels, Price Variability and Global Food Security." *Food Policy* 61: 9–26. https://doi.org/https://doi.org/10.1016/j.foodpol.2016.01.007.

Araujo-Enciso, Sergio René, Ignacio Pérez Domínguez, Fabien Santini, Sophie Hélaine, Koen Dillen, Hubertus Gay, and Pierre Charlebois. 2015. "Documentation of the European Commission's Eu Module of the Aglink-Cosimo Modelling System." *JRC Science and Policy Reports, JRC92618, EUR* 27138.

Araujo-Enciso, Sergio René, Simone Pieralli, and Ignacio Pérez Domínguez. 2020. "Introducing Uncertainty in a Large Scale Agricultural Economic Model: A Methodological Overview." *Computers and Electronics in Agriculture* 178: 105705. https://doi.org/https://doi.org/10.1016/j.compag.2020.105705.

Charlebois, Pierre. 2013. "Description of the methodology and presentation of a generic template for the introduction of a revised feed demand system in Aglink-Cosimo." OECD; Internal Document OECD, Paris.

Chatzopoulos, Thomas, Ignacio Pérez Domínguez, Andrea Toreti, Marcel Adenäuer, and Matteo Zampieri. 2021. "Potential Impacts of Concurrent and Recurrent Climate Extremes on the Global Food System by 2030." *Environmental Research Letters* 16 (12): 124021. https://doi.org/10.1088/1748-9326/ac343b.

Chatzopoulos, Thomas, Ignacio Pérez Domínguez, Matteo Zampieri, and Andrea Toreti. 2020. "Climate Extremes and Agricultural Commodity Markets: A Global Economic Analysis of Regionally Simulated Events." *Weather and Climate Extremes* 27: 100193. https://doi.org/https://doi.org/10.1016/j.wace.2019.100193.

EC. 2018. "EU agricultural outlook for markets and income, 2018-2030". European Commission, DG Agriculture and Rural Development, Brussels. https://ec.europa.eu/info/sites/default/files/food-farming-fisheries/farming/documents/medium-term-outlook-2018-report_en.pdf .

EC. 2021a. "Beef." European Commission. https://ec.europa.eu/info/food-farming-fisheries/animals-and-animal-products/animal-products/beef_en.

———. 2021b. "Commission Publishes Feed Protein and Ethanol Balance Sheets." https://ec.europa.eu/info/news/commission-publishes-feed-protein-and-ethanol-balance-sheets-2020-nov-25_en.

———. 2021c. "Eurostat's External Trade Database. "http://epp.eurostat.ec.europa.eu/newxtweb/.

———. 2021d. "Milk and Dairy Products." European Commission. https://ec.europa.eu/info/food-farming-fisheries/animals-and-animal-products/animal-products/milk-and-dairy-products_en.

———. 2021e. "Short-Term Outlook for Agricultural Markets." https://ec.europa.eu/info/food-farming-fisheries/farming/facts-and-figures/markets/outlook/short-term_en.

Efron, Bradley. 1987. "Better bootstrap confidence intervals". *Journal of the American statistical Association*, 82 (397): 171-185.

Elleby, Christian, Pérez Domínguez, Ignacio, Adenauer, Marcel, and Giampiero Genovese. 2020. "Impacts of the Covid-19 Pandemic on the Global Agricultural Markets." *Environmental and Resource Economics* 76 (4): 1067–79.

Enerdata. 2021. "Enerdata, Intelligence and Consulting." https://www.enerdata.net/.

Fellmann, Thomas, Hélaine, Sophie, & Nekhay, Olexandr. 2014. Harvest failures, temporary export restrictions and global food security: the example of limited grain exports from Russia, Ukraine and Kazakhstan. Food Security, 6(5): 727-742.

Ferrari, Emanuele, Chatzopoulos, Thomas, Pérez Domínguez, Ignacio, Boulanger Pierre, Boysen-Urban, Kirsten, Himics, Mihaly, and Robert M'barek, "Cumulative economic impact of trade agreements on EU agriculture – 2021 update", EUR 30496 EN, Publications Office of the European Union, Luxembourg. 2021, ISBN 978-92-76-27157-4, doi:10.2760/501873, JRC123037.

Hélaine, Sophie, Santini, Fabien, Araujo-Enciso, Sergio René, Dillen, Koen, and Pérez Domínguez, Ignacio. 2016. A stochastic approach of the assessment of EU intervention mechanisms for dairy products. In *conference SFER LML*, Clermont-Ferrand, June.

Howitt, Richard E. 1995. "Positive Mathematical Programming." *American Journal of Agricultural Economics* 77 (2): 329–42.

IHS. 2021. "IHS Markit." https://ihsmarkit.com/index.html.

ILO. 2021. "International Labour Organization. Statistics and Databases." https://www.ilo.org/global/statistics-and-databases/lang--en/index.htm.

Jensen, Hans, Ignacio Pérez Domínguez, Thomas Fellmann, Paul Lirette, Jordan Hristov, and George Philippidis. 2019. "Economic Impacts of a Low Carbon Economy on Global Agriculture: The Bumpy Road to Paris." *Sustainability* 11 (8). https://doi.org/10.3390/su11082349.

Jensen, Hans, Christian Elleby, Ignacio Pérez Domínguez, Thomas Chatzopoulos, and Pierre Charlebois. 2021. "Insect-Based Protein Feed: From Fork to Farm." *Journal of Insects as Food and Feed*, 1–16.

Kavallari, Aikaterini, Thomas, Fellmann, & Stephen Hubertus Gay. 2014. Shocks in economic growth= shocking effects for food security? *Food Security*, 6(4): 567-583.

OECD. 2015. "Aglink-Cosimo Model Documentation." OECD; OECD Publishing, Paris.

OECD. 2018. "Aglink-Cosimo Biofuel Module Documentation." OECD; OECD Publishing, Paris.

OECD/FAO. 2022. "The Aglink Cosimo Model: A Partial Equilibrium Model of World Agricultural Markets."

OIL WORLD (ISTA Mielke GmbH). 2021. "Oil World: Independent Global Market Analyses and Forecasts Since 1958." https://www.oilworld.biz/ista-mielke.

Pieralli, Simone, Ignacio Pérez Domínguez, Christian Elleby, and Thomas Chatzopoulos. 2021. "Budgetary Impacts of Adding Agricultural Risk Management Programmes to the Cap." *Journal of Agricultural Economics* 72 (2): 370–87. https://doi.org/https://doi.org/10.1111/1477-9552.12406.

Regulation of the European Parliament and the Council REG(EU) 1307/2013 https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32013R1307&from=EN.

Santini, Fabien, Tévécia Ronzon, Ignacio Pérez Domínguez, Sergio René Araujo-Enciso, and Ilaria Proietti. 2017. "What If Meat Consumption Would Decrease More Than

Expected in the High-Income Countries?" *Bio-Based and Applied Economics* 6 (1): 37–56. https://doi.org/10.13128/BAE-16372.

Thompson, Wyatt, Joe Dewbre, Patrick Westhoff, Kateryna Schroeder, Simone Pieralli, and Ignacio Pérez Domínguez. 2017. "Introducing Medium-and Long-Term Productivity Responses in Aglink-Cosimo." Washington D.C.: EUR 28560 EN, Publications Office of the European Union, Luxembourg. https://doi.org/10.2760/79492.

Varian, Hal Ronald. 1992. *Third Edition. Microeconomic Analysis*. New York, WW Norton; Company.

15 TABLES

Table 1: Weights for cost of production commodity indexes

EU region	Crop	CPCI..SHEN	CPCI..SHFT	CPCI..SHNT	CPCI..SHSD	CPCI..SHTR
NMS	Barley	0.09	0.15	0.58	0.07	0.12
NMS	Maize	0.14	0.16	0.45	0.14	0.11
NMS	Other cereals	0.09	0.15	0.58	0.07	0.12
NMS	Oats	0.09	0.15	0.58	0.07	0.12
NMS	Pulses	0.14	0.16	0.45	0.14	0.11
NMS	Rice	0.04	0.06	0.85	0.01	0.04
NMS	Rapeseed	0.13	0.19	0.43	0.09	0.15
NMS	Roots and tubers	0.04	0.19	0.24	0.18	0.35
NMS	Rye	0.09	0.15	0.58	0.07	0.12
NMS	Soybeans	0.13	0.05	0.53	0.09	0.2
NMS	Sugar beet	0.08	0.2	0.47	0.08	0.18
NMS	Sunflower	0.13	0.19	0.43	0.09	0.15
NMS	Durum wheat	0.09	0.11	0.64	0.07	0.08
NMS	Soft wheat	0.13	0.19	0.43	0.09	0.15
E14	Barley	0.09	0.15	0.58	0.07	0.12
E14	Cotton	0.07	0.06	0.64	0.05	0.19
E14	Maize	0.08	0.12	0.62	0.07	0.1
E14	Other cereals	0.09	0.15	0.58	0.07	0.12
E14	Oats	0.09	0.15	0.58	0.07	0.12
E14	Pulses	0.08	0.12	0.62	0.07	0.1
E14	Rice	0.04	0.06	0.85	0.01	0.04
E14	Rapeseed	0.08	0.16	0.51	0.06	0.2
E14	Roots and tubers	0.04	0.19	0.24	0.18	0.35
E14	Rye	0.09	0.15	0.58	0.07	0.12
E14	Soybeans	0.08	0.05	0.58	0.06	0.23
E14	Sugar beet	0.09	0.13	0.51	0.06	0.21
E14	Sunflower	0.08	0.16	0.51	0.06	0.2
E14	Durum wheat	0.09	0.11	0.64	0.07	0.07
E14	Soft wheat	0.08	0.16	0.51	0.06	0.2

Note: The weights sum to 1, apart from rounding errors.

Table 2: Correspondence of production costs between category in Aglink-Cosimo and Farm Accountancy Data Network

Category	FADN
Energy	Electricity and fuels
Fertilisers	Fertilisers and soil improvers
Non-tradables	Contract work, other farming overheads, depreciation, wages and own work
Other tradables	Crop protection products, other specific crop costs, veterinary costs and other specific livestock costs, machinery, and buildings
Seeds	Seeds and seedlings purchased as well as those produced/used on farm

Table 3: Vegetable oils and protein meal yields in the EU

Product	NMS	E14
Cottonseed oil Yield	NA	0.16
Cottonseed meal Yield	NA	0.52
Groundnut oil Yield	NA	0.42
Groundnut meal Yield	NA	0.58
Rapeseed oil Yield	0.41	0.42
Rapeseed meal Yield	0.56	0.55
Sunflower oil Yield	0.42	0.42
Sunflower meal Yield	0.52	0.50
Soybean oil Yield	0.20	0.18
Soybean meal Yield	0.79	0.79

Table 4: Oilseeds utilisation in Aglink-Cosimo

Crop product	Meals	Oils
Oilseed oil = OL	Oilseed meal = OM	Oilseed oil = OL
Soybeans = SB	Soybean meal = SM	Soybean oil = SL
Sunflower = SF	Sunflower meal = SFM	Sunflower oil = SFL
Rapeseed = RP	Rapeseed meal = RM	Rapeseed oil = RL
Groundnut = GN	Groundnut meal = GM	Groundnut oil = GL
Cottonseed = CSE	Cottonseed meal = CSM	Cottonseed oil = CSL
Copra (Coconut) = CN	Copra meal = CM	Copra oil = CL
Palm kernel = PKL	Palm kernel meal = KM	Palm kernel oil = KL
		Palm oil = PL

Note: Symbols after the equal signs are product commodity names in the model

Table 5: Weights (w) for beef and veal livestock inventory weighted average

Region	Time t	Time t-1	Time t-2
E14	1.9	0.54	0.1
NMS	1.7	0.35	0.1

Table 6: EU Ad-valorem import tariffs for commodities in 2021

Commodity	Total	In-quota	Out-of-quota	In-quota specific	Out-of-quota specific
Barley	52.13	8.97	52.13	16	93
Biodiesel	0.06	NA	NA	NA	NA
Butter	20.34	20.34	55.1	700	1896
Beef and Veal	0	NA	12.8	NA	NA
Cereal bran	46.4	NA	NA	NA	NA
Cheese	50.13	6.3	50.13	210	1671
Ethanol	0.44	NA	NA	NA	NA
High-fructose corn syrup	101.49	NA	NA	NA	NA
Molasses	7.54	NA	NA	NA	NA
Other cereals	0	NA	39.49	NA	44.45
Pigmeat	10.06	10.06	41.98	208.3	869
Palm kernel oil	3.80	NA	NA	NA	NA
Poultry	15.4	15.4	77.99	NA	1024
Rapeseed oil	6.40	NA	NA	NA	NA
Rye	42.35	NA	42.35	NA	46.72
Sunflower oil	6.40	NA	NA	NA	NA
Sheep meat	0	NA	65.6	NA	2121.67
Soybean oil	6.40	NA	NA	NA	NA
Sugar	29.96	NA	NA	98	339
Soft wheat	NA	NA	NA	12.00	NA
Whey Powder	9.04	NA	NA	NA	NA

Table 7. References for producer prices in the EU

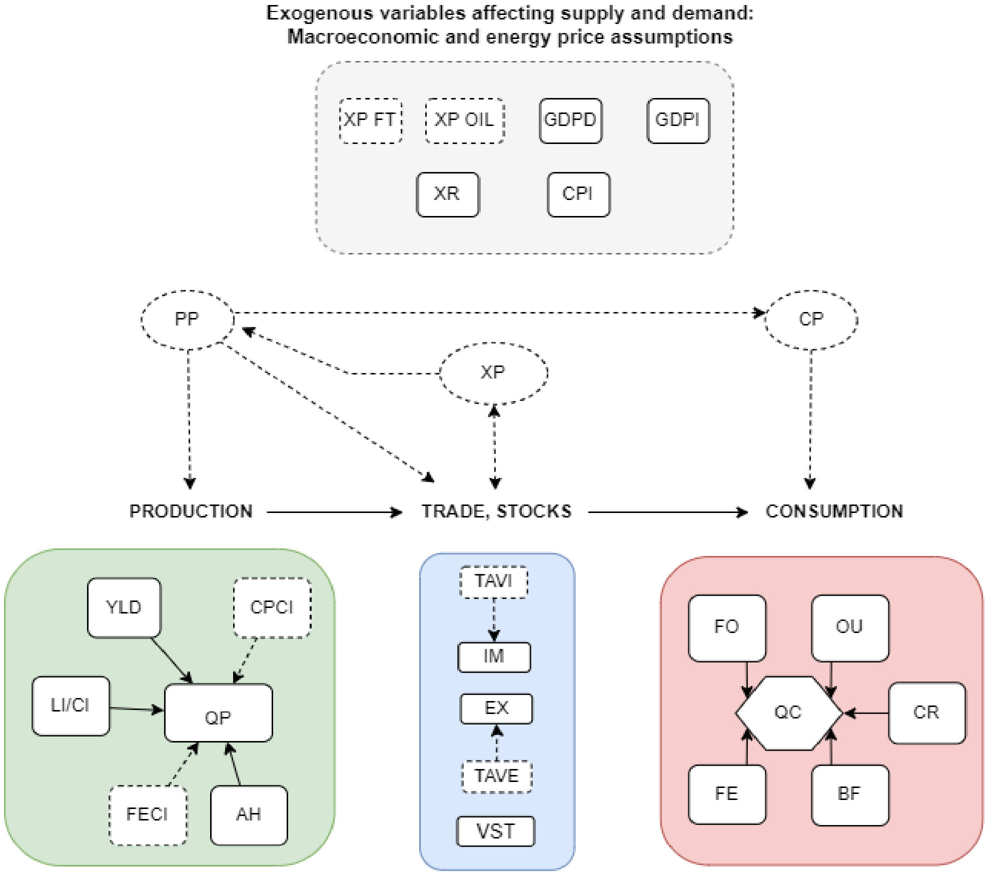
Commodity		Reference prices	
		E14	NMS
Beef	BV	Young Bulls R3	Young Bulls R3
Pig	PK	Class E	Class E
Sheep	SH	Heavy lamb	Heavy lamb
Poultry	PT	Chicken (All)	Chicken (All)
Cheese	CH	Cheddar	Cheddar
Milk	MK	Farm gate price, real fat content	Farm gate price, real fat content
Soft wheat	WTS	Breadmaking common wheat	Breadmaking wheat in Budapest
Durum wheat	WTD	DURUM port-La-Nouvelle	DURUM port-La-Nouvelle
Barley	BA	Feed barley Rouen	Feed barley Poland
Maize	MA	Feed maize Bordeaux	Feed maize Romania Constanta
Oats	OT	Feed oats Hamburg	Feed oats Poland
Rye	RY	Breadmaking rye Hamburg	Breadmaking rye Hamburg
Other cereals	OC	Feed Rye Poland	Feed Rye Poland
Rice	RI	Paddy, Japonica, Italia, Lido	Paddy, Japonica, Italia, Lido
Rapeseed	RP	Europe,00,cif Hamburg	
Soybeans	SB	Brazil, cif Rott (1993-1995; Argentine, cif Rott)	Brazil, cif Rott (1993-1995; Argentine, cif Rott)
Sunflower seed	SF	EU, cif Amersterdam	EU, cif Amersterdam
Rapeseed meal	RM	34%, fob ex-mill Hmb	34%, fob ex-mill Hmb
Soy meal	SM	48%, Brazil, cif Rott	48%, Brazil, cif Rott
Sunflower pellets	SFM	37/38%, Arg., cif Rott until 2011. Starting from 2012 Sunmeal, Ukraine, DAF	37/38%, Arg., cif Rott until 2011. Starting from 2012 Sunmeal, Ukraine, DAF
Rape oil	RL	Dutch, fob ex-mill	Dutch, fob ex-mill
Soybean oil	SL	Dutch, fob ex-mill	Dutch, fob ex-mill
Sunflower oil	SFL	EU, fob N.W.Eur. ports	EU, fob N.W.Eur. ports
Palm oil	PL	crude, 5% FFA, Malaysia/Indonesia, cif North-West Europe	crude, 5% FFA, Malaysia/Indonesia, cif North-West Europe
Biodiesel	BD	Germany (UFOP), B-100	Germany (UFOP), B-100
Ethanol	ET	EU, NEW, FOB T2	EU, NEW, FOB T2

Table 8: References for consumer prices in the EU

Commodity	EU region	Country of reference	Retail product
Wheat	E14	Italy: Rome	Wheat flour, white
	NMS	Poland	
Coarse grains	E14	Denmark: rye bread	Rye bread
	NMS	Poland: rye bread	
Rice	E14	Italy: Rome	Rice, long grain
	NMS	Poland	
White sugar	E14	Italy: Rome	Sugar, white
	NMS	Hungary	
Oilseeds	E14	Luxembourg	Peanuts (groundnuts), without shells
	NMS	Hungary	
Vegetable oil	E14	France	Salad or cooking oil
	NMS	Poland	
Beef	E14	Netherlands	Beef, with bone
	NMS	Poland	
Pigmeat	E14	France	Pork, with bone
	NMS	Latvia	
Sheep meat	E14	Italy: Rome	Lamb, leg
	NMS	Bulgaria	
Poultry	E14	Austria	Chicken, cleaned
	NMS	Czech Republic	
Eggs	E14	Sweden	Chicken eggs, fresh
	NMS	Poland	
Butter	E14	France	Butter
	NMS	Poland	
Cheese	E14	Denmark	Cheese, other
	NMS	Poland	
Fresh dairy products	E14	France	Cow's milk, fresh, whole, pasteurised
	NMS	Hungary	
Skimmed milk powder	E14	Portugal	Cow's milk, powdered, skimmed (non-fat)
	NMS	NA	
Whole milk powder	E14	Portugal	Cow's milk, powdered, whole
	NMS	Hungary	
Ethanol	EU-27	France	France E-85

16 FIGURES

Figure 1. Flowchart of the main relationships and variables in the model.



Acronyms

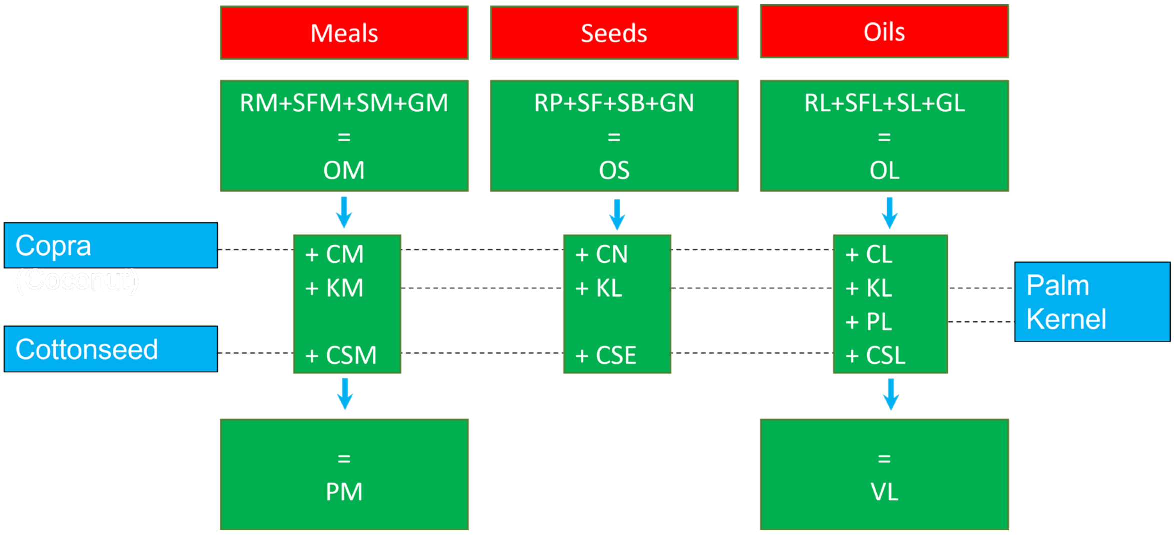
AH: Area harvested
CI: Cow inventory
CP: Consumer price (EUR/t)
CPCI: Cost of production index
CPI: Consumer price index
CR: Crush demand
EX: Exports
FE: Feed use
FECI: Feed expenditure index
FT: Fertilizer
FO: Food consumption
GDPD: GDP deflator
GDPI: GDP index
IM: Imports
LI: Livestock inventory
OIL: Crude oil (Brent)
OU: Other use
PP: Producer price (EUR/t)
QC: Total consumption
QP: Production
TAVE: Export tax
TAVI: Import tax
VST: Changes in stocks (closing-opening)
XP: World price (USD/t)
XR: Exchange rate (EUR/USD)
YLD: Yield

Symbols

Price/cost variable
Quantity variable
Aggregate
Price relationship
Quantity relationship

Source: own elaboration

Figure 2. Details of the oilseeds aggregate in Aglink-Cosimo. Source: Own elaboration



17 ANNEX

17.1 Annex Table A.1: Regions and countries in the EU Aglink-Cosimo module

Aglink		Cosimo			
OECD countries		**OECD countries**		**Non-OECD countries**	
Australia	AUS	Chile	CHL	Egypt	EGY
Canada	CAN	Colombia	COL	Ethiopia	ETH
Switzerland	CHE	Israel	ISR	Indonesia	IDN
Great Britain	GBR	Turkey	TUR	India	IND
Japan	JPN	**Cosimo aggregates**		Iran (Islamic Republic of)	IRN
South Korea	KOR	Other Oceania	OCE	Kazakhstan	KAZ
Mexico	MEX	Other South American and Caribbean	SAC	Malaysia	MYS
Norway	NOR	LDC sub-Saharan Africa	AFL	Nigeria	NGA
New Zealand	NZL	Other sub-Saharan Africa	AFS	Pakistan	PAK
United States of America	USA	Other North Africa	AFN	Peru	PER
		LDC Asia	ASL	Philippines	PHN
OECD country aggregates		Other North Africa Least Developed	ANL	Paraguay	PRY
European Union 27	EUN	Other Asia Developing	ASA	Saudi Arabia	SAU
EU-14 (western 14 Member States)	E14	Central Asia	ASC	Thailand	THA
EU-13 (new Member States)	NMS	Other Eastern Europe	EUE	Ukraine	UKR
		Other Near East Pacific Meat Market	NEO	Vietnam	VNM
Non-OECD countries		Atlantic Meat Market	ATL	South Africa	ZAF
Argentina	ARG	Pacific Meat Market	PAC	Uruguay	URU
Brazil	BRA	World	WLD		
China	CHN	Cosimo	COS		
Russia	RUS	Aglink	AGL		

17.2 Annex Table A.2: Commodities in the EU Aglink-Cosimo module

Commodity	Description	Commodity	Description
AGO	Agricultural Crops Other	MT	Millet
AGR	Agricultural (including crops and pasture and fodder)	NR	Non-ruminant
APF	Average Protein Feed	OC	Other cereal
BA	Barley	OCG	Other coarse grains
BD	Biodiesel	OFP	Other fat products
BF	Biofuel	OL	Oilseed oils
BP	Dried Beet Pulp	OLN	Other land use
BT	Butter	OM	Oilseed meals
BV	Beef and Veal	ONP	Other dairy products cont. non-fat solids
CA	Casein	OOS	Other oilseeds
CEB	Cereal Bran	OP	Other poultry
CGF	Corn Gluten Feed	OT	Oats
CH	Cheese	OX	Land devoted to crops other than cereals, oilseeds, pasture and fodder crops
CK	Chicken	PA	Pasture
CL	Copra (coconut) oil	PAF	Pasture and fodder
CM	Copra (coconut) meal	PK	Pork
CN	Copra (coconut)	PL	Palm oil
CR	Crop	PM	Total protein meal
CRP	Crop	PS	Pulses
CRX	Annual crop not included elsewhere	PT	Poultry
CSE	Cotton Seed	RI	Rice
CSL	Cotton Seed Oil	RL	Rapeseed oil
CSM	Cotton Seed Meal	RM	Rapeseed meal
CT	Cotton	RP	Rapeseed
DDG	Distiller's Dried Grains	RT	Roots and tubers
DIE	Diesel	RU	Ruminants
EG	Eggs	RY	Rye
ET	Ethanol	SB	Soybean
FDP	Fresh Dairy Products	SBE	Sugar beet
FH	Fish	SCA	Sugar cane
FM	Fish meal	SET	Set-aside
FO	Food	SF	Sunflower
FST	Forestry	SFL	Sunflower oil
GAS	Gasoline	SFM	Sunflower meal
GL	Groundnut (oil)	SH	Sheep meat
GM	Groundnut (meal)	SL	Soybean oil

Commodity	Description	Commodity	Description
GN	Groundnut	SM	Soybean meal
HFCS	High-fructose corn syrup	SMP	Skimmed milk powder
HPF	High-protein feed	SO	Sorghum
KL	Palm kernel oil	SU	Sugar
KM	Palm kernel meal	SUR	Sugar raw
LND	Other land	SUW	Sugar white
LPF	Low-protein feed	SW	Sweetener
MA	Maize	VL	Vegetable oils
MBM	Meat and bone meal	WMP	Whole milk powder
MD	Meadow	WT	Wheat
ME	Macroeconomic	WTD	Durum wheat
MK	Milk	WTS	Soft wheat
MOL	Molasses	WYP	Whey powder

17.3 Annex Table A.3: Items in the EU Aglink-Cosimo module

Item	Description
ADJ..PPFE	Adjustment factor protein feed
AH	Area Harvested; kha
AH..SHR	Share of area harvested; %
BF	Biofuel feedstock
BF..SHR	Biofuel feedstock share
CI	Cow inventory; head
CP	Consumer price; national currency/t
CP..MAR	Consumer price margin; national currency/t
CPCI	Cost of production commodity index
CPCI..BF	Cost of production commodity index biofuel
CR	Crushed; kt
CRMAR	Crush margin; national currency/t
CW	Average carcass weight; t/head
DEL	Deliveries to dairies; kt
EPA	Effective support payments; national currency/ha
EPA..BUDGET	Effective support payments EU envelope; national currency
EPA..DP	Effective support payments affecting area; national currency/ha
EPI	Effective support payments affecting inventory; national currency/head
EPI..BUDGET	Effective support payments affecting inventory EU envelope; national currency
EPQ	Effective support payments affecting quantity; national currency/t
EX	Exports; kt
EX..SUB	Subsidised exports; kt
EX..UNS	Unsubsidised exports; kt
EXM	Meat exports; kt
EXM..ATL	Meat exports to the Atlantic market; kt
EXM..PAC	Meat exports to the Pacific market; kt
EXM..UNS	Meat unsubsidised exports; kt
EXM..XCHN	Meat exports to the Chinese market; kt
EXP	Export price; national currency/t
FAT	Fat; %
FCR	Feed conversion ratio
FD	Feed consumption; kt
FE	Feed consumption; kt
FE..SHR	Feed consumption share; decimal proportion
FECI	Feed cost index
FL	Fuel; kt
FL..HBLD	Fuel, high blend; kt
FL..LBLD	Fuel, low blend; kt
FO	Food consumption; kt
FO..SHR	Food share; decimal proportion
FU	Farm use; kt
GDPD	Gross domestic product deflator; index
GDPI	Gross domestic product index, ratio deflated; index
GDPN	Gross domestic product index, numerator; index

Item	Description
GDPR	Gross domestic product ratio, numerator/deflator; index
GDPUS..PC	Gross domestic product, per capita; 1000 USD
IM	Imports; kt
IM..EBA	Imports from Everything But Arms; kt
IM..OTH	Other imports, excluding internal trade; kt
IM..SHR	Import share; decimal proportion
IMM	Meat imports; kt
IMP	Import price; national currency/t
IP	Price incentive; national currency/ha
IST	Ending intervention stocks; kt
LI	Live inventory; head
LU	Land use; kha
LU..SHR	Land use share; decimal proportion
LU..SHR..EQ	Land use share; decimal proportion
MAR	Margin between wholesale and retail; national currency/unit of product
NFS	Non-fat solid content; decimal proportion
NT	Net trade; kt
OU	Other use; kt
PCST	Production cost index
POP	Population; thousand
PP	Producer price; national currency/t
PP..ET	Commodity price for ethanol use; national currency/t
PP..FAT	Market clearing price for milk fat; national currency/t
PP..NFS	Market clearing price for milk non-fat solids; national currency/t
PP..PRAT	Quality adjustment factor; decimal
PR	Price ratio between biofuel and conventional substitute fuel; index
PRST	Private stocks; kt
QC	Total consumption; kt
QC..OBL	Quantity consumed, mandated biofuels; kt
QC..TRAN	Quantity consumed, fuel for transportation; kt
QC..TRAN..HBLD	Quantity consumed, fuel for transportation, high blend; kt
QC..TRAN..LBLD	Quantity consumed, fuel for transportation, low blend; kt
QCS	Consumption share; decimal proportion
QCS..CALC	Total consumption share (first generation, second generation, waste products); decimal proportion
QCS..EFF	Effective consumption share; decimal proportion
QCS..LBLD	Consumption share, low blend; decimal proportion
QCS..LBLD..EQ	Calculated consumption share, low blend; decimal proportion
QCS..LIMIT	Calculated consumption share, blend limit; decimal proportion
QCS..OBL	Calculated consumption share, obligatory; decimal proportion
QCS..OBL..AD	Calculated consumption share, obligatory; adjusted energy equivalent decimal proportion
QCS..OBL..VAD	Calculated consumption share, obligatory; volumetric decimal proportion
QCS..SEC	Consumption share, second generation; decimal proportion
QCS..WST	Consumption share, waste products; decimal proportion
QCSV	Consumption share adjustment of the actual mandate; decimal proportion
QP	Quantity produced; kt

Item	Description
QP..BBP..VAL	Biofuel value of beet pulp
QP..BD	Quantity produced, biodiesel; kt
QP..BV	Quantity produced, from beef and veal; kt
QP..COW	Quantity produced, milk from cows; kt
QP..DY	Quantity produced from only cows' milk; kt
QP..ET	Quantity produced from ethanol; kt
QP..ND	Quantity produced other than from cows' milk; kt
QP..PK	Quantity produced from pigmeat; kt
QP..PT	Quantity produced from poultry; kt
QP..SH	Quantity produced from sheep meat; kt
QPS	Slaughtered production; kt
RET	Returns per tonne; local currency/t Carcass Weight
RH	Returns per hectare; local currency/ha
RM..BD	Return margin, biodiesel; local currency/t
RM..ET	Return margin, ethanol; local currency/t
SFP	Single farm payment factor; decimal proportion
SHP	Shadow price
SHR	Total demand to feed demand share; decimal proportion
SLH	Slaughtered animals; thousand head
ST	Ending stocks; kt
SWG	Sweetener; kt
TAVI	Ad-valorem import tariff; %
TAVI..IQS	Ad-valorem import tariff, in-quota; %
TAVI..OQS	Ad-valorem import tariff out-of-quota; %
TRQ	Tariff rate quota; kt
TSP..OQS	Specific tariff out-of-quota; local currency/t
VST	Change in stocks; kt
XR	Exchange rate; national currency/USD
YLD	Yield; t/ha

17.4 Annex Table A.4: World reference prices in Aglink-Cosimo

Cereals	**Description**
Wheat	No 2 Hard red winter wheat, ordinary protein, United States f.o.b. Gulf ports (June/May)
Coarse grains	No 2 Yellow corn, United States f.o.b. Gulf Ports (September/August)
Rice	FAO All Rice Price Index normalized with India (2014-2016), Indica high quality 5% broken (January/December)
Oilseeds	
Soybeans	Soybean, U.S., CIF Rotterdam (October/September)
Other oilseeds	Rapeseed, Europe, CIF Hamburg (October/September)
Protein meals	Weighted average meal price, European port
Vegetable oils	Weighted average price of oilseed oils and palm oil, European port
Fibre crops	
Cotton	Cotlook A index, Middling 1 3/32", c.f. far Eastern ports (August/July), INSEE France
Sweeteners	
Raw sugar	Raw sugar world price, ICE contract No 11 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, price EU	EU average beef producer price
Beef and veal, price US (PAC)	US choice steers, 5-area Direct; Nebraska– lw to dw conversion factor 0.62
Beef and veal, price (ATL)	Brazil: frozen beef, export unit value, product weight
Pigmeat, price EU	EU average pigmeat producer price
Pigmeat, price US (PAC)	US barrows and gilts, National base 51-52% lean– lw to dw conversion factor 0.72
Pigmeat, price BRA (ATL)	Brazil frozen pigmeat producer price
Poultry, price EU	EU average producer price
Poultry, price US (PAC)	US wholesale weighted average broiler price, 12 cities
Poultry, price BRA (ATL)	Brazil average chicken for slaughter producer price
Sheep meat	Beef and Lamb New Zealand lamb schedule price, all weighted grades 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 that for reduction

Cereals	**Description**
Fish meal	Fish meal, 64-65 % protein, Hamburg, Germany
Fish oil	Fish oil any origin, north-west Europe
Dairy products	
Butter	F.o.b. export price, butter, 82 % butterfat, Oceania
Cheese	F.o.b. export price, cheddar cheese, 39 % moisture, Oceania
Skimmed 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	Ethanol, US, Midwest Average, Rack Price
Biodiesel	Producer price Germany net of biodiesel tariff
Feed products and other crops	
Distiller's Dried Grains	Wholesale price, central Illinois, USA
Dried beet pulp	Dried beet pulp unit export price of the USA
Cereal brans	Wheat middling in Buffalo, NY
Meat and bone meal	Meat and bone meal price, central USA
Corn gluten feed	Corn gluten feed price, 21 % protein, Midwest, USA
Roots, tubers	Thailand, Wholesale, Bangkok, Cassava (flour)
Pulses	Canadian field pea producer price (August/July)

17.5 Annex Table A.5: Stochastic yields

Aggregate Region	Europe		Black Sea Area			South America				NZL
Commodity	E14	NMS	KAZ	UKR	RUS	ARG	BRA	PAR	URU	
Common wheat	X	X	X	X	X	X	X	X	X	
Durum wheat	X	X								
Barley	X	X				X				
Maize	X	X		X		X	X	X	X	
Milk										X
Oth. coarse grains				X				X	X	
Oats	X	X								
Rye	X	X								
Other cereals	X	X								
Rice	X									
Other Oilseeds			X	X				X		
Soybean	X	X	X	X		X	X	X		
Rapeseed	X	X								
Sunflower seed	X	X			X	X				
Palm oil										
Sugar beet	X	X			X					
Sugar cane						X	X			
Aggregate Region	North America			South-East Asia				AUS	CHN	IND
Commodity	CAN	MEX	USA	IDN	MYS	THA	VTM			
Common wheat	X	X	X					X	X	X
Durum wheat										
Barley	X							X		
Maize	X	X	X						X	
Milk								X		
Oth. coarse grains										
Oats	X									
Rye										
Other cereals										
Rice			X			X	X		X	X
Other Oilseeds										
Soybean	X		X							
Rapeseed	X							X		

Aggregate Region	**Europe**		**Black Sea Area**			**South America**				**NZL**
Commodity	**E14**	**NMS**	**KAZ**	**UKR**	**RUS**	**ARG**	**BRA**	**PAR**	**URU**	
Sunflower seed										
Palm oil				X	X					
Sugar beet			X						X	
Sugar cane			X			X		X	X	X

Note: Shading indicates the correlated yields in geographic region aggregates; Annex Table A.6

17.6 Annex Table A.7: Stochastic macroeconomic variables

Country/Region	Consumer Price Index	GDP Deflator	GDP Index	Exchange Rate (National Currency/USD)	Oil price
Australia	X	X	X	X	
Brazil	X	X	X	X	
Canada	X	X	X	X	
China	X	X	X	X	
EU	X	X	X	X	
India	X	X	X	X	
Japan	X	X	X	X	
New Zealand	X	X	X	X	
Russia	X	X	X	X	
USA	X	X	X	X	
World					X

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