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An EU-Wide Individual Farm Model for Common Agricultural Policy Analysis (IFM-CAP)

First application to Crop Diversification Policy

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Abstract

This report presents the first EU-wide individual farm-level model (IFM-CAP) aiming to assess the impacts of CAP on farm economic and environmental performance. The rationale for such a farm-level model is based on the increasing demand for a micro-simulation tool able to model farm-specific policies and to capture farm heterogeneity across the EU in terms of policy representation and impacts. Based on positive mathematical programming, IFM-CAP seeks to improve the quality of policy assessment upon existing aggregate and aggregated farm-group models and to assess distributional effects over the EU farm population. To guarantee the highest representativeness of the EU agricultural sector, the model is applied to every EU-FADN (Farm Accountancy Data Network) individual farm (around 60 500 farms).

The report provides a detailed description of the IFM-CAP model prototype in terms of design, mathematical structure, data preparation, modelling livestock activities, allocation of input costs and the calibration process. The theoretical background, the technical specification and the outputs that can be generated from this prototype are also briefly presented and discussed.

The report also presents an application of the model to the assessment of the effects of the crop diversification measure. The results show that most non-compliant farms (80 %) chose to reduce their level of non-compliance following the introduction of the diversification measure owing to the sizable subsidy reduction imposed. However, the overall impact on farm income is rather limited: farm income decreases by less than 1 % at EU level, and only 5 % of the farm population will be negatively affected. Nevertheless, for a small number of farms, the income effect could be more substantial (more than –10 %).

Acknowledgements

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1. Introduction

Over the last two decades, the Common Agricultural Policy (CAP) has undergone a gradual change from market intervention instruments (e.g. price support) to decoupled farm-specific measures attempting to enhance the environmental performance of the EU agricultural sector. This became evident with the introduction of the Single Payment Scheme (SPS) in 2005. The 2013 CAP reform goes further in this direction by proposing a mandatory component to direct payments, namely 'greening', with the aim of supporting agricultural practices beneficial to the climate and the environment. Other farm-specific measures introduced by the recent CAP reforms include, among others, the capping of direct payments and young farmer and small farmer schemes. The uptake and economic effects of these farm-specific measures differ significantly between farms depending, among other things, on their size, specialisation, resource endowment, location and socioeconomic characteristics.

There is a wide range of applied agricultural models available in the literature that attempt to investigate the impact of the CAP, spanning farm-type optimisation models to general equilibrium models (Britz, 2011; Buysse et al., 2007a; de Muro and Salvatici, 2001; Gocht and Britz, 2011; Gocht et al., 2013; Gohin, 2006; Gomez y Paloma et al. 2013; Helming et al., 2010; Louhichi et al., 2010, 2013; OECD, 2006; Offermann et al., 2005). However, most of the models available are implemented at an aggregate level (regions, countries, group of countries) and are not able to fully capture the impacts of these new policy measures at a disaggregated (farm) level. Although farm-type models can assess these farm-specific policies to some extent, they are subject to aggregation bias, they reduce farm heterogeneity considerably and they cannot model a number of CAP policies for which eligibility depends on individual farm characteristics and location. For example, in the case of the crop diversification measure, certain farms have to produce a minimum of two crops, with the main crop representing a maximum of 75 % of the arable area. By construction, the cropping pattern is much more diversified for a representative farm than it is for the actual individual farms on the basis of which the representative farm was created. As a result, the crop diversification requirement will usually be respected (not binding) at the level of the representative farm, although in reality the restriction is binding at the level of individual farms. Moreover, aggregated farm-group models can represent only average effects for a set of pre-determined farm types, whereas an individual farm-level model provides the distribution of effects over the farm population and allows the aggregation of the results at different levels (Nomenclature of Territorial Units for Statistics (NUTS 2), Member State (MS), EU) or by farm type (farm size, specialisation, etc.), depending on the specific policy question to be answered.

Another drawback of existing farm models is that most of them are developed for a specific purpose and/or location and, consequently, are not easily adapted and reused for other applications and contexts (Louhichi et al., 2010). Out of a large number of EU-based representative farm models, only two have full EU coverage: Common Agricultural Policy Regional Impact Assessment Farm Type (CAPRI-FT) (Gocht and Britz, 2011; Gocht et al., 2013) and Agriculture, Recomposition de l'Offre et Politique Agricole (AROPAj (De Cara and Jayet, 2011). The other models cover either a specific MS (Forest and Agricultural Optimisation Model (FAMOS) (Schmid, 2004)) or a selected set of MSs/regions (Farm Modelling Information System (FARMIS)

(Offermann et al., 2005), Farm System Simulator (FSSIM) (Louhichi et al., 2010), Agricultural Policy Simulator (AgriPoliS) (Kellermann et al., 2008) and Stylised Agri-environmental Policy Impact Model (SAPIM) (OECD, 2010)).

Given the shortcomings of the available agricultural policy modelling tools, the Joint Research Centre started developing an individual farm-level simulation model, named IFM-CAP (Individual Farm Model for Common Agricultural Policy Analysis), for the *ex ante* assessment of the medium-term adaptation of individual farmers to policy and market changes. The main expectations from this micro-simulation tool are that it will: (i) allow a more flexible assessment of a wide range of farm-specific policies; (ii) be applied on a EU-wide scale; (iii) reflect the full heterogeneity ([1]) of EU farms in terms of policy representation and impacts; (iv) cover all main agricultural production activities in the EU; (v) permit a detailed analysis of different farming systems; and (vi) estimate the distributional impacts of policies across the farm population. The typical questions that we attempt to answer with IFM-CAP are the following: How is farm income affected by policy reforms? Which farms would gain and which would lose? Where are the affected farms located? What is their production specialisation? Are small farms more affected than large ones? How many full-time and part-time jobs are potentially affected by the policy reform?

The IFM-CAP model is a static positive mathematical programming model, which builds on the EU-FADN data, potentially complemented by other relevant EU-wide data sources such as the Eurostat, Farm Structure Survey (FSS) and CAPRI databases. It consists of solving, at given prices and subsidies, a general maximisation problem in terms of input choice and land decisions, subject to a set of constraints representing production technology and policy restrictions. In order to reach the best representativeness and to capture the full heterogeneity of the EU farm population, the whole FADN farm constant sample between 2007 and 2009 (around 60 500 farms) is individually modelled.

The IFM-CAP model starts with a simplified prototype, to which improvements will be added at different steps of the model's development (Table 1 summarises the main features of this prototype). After refinement of this prototype, farm and market interactions will be added; improvements will also be made regarding the modelling of farm behaviour (e.g. modelling of risk and of labour and capital allocations). Finally, additional issues such as the modelling of environmental issues and second pillar policies will be considered (see section 11).

This report provides a detailed description of the IFM-CAP prototype in terms of design, mathematical structure, data preparation, modelling livestock activities, allocation of input costs and calibration process. The theoretical background, the technical specification and the outputs that can be generated from this prototype are also briefly presented and discussed.

([1]) The Farm Accountancy Data Network (FADN) survey (therefore the IFM-CAP model) does not cover all the agricultural holdings in the EU but only those that, because of their size, could be considered commercial (the specific threshold varies by each MS).

Table 1. Main features of the IFM-CAP prototype

Model name	Individual Farm Model for Common Agricultural Policy Analysis (IFM-CAP)
Institution responsible for development and maintenance	Institute for Prospective Technological Studies (IPTS) (in-house model development and maintenance) and Directorate General for Agriculture and Rural Development (DG-AGRI)
Type of model	Individual farm model running for the whole FADN sample (and therefore all the EU regions and sectors), except farms with less than three years' observation during the base year period
Methodology	Comparative static and non-linear programming model
Model calibration	Calibrated for an average of years (3 years) using positive mathematical programming (PMP)
Objective function	Farm income maximisation: (revenues – accounting costs + pillar I subsidies – PMP terms)
Revenues	Production value by activity: price × yield × activity level (ha or head)
Accounting costs	Operating costs per unit of each production activity
Subsidies	First pillar policies: coupling and decoupling (SPS and Single Area Payment Scheme (SAPS))
Constraints	
Land constraint	Sum of area by activity less or equal to total farm land endowment defined by type of use (arable and grassland)
Labour, capital	Captured by PMP terms
Policy constraints	Set-aside, quotas, greening, capping, modulation, regional ceiling for premiums, etc.
Livestock	Animal demography and livestock constraint balancing feed demand and feed supply
Other considerations	
Price, yield and subsidies	Exogenous variables derived at farm level from FADN
Input costs by activity	Estimated using econometric estimation (highest posterior density (HPD) estimation with prior information derived from the DG-AGRI input allocation module)
Total farm land endowment	Fixed at base year level
Technological progress	Yes, using an exogenous yield trend
Structural change	No
Changes in management practices	No
Environmental indicators, public goods and externalities	No
Market interactions	No
Time horizon	2020/22 (extensive use of results from Aglink/CAPRI baseline work)
Potential scenarios	CAP first pillar (i.e. greening, Basic Payment Scheme, etc.); price change; input cost change
Model results	
Type of model results	Production, land use, land allocation by activity within the farm, farm income, variable costs, first pillar subsidies, distribution of income and subsidies among farmers (base year, baseline and policy scenarios)
Farm level	Single farm units
Farm group aggregation	By farm typology, farm size or other relevant dimension [using farm weighting factors from FADN (2)]
Regional aggregation	FADN regions, NUTS, MS, EU
Data needs and other considerations	
FADN data	Constant sample single observations (2007, 2008, 2009)
Other supporting data	Official statistical sources (e.g. Eurostat, FSS), scientific literature, other models (e.g. CAPRI), etc.
Programming language	General Algebraic Modelling System (GAMS)

(2) The farm weights are adjusted taking into consideration the constant sample used in the model.

2. IFM-CAP prototype: specification and mathematical structure

IFM-CAP is a constrained optimisation model that maximises an objective function subject to a set of constraints. For the current prototype, we have assumed that farmers maximise their income at given yields, product prices and production subsidies, subject to resource (arable and grassland and feed requirements) and policy constraints such as sales, quotas and set-aside obligations. Land constraints are used to match the available land that can be used in a production operation and the possible uses made of it by the different agricultural activities. Constraints relating feed availability to feed requirements are used to ensure that the total energy, protein and fibre requirements are met by farm-grown or/and purchased feed. For certain animal categories, additional minimum or maximum requirements by type of feeding regarding the animal's diet are introduced.

Farm income is defined as the sum of gross margins minus a non-linear (quadratic) activity-specific function. The gross margin is the total revenue including sales from agricultural products and compensation payments (coupled and decoupled (3) payments) minus the accounting variable costs of production activities. The accounting costs include costs of seeds, fertilisers, crop protection, feeding and other specific costs. The quadratic activity-specific function is a behavioural function introduced to calibrate the farm model to an observed base year situation (4), as is usually done in positive programming models. This function intends to capture the effects of factors that are not explicitly included in the model such as price expectation, risk aversion, labour requirement and capital constraints (Heckelei, 2002).

The FADN database provides only total accounting costs per variable input category (e.g. seeds, fertiliser, pesticide, feed, etc.), without indicating the unit input costs of each (crop and animal) output that is needed to capture policy impacts and to represent technologies in an explicit way. To overcome this lack of information, we opt for a Bayesian econometric estimation of unit input costs based on the farm-level input costs per category reported in FADN, assuming a Leontief production function (i.e. input use increases linearly with production activity levels).

The removal of the accounting variable costs from the quadratic behavioural function by introducing a Leontief production function for variable input costs, was motivated by the fact that the primal technology representation through the Leontief production function (i) provides an explicit link between production activities and the total physical input use, (ii) eases the linkage to environmental indicator calculation, and (iii) allows the simulation of policy measures linked to specific farm management. According to Heckelei and Wolff (2003), the main disadvantage of this approach is the lack of rationalisation, as intermediate input uses are assumed to be independent of the unknown marginal costs captured by the quadratic behavioural function.

A single model template was applied for all modelled FADN farms in order to ensure a uniform handling of all the individual farm models and their results. That is to say, all the individual farm models have an identical structure (i.e. they have the same

(3) All farm area is assumed to be eligible.

(4) In principle, any non-linear convex function with the required properties can reproduce the base year solution. For simplicity, and in the absence of any strong arguments for other types of functions, a quadratic function is usually employed.

equations and variables, but the model parameters are farm specific), and no cross-farm constraints or relationships are assumed in the current version of the model, except in the calibration phase, in which all individual farms in each region are pooled together to estimate the behavioural function parameters. To render equations easily understandable, vectors are designated by bold lower case letters, matrices by upper case letters and scalars by italic letters. For simplicity, indices for farms are omitted.

The general mathematical formulation for IFM-CAP is as follows:

$$\underset{x\geq 0}{\text{Max}}\ \boldsymbol{\pi} = \mathbf{p}'(\mathbf{y}\circ\mathbf{x}) + \mathbf{s}'\mathrm{x} - \mathbf{C}\mathrm{x} - \mathbf{d}'\mathrm{x} - 0.5\mathrm{x}'\mathbf{Q}\mathrm{x} \qquad (1)\ [5]$$

S.t.

$$\mathbf{A}\mathrm{x} \leq \mathbf{b} \quad [\boldsymbol{\rho}] \qquad (2)$$

where π is the objective function value, **x** is the (N × 1) vector of non-negative activity levels (i.e. acreages) for each agricultural activity *i*, **p** is the (N × 1) vector of product prices (including feed and young animal prices), **y** is the (N × 1) vector of yields, **s** is the (N × 1) vector of production subsidies (coupled and decoupled payments), **C** is the (N × K) matrix of accounting unit cost for K input categories (seed, fertiliser, plant protection, other specific costs and feeding costs), **d** is the (N × 1) vector of the linear part of the behavioural activity function and **Q** is the (N × N) symmetric, positive (semi-) definite matrix of the quadratic part of the behavioural activity function.

A is the (N × M) matrix of coefficients for M resource and policy constraints (land, obligation set-aside and quotas), **b** is the (M × 1) vector of available resources (arable and grassland) and upper bounds to the policy constraints, and **ρ** is the vector of their corresponding shadow prices. Product prices, yields, subsidies, set-aside rate, quotas (sugar beet and milk) and land availability are given (i.e. derived from FADN or estimated in the data preparation step) and are assumed to be known with certainty. The parameters **C**, **d** and **Q** are estimated using highest posterior density (HPD) estimation (Heckelei et al., 2008) [6].

In each farm and for each activity *i*, total production can be used for sales, on-farm use for feeding animals or for others uses (including losses and seeding):

$$y_i x_i = q_i = t_i + u_i + e_i \quad \forall\, i = 1,\ldots, N \qquad (3)$$

x is the (N × 1) vector of non-negative activity levels (i.e. acreages) for each agricultural activity i, **y** is the (N × 1) vector of yields, **q** is the (N × 1) vector of produced quantities (i.e. production), **t** is the (N × 1) vector of sales/purchases quantities (or sales/purchases of animals), **u** is the (N × 1) vector of used quantities for feeding, and **e** is the (N × 1) vector of losses and on-farm use for seeding.

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[5] The symbol ∘ indicates the Hadamard product.

[6] A detailed mathematical description of IFM-CAP prototype is given in Table A 1 in Annex A.

3. IFM-CAP database

This section provides a brief description of the data used and data treatment procedures applied in IFM-CAP. As mentioned above, IFM-CAP is parameterised using FADN data for the three-year average around 2008 (2007, 2008 and 2009). However, before using the FADN data, several steps were performed in order to screen data and to convert them to a format that is compatible with the IFM-CAP modelling framework. This activity included in particular data adjustment to IFM-CAP model needs, identification and correction of out-of-range values and outliers, handling missing values and addressing the issue of variables that are not available in FADN.

3.1. Data requirement

Three types of data are required for running the first prototype of IFM-CAP: farm resource data, input–output data for production activities, and calibration data.

(i) **Farm resource data** involves available farmland (i.e. total utilised agricultural area (UAA), arable land and grassland), sugar beet quota rights and the minimum set-aside rate. These data are used for setting lower/upper bounds for resource and policy constraints in the model. Farmland is directly available in FADN. Sugar beet quotas are estimated using the national share of quota because for most of the MSs these data are not reported in the FADN database (see section 5). The set-aside rate is set to the observed rate (i.e. the proportion of set-aside in the total area) ([7]). Data on labour, energy, water and capital resources are not included, as they are not explicitly modelled but captured by the behavioural function (i.e. PMP terms).

(ii) **Input and output data for production activities** consist of yields, product prices, production subsidies and accounting unit costs for all crop and animal activities on each farm. These data are used for the calculation of the gross margin per hectare or per head of each production activity to be embedded in the model objective function, as well as for the definition of input coefficients for resource and policy constraints. The data on yields, prices and subsidies are derived from FADN. Data on accounting unit costs for crops (i.e. specific costs related to seeds, fertilisers, crop protection and other crop-specific costs) are estimated using a Bayesian approach with prior information on input–output coefficients from the DG-AGRI input allocation module (see section 4). The feeding costs are also estimated using a Bayesian approach with prior information on animal feed requirements from CAPRI and data on farm level feed costs, feed prices, feed nutrient contents and fodder yields from FADN, CAPRI and Eurostat, respectively (see section 7.2). The list of crop activities defined in the IFM-CAP model and the extraction rules for each activity are provided in Table A 3 in Annex A. The extraction rules for the livestock activities are explained in section 6.1, as they are more complex owing to the livestock herd demography.

(iii) **Calibration data** consist of activity levels (i.e. hectares or heads), rental prices, the gross margin differential between sugar beet and the next best alternative crop and supply elasticities at NUTS 2 level. The observed activity level (x^0) is used to calibrate

([7]) Note that the set-aside rate was not set to the policy rate because for some farms the observed rate is lower than the policy rate, which can inhibit model calibration.

the model, assuming it is the optimal crop allocation in the base year. The land rental prices, the supply elasticities and the gross margin differential between sugar beet and the next best alternative crop are used as prior information. Section 7 describes in detail how these data are used in the calibration process.

Overall, most of the required data for the first prototype of IFM-CAP come directly or indirectly from FADN with the exception of some data linked to feed crops and animal activities (see section 6) or those used as prior information for model calibration (see section 7) or for the estimation of sugar beet quota and prices (see section 5). For example, the majority of calibration and farm resource data are recorded in the FADN data and, thus, are used in the modelling exercise directly. However, some other data such as prices and yields are not directly reported in FADN and, therefore, are derived from the original FADN variables using simple assumptions. For example, prices are approximated by dividing production value (TP) with the production quantity (QQ). Production value (TP) is reported in FADN as the sum of sales, own consumption and change of stocks, which may result in negative, very small or very large positive (i.e. out-of-range) values for the derived prices in a given year. In fact, high carry-over stock and a consequent drop in prices may lead to a negative total production value and ultimately generate a negative output price. For the modelling exercise it is not suitable to use out-of-range (i.e. negative, outliers) or zero values for prices and yields, as they are key factors in determining the farmer's decisions. Section 3.3 (i) describes in detail the rule used to identify outliers and missing values for yields and prices, (ii) provides some examples of identified outliers, and (iii) explains how we deal with them.

The left-hand side of Figure 1 summarises the data needs of IFM-CAP and their sources. As shown in this figure, some data are not used directly in the optimisation process but only as prior information in the estimation procedure of certain input coefficients.

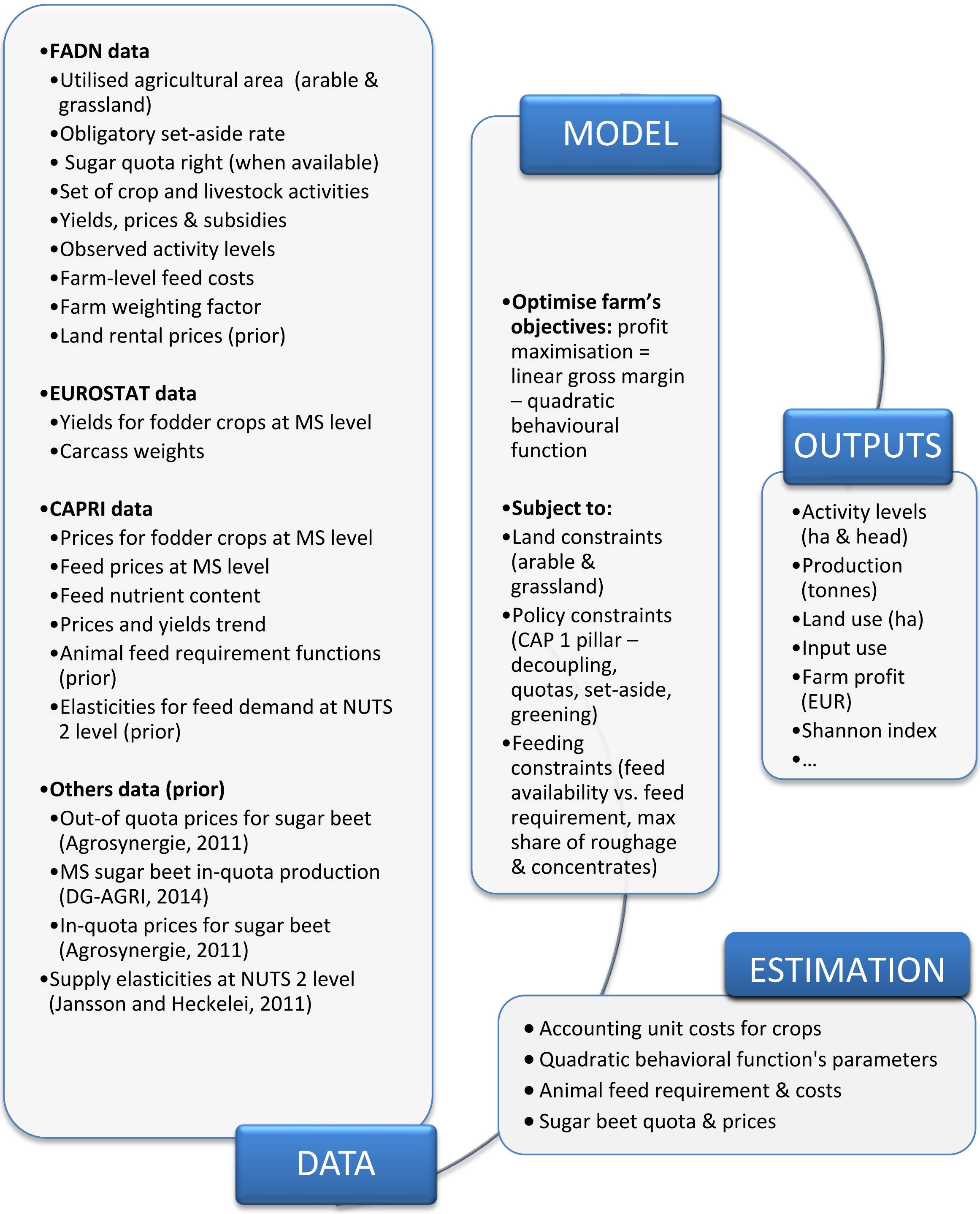


Figure 1. IFM-CAP prototype description

3.2. Selection of farm constant sample

A constant sample of farms for the base year period 2007–2009 is selected and stored in a single file to facilitate data management. Figure 2 shows the number of farms in the constant sample. In the EU-27 ([8]), of the total 81 114 farms sampled in 2007, only

([8]) In the IFM-CAP model, Belgium and Luxembourg are grouped together as one country (indicated by BL) because of data availability (trade data) and the similarity of their agriculture.

60 552 remained in the sample until 2009. The proportion of farms that remain in the constant sample varies strongly across MSs.

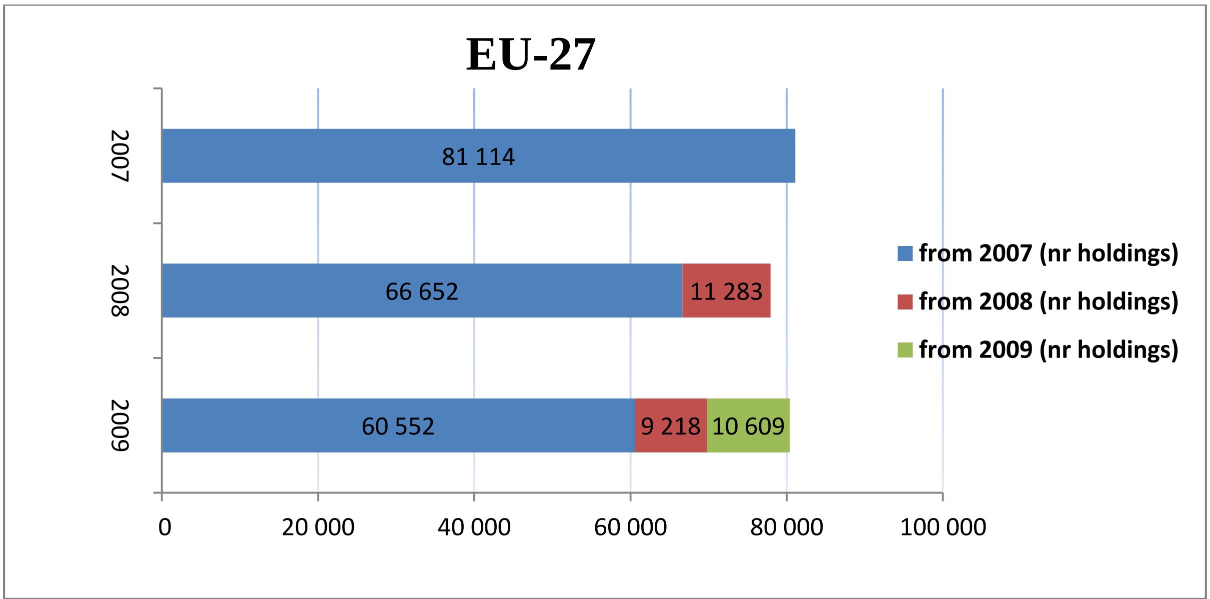


Figure 2. Evaluation of the number of FADN farms in the EU-27

The FADN is a representative stratified sample with regard to regional disaggregation (FADN regions), production specialisation and farm size. An individual weighting scheme is applied to each farm in the sample corresponding to the number of farms it represents in the total population. The weighting scheme allows aggregation of results at different regional levels (e.g. NUTS 2, MS, EU level) or by farm type according to specialisation, farm size, etc. Because we consider the constant sample, the weights need to be adjusted in order to account for the farms in the FADN sample that are excluded from the final database used in IFM-CAP. The adjusted weights (indicating the number of farms represented in each dimension cell as the combination of region, economic size and type of farming) will be used in particular for (i) the calculation of the three-year averages around 2008, used as base year, (ii) the calculation of average data at NUTS 2 level to be used during the data preparation routine for handling missing values, and (iii) the aggregation of model results by region (NUTS 2, MS and EU) and by farm type (specialisation, size).

3.3. Data screening and treatment

The purpose of the FADN data screening is to remove aberration and to check to what extent these data need to be adjusted to reflect the IFM-CAP modelling requirements. The key data that have been screened are: yields, product prices, production quantities and production values. The data screening involves two steps: (i) detecting and handling outliers; and (ii) identifying and addressing the problem of zero/missing and negative values. The data treatment was applied to the raw data before averaging them over the three years considered in the model.

Outliers

Outliers are observations that are numerically distant from the rest of the data. In our case, they concern mainly prices and yields and may originate for various reasons:

- Because prices and yields are derived from other FADN data (based on total production value, production quantity and areas), their values in some farms may deviate significantly from the rest of the sample if underlying data do not portray sufficient information to identify their true value (e.g. because of high carry-over stock combined with a high price ([9])). The formulas for price and yield calculation are given as follows:

  Prices are derived as: $\mathbf{p} = \mathrm{TP} / \mathrm{QQ}$

  Yields are derived as: $\mathbf{y} = \mathrm{QQ} / \mathrm{AA}$

  where TP is production value (euros); QQ is production quantity (tonnes); AA is production area (hectares)

  TP is calculated as: $\mathrm{TP} = \mathrm{SA} + \mathrm{FC} + \mathrm{FV} - (\mathrm{BV} - \mathrm{CV})$

  where SA is sales; FC is farm consumption; FV is farm use; BV is opening stock; CV is closing stock

- Because of high heterogeneity in yields and prices for specific activities included in a given aggregated activity group (e.g. flower (FLOW), other cereals (OCER), other vegetables (OVEG)), as well as for crops with yields strongly dependent on climatic conditions or variety cultivated (e.g. tobacco (TOBA), potatoes (POTA), olives (OLIV), and pasture (GRAS)).

- Because farmers may have imputed incorrect information in particular for output quantity and/or output value in the FADN farm returns.

In the case of yields, the outliers were kept unchanged. This was motivated by the fact that there can be high yield heterogeneity owing to variation in the natural conditions (e.g. soil type, weather effects, infections and diseases) and management practices (e.g. irrigation, crop variety, input application).

For prices, normality tests have been carried out, and for consistency we have used a non-parametric method (the interquartile range (IQR)) for determining and replacing the outliers in prices.

The IQR is a measure of statistical dispersion, being equal to the difference between the upper and lower quartiles:

$$IQR = Q3 - Q1$$

This data treatment was conducted at NUTS 2 level. More precisely, it is a trimmed estimator, defined as the 25 % trimmed mid-range, and it is the most significant basic robust measure of scale. It is the third quartile of a box and whisker plot minus the first quartile. An outlier is defined as any value that lies at more than one and a half times the length of the IQR, therefore:

$$if\ Xi < (\ Q1 - 1.5\ \times\ IQR\ ) > Lower\ outlier$$

([9]) The opening valuation is based on the value of the stocks at the start of the accounting year at farm gate prices current at that time.

$$if\ Xi > (Q3 + 1.5 \times IQR) > Upper\ outlier$$

We have identified a total of 27 788 upper outliers and 12 197 lower outliers for prices representing around 7 % of the total number of prices for the three years (2007–2009).

We have analysed two options of treating outliers: discarding (trimming) and winsorising (transforming). As the number of outliers was large and in order to keep the FADN sample intact, we have decided to transform the (lower/upper) outliers using the values of the (lower/upper) outlier threshold defined as follows:

Lower outlier threshold = $Q1 - 1.5 \times IQR$

Upper outlier threshold = $Q3 + 1.5 \times IQR$

The IQR is equal to the difference between the upper (Q3) and lower quartiles (Q1) defined at the NUTS 2 level:

$$IQR = Q3 - Q1$$

Variables with zero and negative values

FADN assigns zero values to variables for which data is not collected. For this reason it is often difficult to distinguish between a variable with a missing value and a variable with an observed zero value. We treat all zero values for existing (non-zero) activity levels as 'missing values' in our data management tool and replace them with a specific value when necessary.

Three crucial FADN variables are used for calculating prices and yields: total production value (TP); output quantity (QQ); and areas (AA). In the first step, all the negative values associated with output quantities and areas have been substituted by a zero value. After conducting this procedure, a total of 123 236 'missing' (zero) values were identified for TP and QQ over the three years considered in the model. This represents around 20 % of crop activities for which activity level – area (AA) – is non-zero. Because prices and yields are derived from total production and output quantity, their value cannot be calculated. In addition, 1 486 variables (representing 0.20 %) are identified with negative total production value (TP) (therefore price). To address this problem, we have implemented the following corrections:

1. *Total production (TP) is 'negative'*: we set crop prices to the average price at the NUTS 2 level. If the NUTS 2 prices are not available, we use average national prices. Next, we recalculate total production value (TP) based on the new price and the reported output quantity (QQ).

2. *Total production (TP) is 'missing'*: if output quantity (QQ) is positive while total production value (TP) is missing, we set crop prices equal to the average crop price at NUTS 2 level, assuming that prices cannot be equal to zero. If the average regional prices are not available, we use average national prices. Next, we recalculate total production value (TP) based on the new price and the reported output quantity (QQ).

3. *Output quantity (QQ) is 'missing'*: if activity level/area (AA) and total production value (TP) are available, while output quantity (QQ) is not, we set crop yield equal to the average regional (NUTS 2) yield, recalculate the output quantity (QQ) based on the new yield, and recalculate the price based on the total production value (TP) and new output quantity (QQ). As above, if the average regional yields are not available, we use average national yields.

4. *Output quantity (QQ) and total production (TP) are 'missing'*: if activity level/area (AA) exists, while total production value (TP) and output quantity (QQ) are not available, we set crop prices equal to the average regional price ([10]) and crop yield equal to zero. We assume that production/yield can be equal to zero but not prices. In cases in which the average regional price is not available, we use the average national price.

3.4. Extraction rules for subsidies

The current version of the IFM-CAP prototype relies fully on subsidy data available in FADN. The FADN (and thus also IFM-CAP) covers both coupled and decoupled CAP payments. The *coupled payments* for crops (SUBCRO) include compensatory payments for annual and permanent crops (SUBCRO_COP), set-aside (SUBCRO_SETA), other specific crop payments (SUBCRO_OTHER) and other coupled subsidies (SUBART) ([11]). The *decoupled payments* (SUBDEC) include Single Payment Scheme ([12]) (DPSFP), Single Area Payment Scheme (DPSAP) and additional aid (DPAID). Rural Development Subsidies are not included in the model at this stage (Table 2 and Table 3).

Coupled crop payments are distributed to eligible crops ([13]). They are calculated per hectare for each eligible activity based on area proportions in the total eligible area. This means that in cases where there is more than one activity benefiting from the payment (e.g. DPCER), subsidies are distributed over all eligible activities using the area proportions. In the special case in which all eligible activities have 'zero' area in the database, the payment is distributed to all farm activities using the area proportions as the distribution key.

In the livestock sector, four types of coupled animal payments are considered: dairy subsidies (SUBLIV_DAIR), other cattle subsidies (SUBLIV_OTCA), sheep and goat subsidies (SUBLIV_SHGO) and other livestock subsidies (SUBLIV_OTHER). Given that these subsidies are distinguished by livestock type (cattle, sheep and goat, etc.) and animal category (cows, heifers, male cattle, etc.), they are calculated per head. As in the arable sector, they are distributed over eligible animal activities based on the proportion of each eligible activity in the total number of animals benefiting from these payments. Table 3 summarises the rules used for the extraction of animal subsidies from FADN.

([10]) When replacing prices or yields for a single year with an average price/yield, we calculate the deviation from average prices/yields for the other two years and adjust assigned average price/yield by the average deviation for the two years.

([11]) The extraction rules for the subsidies follow in part the ones implemented in FADNTOOL. Other coupled subsidies include those granted under the Article 68 of Regulation (EC) No 73/2009.

([12]) Often referred to as Single Farm Payment.

([13]) The crop and livestock activities benefiting from each payment (and by year) are specified in Table A 6 in Annex A.

Table 2. Extraction rules for coupled crop payments and decoupled payments from Table J and M in FADN

Categories subsidies	GAMS acronym s	FADN Table	Extraction rule
Coupled payments	SUBCRO	**J + M**	
Compensatory payments per area	SUBCRO_COP	M	M (602CP...614CP) + M618CP + M(622CP...629CP) + M(632CP...634CP) + M638CP + M655CP
Set-aside premiums	SUBCRO_SETA	M	M650CP
Other crop payments	SUBCRO_OTHER	J	JC(120...145) + JC146 + JC(147...161) + JC185 + JC(281...284) + JC(296...301) + JC(326...357) + JC(360...374) + JC952
Art. 68 subsidies	SUBART	J	JC956
Decoupled payments	SUBDEC	**J**	**JC670 + JC680 + JC955**
Single farm payment	DPSFP	J	JC670
Single area payment	DPSAP	J	JC680
Additional aid	DPAID	J	JC955

Table 3. Extraction rule for coupled animal payments

Subsidies in FADN	GAMS acronym	GAMS acronym.	Description	Extraction rule
Subsidies dairying	SUBLIV_DAIR	DPDCOW	Direct payments to dairy cows	M770CP
		JCDOW	Other payments to dairy cows	JC30 + JC32 + JC163
Subsidies other cattle	SUBLIV_OTCA	DPBULF	Special premiums to bulls and steers	M710CP
		DPSCOW	Direct payments to suckler cows	M731CP
		DPNE_MEAT	Additional payments to bovine meat cattle	M735CP
		DPSL_ADCT	Slaughter premium for adult cattle	M742CP
		DPSL_CALV	Slaughter premium for calves	M741CP
		DPADDPNA	Additional payments (national envelope)	M760CP
		DPEXTENS	Extensification payment for bulls, steers and suckler cows	M750CP
		JCBULF	Payments bull fattening	JC25 + JC27
		JCSCOW	Payments suckler cow	JC32
		JCHEIR	Payments heifers raising	JC26 + JC28
		JCHEIF	Payments heifers fattening	JC29
		JCCAR	Payments calves raising	JC24
		JCCAF	Payments calves fattening	JC23
		JCCATT	Payments cattle	JC52 + JC307
		JCOCAT	Other payments other cattle	JC31
Subsidies sheep and goats	SUBLIV_SHGO	JCSHGO	Payments sheep and goat fattening	JC54 + JC55 + 308
		JCSHGM	Payments sheep and goat milk	JC38 + JC40 + JC(164....JC168)
Subsidies on other livestock	SUBLIV_OTHER	JCPIGF	Payments for pig fattening	JC45 + JC46
		JCPIGS	Payments for pigs and sows	JC309 + JC56
		JCSOWS	Payment for sows	JC44
		JCHENS	Payments for hens	JC48 + JC169 + JC43
		JCPOUF	Payments for poultry	JC47 + JC49 + JC310
		JCPOU	Payments for hens and poultry	JC57
		JCOANI	Payments for other animals	JC50 + JC58
		JCOTHLI	Other payments livestock	JC951 + JC170 + JC171 + JC311

For the decoupled payment (i.e. SUBDEC), we calculate the payment value on each farm on the basis of the received decoupled aid and the number of eligible hectares. All the eligible area on each single farm receives a uniform per hectare decoupled payment (Table 2).

4. Input cost estimation

FADN collects the monetary value of crop inputs, livestock inputs and other farm costs (e.g. overheads, depreciation, hired labour costs, interest costs) at farm level.

Information on how these aggregate costs are distributed over specific farm activities is not recorded. Starting from the reported farm-level aggregate input costs, we therefore estimate activity-specific unit input costs using a Bayesian econometric approach ([14]). The resulting estimated accounting units costs for **K** input categories (seed, fertiliser, plant protection and other specific costs) are directly incorporated in the model's objective function (π) as the elements of the matrix **C** (N × K) in equation (1) above.

4.1. Leontief technology specification

For the estimation of input costs, we assume a Leontief production function for intermediate inputs (i.e. input use increases linearly with the production activity levels). Such a linear input demand equation has been used widely in the literature (e.g. Léon et al., 1999; Kleinhanss et al., 2011). This allows us to link production activities and total physical input use. However, the rigid technology assumption and the failure to consider, for example, soil quality and crop rotation effects in input use can be a serious limitation. One common way to handle these problems and make the technology set more flexible, without departing from the Leontief specification, is to include activities with discretely varying input intensities.

Hence, input allocation is assumed to display the following linear relationship to output:

$$\mathbf{z} = \mathbf{Hv} + \mathbf{u} \tag{4}$$

where **z** is the (K × 1) vector of input costs, **v** is the (N × 1) vector of total value of outputs, **H** is an (N × K) matrix of unknown input–output coefficients and **u** is the (K × 1) vector of random errors.

This relationship can be expressed by farm and input category as follows:

$$z_{f,k} = \sum_i H_{i,k} v_{f,i} + u_{f,k} \tag{5}$$

where $z_{f,k}$ $x_{if}$is the total (explicit) cost of variable input *k* (k = 1,…, K) for farm *f* (f = 1, …, F) recorded in FADN, $v_{f,i}$ is the total value of output *i* (I = 1,…, N) for farm *f*, $H_{i,k}$ α_{ik} is the expenditure on input *k* required per unit of output value *i* and $u_{f,k}$ is a random disturbance term which is specific to each input category and to each farm (Errington, 1989). It is assumed that farms within the same region and the same farm type have a common technology, and thus the same input–output coefficients $H_{i,k}$ (i.e. the index for farm types is omitted here).

In order to ensure that the accounting balance between total revenue and total cost is respected, the following accounting restriction is imposed for each output *i*:

$$\sum_k H_{i.k} = 1 \tag{6}$$

([14]) In parallel, an alternative way of estimating the costs of production is being tested, making use of the cost function approach, which would alter the entire modelling approach (see section 11).

Following Léon et al. (1999), this is achieved by introducing a residual input category ‘value added’ with corresponding monetary input coefficients equal to the difference between the total revenue and the sum of all other monetary input coefficients across input categories. Similar to other input categories, value added is restricted to being positive, assuming that, for each type of output *i* averaged (across all farms) total cost cannot exceed total revenue.

4.2. Highest posterior density estimation

In order to select the most accurate method for estimating the unknown input–output coefficients $H_{i,k}$ α_{ik}, we have tested several alternative estimation approaches for a sample of 565 farms in a region in France, for which details on activity-level input costs were recorded. We aggregated the crop-specific input costs at farm level, and tested the performance of different methods (including seemingly unrelated regressions (SURs), entropy and highest posterior density (HPD) estimation) in recovering the true disaggregated crop-specific input costs (for details on these alternative estimation approaches and their performance, see Colen et al., 2014). As prior information for the entropy and HPD approach, we propose the use of the results of the input allocation key that was developed by DG-AGRI and we compare this with alternative types of prior information that were proposed in earlier studies. The key allocates total accounting costs to individual output activities based on the proportion of activity output value in the total output value (for details see Table A 7 in Annex A). Several accuracy criteria showed that the HPD approach, using the inputs allocated according to the input allocation key as prior information, performed best. HPD also has a significantly lower computational demand, which is non-negligible given the large sample of individual farms in the IFM-CAP model.

Hence, we estimate the input–output coefficients, $\mathbf{H}$, by NUTS 2 region and farm type, using the HPD approach and prior information $\overline{\mathbf{H}}$ based on the input allocation key developed by DG-AGRI. The HPD approach minimises the normalised least square deviation between the estimated input–output coefficients and the prior information. This Bayesian approach was proposed by Heckelei et al. (2005) as an alternative to entropy methods for deriving solutions to underdetermined systems of equations. They argued that the main advantage of this approach is that it allows a more direct and straightforward interpretable formulation of available a priori information and a clearly defined estimation objective. In the HPD estimation the model parameters are treated as stochastic outcomes. In this context, the method distinguishes between the prior density, $\mathbf{p(H)}$, which summarises a priori information on parameters, and the likelihood function, $\mathbf{L(H|v)}$, which represents information obtained from the data in conjunction with the assumed model. The combination of the prior density and the likelihood function results in a posterior density that can be expressed as (e.g. Zellner, 1971, p. 14).

$$\mathbf{z(H|v) \propto (p(H)L(H|v))} \qquad (7)$$

where $\mathbf{z}$ denotes posterior density, $\propto$ is the proportionality, $\mathbf{H}$ are the parameters to estimate and $\mathbf{v}$ is the vector of observations. This approach is extensively discussed in Heckelei et al. (2008). This leads to the following estimation problem:

$$Min\ HPD = [vec(\mathbf{H} - \bar{\mathbf{H}})]' \textstyle\sum^{-1} [vec(\mathbf{H} - \bar{\mathbf{H}})]$$

Subject to:

$$\mathbf{z} = \mathbf{Hv} + \mathbf{u} \tag{8}$$

$$\mathbf{I'H} = \mathbf{1}$$

where $\bar{\mathbf{H}}$ contains the prior values and HPD is the prior density function of the form vec(H) ~ N(vec($\bar{\mathbf{H}}$),∑). The prior values, $\bar{H}_{i,k}$, are the mean input–output coefficients by NUTS 2 region and farm type, obtained through DG-AGRI's input allocation key (see Table A 7). The covariance matrix, ∑, is set equal to a diagonal matrix with elements twice the variance of the input–output coefficients obtained from the input allocation key method: $(2\sigma^H)^2$. For the error term, **u**, we use a prior density function of the form N(0,∑), with prior mean zero and with twice the squared standard deviation of the error $(2\sigma^u)^2$ as elements of the diagonal covariance matrix. For more details, refer to Table A 3 in Annex A.

The solution to this optimisation problem provides estimates for the unknown input–output coefficients, $H_{i,k}$, for each region and farm type and for the error term, **u**.

This approach does not ensure that all input costs are fully distributed over activities. Therefore, for each farm we proportionally allocate the remaining non-distributed costs across the different activities, leading to a farm-specific corrected input–output coefficient, $\widetilde{H}_{f,i,k}$. These corrected input–output coefficients ensure that aggregate input costs are completely distributed, and further improve the accuracy of input cost estimates (see Colen et al., 2014). Based on these corrected coefficients, $\widetilde{H}_{f,i,k}$, and the value of production per observed activity level, $v_{f,i}/x^0_{f,i}$, the unit input costs of the matrix **C** (N × K), i.e. the input costs per hectare of activity *i*, can be calculated as follows:

$$\widetilde{H}_{f,i,k} = H_{i,k} \frac{z_{f,k}}{\sum_i H_{i,k} v_{f,i}} \tag{9}$$

$$z_{f,k} = \sum_{i=1}^{n} \widetilde{H}_{f,i,k} v_{f,i} = \sum_{i=1}^{n} C_{f,i,k} x^0_{f,i} \tag{10}$$

Hence,

$$C_{f,i,k} = \widetilde{H}_{f,i,k} \frac{v_{f,i}}{x^0_{f,i}} \tag{11}$$

For illustration, the resulting average estimated input costs per hectare, $C_{i,k}$, are reported for each crop and input cost category in Table A 8 (Annex A) for the regions Burgundy and Andalusía.

5. Estimation of sugar beet quota

The common market organisation for sugar is subject to production controls implemented by a system of supply quotas. The quotas are defined for each MS, which allocates the quota to sugar refineries, which in turn allocate 'delivery rights' to individual farms. The quota specifies the amount of 'quota beet' (in-quota sugar beet) farms can deliver at supported prices. Any quantities sold beyond the quota (out-of-quota sugar beet) have to be sold at international prices and thus they receive a lower price than the in-quota beet (Agrosynergie, 2011; Burrell et al., 2014; European Commission, 2013).

The IFM-CAP cannot fully rely on FADN data for modelling the sugar beet quota system. The FADN contains records on sugar beet area (K131AA), total sugar beet production (K131QQ ([15])), average sugar beet price (p) (K131TP/K131QQ) and sugar beet in-quota quantity (L421I). Although there are data available on sugar beet quota (L421I) for several MSs (i.e. Austria (AT), Belgium-Luxembourg (BL), Germany (DE), Lithuania (LT), the Netherlands (NL), Poland (PL), Spain (ES), Sweden (SE) , Greece (EL) and the United Kingdom (UK)) ([16]), their quality needs to be considered carefully. Only in four MSs (i.e. Belgium-Luxembourg, Germany, Lithuania and Poland) is the ratio between the reported MS sugar quota (DG-AGRI, 2014) and the quota in FADN (aggregated at MS level using the farm weights for the average year) within a reasonable range, i.e. between 0.5 and 1.5 ([17]). This implies that the data for in-quota prices, sugar beet quota and out-of-quota prices, which are indispensable for the modelling of quota regime in IFM-CAP, cannot be fully recovered from FADN and need to be estimated and/or extracted from other data sources. Other potential data sources available for the entire EU that can supplement the FADN data include FSS and DG-AGRI (see Table A 12).

Table A 13 provides a comparison of the (weighted) FADN data with the FSS data for area, production and yield of sugar beet averaged for the years 2007–2009. On average, FADN reports higher values (for production and area) than FSS (by around 25 %), implying that sugar beet is over-represented in the FADN sample compared with the total population ([18]). There are some MSs in which this difference is very large. For example, for Spain and Romania the sugar beet area in FADN is 108 % and

([15]) The reported quantity is net of sugar beet tops.

([16]) It has been assumed that the reported quota data is in sugar beet (instead of sugar).

([17]) The ratio between the MS quota reported by DG-AGRI (DG-AGRI, 2014) and the one in FADN is the following: EL = 0.00; BL = 1.42; DE = 1.26; ES = 1.59; LT = 1.12; NL = 0.18; AT = 49.67; PL = 0.63; SE = 0.30; UK = 2.76.

([18]) The explanation could be that the FADN covers only commercial farms and that the representativeness of the FADN sample is constructed from location of the farm (region), economic size and type of farming and not from each production activity. Hence, the FADN may not be representative with respect to each activity (e.g. sugar beet production).

228 % higher, respectively, than in FSS. Other MSs with a large deviation are Finland, Latvia, Sweden and the United Kingdom ([19]).

To estimate the sugar beet quota for IFM-CAP we follow the approach of Adenäuer (2005), who also uses FADN data at farm level to estimate sugar beet quota. According to the literature, the profit maximising behaviour of farms is not sufficient to explain observed out-of-quota sugar production owing to (i) a cross-subsidisation effect between in-quota and out-of-quota production, (ii) the quota insurance strategy employed by farms in order to ensure fulfilment of their quota in the event of a poor sugar beet harvest, and (iii) uncertainties about sugar policy changes (Adenäuer 2005; Buysse et al., 2007b; Burrell et al., 2014; Gohin and Bureau, 2006). In addition, FADN does not report crop-specific costs and their identification is not straightforward (Langrell et al., 2012; Ronzon et al., 2014) ([20]).

Following the approach of Adenäuer (2005), we employ the HPD estimation approach to estimate sugar beet quota. The HPD approach minimises the sum of the farm-level relative squared difference between the estimated data and the prior information for the sugar quota production, between the reported farm sugar beet price and the EU average price (denoted as price correction factor), and between the MS prices (in-quota and out-of-quota) and the EU average price. For some farms the estimated sugar beet production might be lower than the reported FADN quota. As a result, the estimation approach allows for underdelivery of the quota (u_f^q). The prior information for the single farm in-quota production ($\overline{\mathbf{q}_\mathbf{f}^\mathbf{q}}$) is obtained by multiplying the ratio of MS sugar beet production quota reported by DG-AGRI (DG-AGRI, 2014) ([21]) by MS production quantity (derived from FADN) with the individual farm sugar beet production. In the case of Belgium-Luxembourg, Germany, Lithuania and Poland (MSs in which the reported aggregated FADN in-quota production is between 0.5 and 1.5 of the total reported by DG-AGRI), the prior information used is the reported FADN in-quota production divided by the ratio at MS level of the aggregated in-quota FADN sugar beet divided by the MS sugar beet quota production reported by DG-AGRI (DG-AGRI, 2014).

([19]) The sugar beet area reported in the balance sheet of sugar production by DG-AGRI (DG-AGRI, 2014) is lower than the area reported in FSS and FADN: the total area in MSs (those with quota) reported by DG-AGRI is 1 519 000 ha, while in FSS and FADN the total area is 1 631 000 and 1 950 000 ha, respectively. The difference between the FSS and DG-AGRI data is because the former data include only sugar (or the sugar equivalent of sugar beet) produced under the quota system (i.e. in-quota and out-of-quota sugar) whereas the latter also includes other types of sugar (e.g. the sugar equivalent of sugar beet used for feeding livestock). The reason why the sugar beet data differ between FSS and FADN is that, by the nature of its construction, FADN is not representative of sugar beet production, but representativeness is based on the number of farms in a specific farm typology (specialisation and economic size) and FADN region.

([20]) Two methods are most often applied in the literature to identify the crop-specific costs from FADN data. The first method selects a sub-sample of farms specialised in the studied crop; then the crop-specific costs of the farms are regarded as the costs of the studied crop. The disadvantage of using this approach for sugar beet is that sugar beet is usually cultivated in rotation with other crops; hence, there are only a few farms highly specialised in sugar beet production in the FADN sample. The second approach widely used in the literature employs an estimation technique to allocate costs to specific crops (Agrosynergie, 2011; Langrell et al., 2012; Ronzon et al., 2014).

([21]) Two other specifications have been tested in which the MS production is the one reported by DG-AGRI (DG-AGRI, 2014) and FSS. However, the goodness of fit of the model did not improve.

The MS-level sugar beet quota is extracted from DG-AGRI (DG-AGRI, 2014), while the MS sugar beet production quantity results from aggregating the FADN data. The standard deviation (σ_f^q) is assumed to be 20 % of the prior. In the case of the price correction factors, the aim is to obtain farm prices close to the MS prices. Consequently the priors $\overline{c_f^q}$ and $\overline{c_f^w}$ are assumed to be zero and the standard deviation was assumed to be EUR 5/tonne as in Adenäuer (2005). The prior information for EU-prices for in-quota and out-of-quota sugar beet are EUR 30 and EUR 20/tonne, respectively ([22]) ($\overline{P_{EU}^q}$ *and* $\overline{P_{EU}^w}$). The in-quota EU sugar beet prices are derived from Agrosynergie (2011) ([23]). For the out-of-quota EU sugar beet prices, the same ratio between in-quota and out-of-quota sugar prices as that used in Agrosynergie (2011) was assumed (i.e. the in-quota sugar prices are on average higher than out-of-quota prices by a factor of 1.5) ([24]). The standard deviation is assumed to be 20 % of the average EU sugar beet prices; i.e. EUR 6 and EUR 5/tonne for in-quota and out-of-quota sugar beet prices, respectively($\boldsymbol{\sigma_{EU}^{Pq}}$ and $\boldsymbol{\sigma_{EU}^{Pw}}$).

The farm-level components in the objective function were weighted by the number of farms in each MS (F_{MS}).

The general formulation of the HPD approach is presented as follows:

$$\mathrm{Min}\left[\frac{1}{F_{MS}}\frac{\left(q_f^q-\overline{q_f^q}\right)^2}{\left(\sigma_f^q\right)^2}+\frac{1}{F_{MS}}\frac{\left(c_f^q-\overline{c_f^q}\right)^2}{\left(\sigma_f^{cq}\right)^2}+\frac{1}{F_{MS}}\frac{\left(c_f^w-\overline{c_f^w}\right)^2}{\left(\sigma_f^{cw}\right)^2}+\frac{\left(P_{MS}^q-\overline{P_{EU}^q}\right)^2}{\left(\sigma_{EU}^{Pq}\right)^2}+\frac{\left(P_{MS}^w-\overline{P_{EU}^w}\right)^2}{\left(\sigma_{EU}^{Pw}\right)^2}\right] \quad (12)$$

$$q_f^{SUGB}=((q_f{}^q-u_f^q)+q_f{}^w)/S_{MS} \quad (13)$$

$$q_f^{SUGB}p_f^{SUGB}=(p_f{}^q(q_f{}^q-u_f^q)+p_f{}^w q_f{}^w)/S_{MS} \quad (14)$$

$$\sum_{i\subset MS} q_f^q\cdot wf_f\le Q_{MS} \quad (15)$$

$$p_f{}^q=p_{MS}^q+c_f^q,\ p_f^w=p_{MS}^w+c_f^w$$

$$p_f{}^q\ge p_f^w \quad (16)$$

$$p_i^w<p_i^q$$

([22]) There is a high heterogeneity (at MS level) in the reported average FADN prices: BL = 17.7; DK = 27.5; EE = 6.9; LT = 20.7; LV = 24.0; DE = 30.6; EL = 36.5; ES = 29.9; FR = 17.3; IT = 28.8; NL = 32.2;AT = 31.6; PT = 28.9; SE = 30.3; FI = 18.5; UK = 30.7;CZ = 31.5; HU = 22.3; PL = 29.0; SK = 15.3;RO = 31.6; IR = 26.3; SI = 51.9; BG = 57.3.

([23]) The effective in-quota EU sugar beet prices reported by Agrosynergie (2011) for 2007, 2008 and 2009 are EUR 30.1, EUR 30.6 and EUR 33.7/tonne, respectively.

([24]) The in-quota sugar prices were EUR 606, EUR 565 and EUR 483/tonne in 2007, 2008 and 2009, respectively. The out-of-quota sugar prices can be approximated with the 'industrial sugar' prices, which were EUR 271, EUR 298 and EUR 300/tonne in 2007, 2008 and 2009, respectively. These prices are lower than the world prices, which were equal to EUR 285, EUR 399 and EUR 463/tonne in 2007, 2008 and 2009, respectively (Agrosynergie, 2011).

$$p_f^q > 26.29 \quad (17)$$

$$u_f^q \cdot q_f{}^w = 0 \quad (18)$$

$$u_f^q < q_f{}^q$$

where **f** indexes farm, $\mathbf{q^{SUGB}}$ is the farm sugar beet production, $\mathbf{q^q}$ and $\mathbf{q^w}$ are the farm sugar in-quota production and out-of-quota production (in tonnes), respectively, $\mathbf{S_{MS}}$ is the national average percentage sugar content per beet derived from USDA (2010), $\mathbf{P^{SUGB}}$ is the farm sugar beet price (derived from FADN), $\mathbf{P_{MS}^q}$ and $\mathbf{P_{MS}^w}$ are the MS sugar beet in-quota and out-of-quota prices, respectively, which are adjusted at farm level by the correction factors $\mathbf{c_{fq}}$ and $\mathbf{c_{fw}}$ to obtain the farm level in-quota and out-of-quota prices $\mathbf{p^q}$ and $\mathbf{p^w}$, respectively. $\mathbf{Q_{MS}}$ represents the total sugar quota production at MS level reported by DG-AGRI (DG-AGRI, 2014) and $\mathbf{w_f}$ is the FADN farm weighting factor.

The variables to be estimated at farm level are $\mathbf{q^q}$, $\mathbf{q^w}$, $\mathbf{p^q}$, $\mathbf{p^w}$, $\mathbf{c_w}$ and $\mathbf{c_q}$, whereas the variables P^W and P^Q are estimated at MS level. Equation (13) ensures that the sum of farm-specific sugar in-quota and out-of-quota (converted to sugar beet by the factor S_{MS}) is equal to observed farm sugar beet production. Equation (14) is used to balance observed sugar beet revenue between the estimated and reported values in FADN. Equation (15) restricts the weighted sum of quotas over all farms at MS level to less than the reported in-quota MS sugar production. Equation (16) sets the farm-specific prices equal to the MS average price adjusted by a farm-specific correction term for both in-quota and out-of-quota sugar beet. In addition, the out-of-quota price cannot be higher than the in-quota price. Equation (17) constrains the in-quota sugar beet price to be higher than the minimum price set in the EU regulation (i.e. EUR 26.29/tonne) ([25]). Equation (18) ensures that there is no underdelivery of quota if there is out-of-quota production and that the underdelivery of quota is lower than the farm sugar quota.

Note that sugar beet prices received by farms and farm production decisions might be affected by other sugar sector-related factors such as the price of sugar substitutes (e.g. isoglucose), the downstream supply chain (bioethanol, sugar processing) and sugar trade policies (e.g. tariff-rate quotas (TRQs)) (Burrell et al., 2014). The IFM-CAP model does not include policies and sectors beyond the farm level (e.g. TRQs, isoglucose, bioethanol) and thus these factors are not accounted for when estimating the base year quota. However, they may be captured indirectly through the price wedge they may cause between the in-quota and the out-of-quota sugar beet.

([25]) This constraint has not been imposed in the final model estimation, as the goodness of fit of the model comparing the reported and the estimated FADN quota is lower than when the restriction is not imposed and also when the out-of-quota sugar-beet prices become very low (unrealistic) for some MSs.

Table 4 provides an accuracy test for the HPD estimated results. Using ordinary least squares (OLS) regression, we assess the correlation between the estimated in-quota production and the actual in-quota production, as reported in FADN for MSs for which these data are of reasonable quality (i.e. Belgium-Luxembourg, Germany, Lithuania and Poland). We report the slope and the R^2 coefficient for the estimated linear model.

Table 4. Estimated IFM-CAP in-quota sugar beet production versus FADN reported quota

Member State	Slope	R^2
Poland	0.279	0.296
Germany	0.640	0.761
Belgium-Luxembourg	0.702.	0.974
Lithuania	0.889	0.884

Note: OLS regression results for the linear model where IFM-CAP estimated in-quota production = slope × FADN-reported quota + error.

The R^2 coefficient indicates the goodness-of-fit of the OLS regression. It is is very close to one in Belgium-Luxembourg and Lithuania, indicating that the variance in sugar beet in-quota production is explained largely by the linear regression model. The R^2 coefficient is low in the case of Poland owing to the low correlation between total production and in-quota production ($R^2 = 0.24$, whereas in the case of Germany, Belgium-Luxembourg and Lithuania is 0.80, 0.97 and 0.92, respectively).

6. Modelling livestock activities

6.1. Definition of livestock activities and outputs

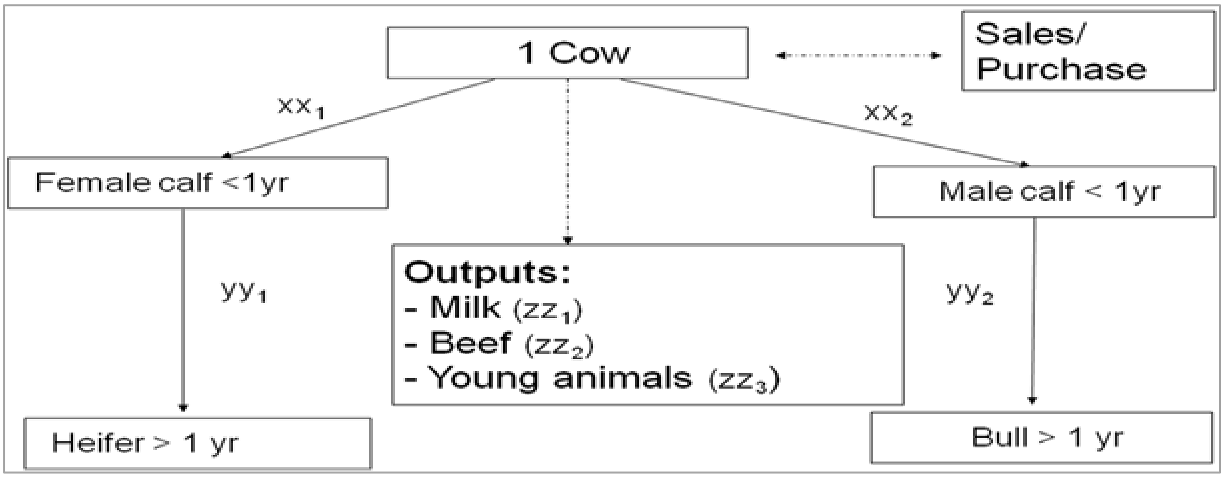
Four categories of livestock activities are modelled in IFM-CAP, i.e. cattle (dairy and beef), pigs, small ruminants (sheep and goats) and other animals. For certain categories (e.g. cattle and small ruminants) two different systems can be considered: rearing and fattening systems. The core element of a rearing system is an adult animal (i.e. productive animal) and a proportion of young animals. That is, all animal categories of the same 'family' are regrouped together under one animal component, assuming a fixed herd composition. The proportions of young animals were derived from the herd composition data, as defined in FADN ([26]). For example, in the case of dairying activity, one dairy component may comprise one dairy cow plus proportions of calves, heifers and bulls. That is, a typical dairy activity may consist of 1 cow, 0.28 heifers, 0.34 calves and 0.02 bulls (Figure 3). The source of each animal category can be either reared on the farm or purchased at the market. At the same time, farm-reared animals can be sold.

This modelling approach to livestock rearing systems implies that the number of adult animals (e.g. cows) is determined endogenously by the model. However, for each animal category (e.g. cattle) and on each farm, the proportion of young animal activities (e.g. calves, heifers) per adult animal is assumed to be constant. That is, the number of young animal activities changes in the same proportion as the change in the

([26]) On some farms they are equivalent to replacement rate.

number of adult animals. The advantage of this approach is that we do not run the risk that scenario simulations lead to unrealistic results (e.g. a large number of adult animals without any young animals or vice versa). The disadvantage is that the model responses in terms of the number of young animals fully depend on the adjustments to the adult animals (and vice versa) ([27]).

Figure 3 summarises the dynamic nature of the herd cycle in a static framework according to the modelling approach used.



Notes: xx_1, xx_2, yy_1 and yy_2 indicate proportions of young animals; zz_1,zz_2,zz_3 indicate output coefficients.

Figure 3. Structure of dairy cow activity

Beef activities are modelled in a similar way. Different methods of representing beef production are possible and are defined by differences in the composition of the animal categories. For example, this may include a suckler system comprising a cow and its offspring, and a fattening system, which merely fattens purchased young animals up to the point of sale.

According to this modelling approach, activity levels of livestock activities by animal category for rearing systems can be computed for the base year as follows:

$$\mathbf{x_{f,i}} = \mathbf{share_{f,i}} * (\mathbf{x_{f,"dcow"}} + \mathbf{x_{f,"scow"}}) \quad (19)$$

$$\mathbf{x_{f,"dcow"}} = \mathbf{x^0_{f,"dcow"}} + \mathbf{t_{f,"dcow}} \quad (20)$$

$$\mathbf{x_{f,"scow"}} = \mathbf{x^0_{f,"scow"}} + \mathbf{t_{f,"scow}} \quad (21)$$

For fattening systems, the following equation is used to compute activity levels:

([27]) Currently we are exploring other modelling options for livestock. For example, one alternative option could be to endogenise the share of each animal category by proposing alternative shares with different input–output coefficients in the simulation phase (i.e. allowing the choice of different technologies). Another option is to use an input–output approach based on individual animal activity (i.e. no direct link between adult and young animal categories) and calibrated with a quadratic behavioural function on each animal activity such as for crops. However, the disadvantage of this approach is that the model simulated effects for the livestock sector will depend mainly on the prices of animals (sales and purchases) which may not reflect the livestock management system applied in reality by farms.

$$\mathbf{x_{f,i}} = \mathbf{x^0_{f,i}} + \mathbf{t_{f,i}} \quad (22)$$

where **f** indexes farm, **x** is the vector of non-negative activity level (i.e. animal number) for each of ***n*** animal activities, $\mathbf{x^0}$ is the vector of farm-reared activity level for each of ***n*** animal activities, **share** is the vector of young animal proportions derived from FADN and **t** is the (n × 1) vector of sales/purchase of animals. Indexes **dcow** and **scow** indicate dairy cows and suckler cows, respectively.

Small ruminant activities (sheep and goat) for meat and milk production are modelled in a manner similar to dairy and beef activities. FADN data are used to identify the predominant livestock activities across the regions of the EU and to derive related animal proportions, production levels and replacement rates.

Table 5 describes the set of livestock activities included in IFM-CAP and the rules used for extracting their numbers (i.e. activity level) by animal category from FADN (Table D) for the base year period.

Table 5. Extraction rules for herd sizes for livestock activities from Table D in FADN

Production activity	IFM-CAP acronym	FADN Table	Extraction rule
Cattle	**ACAT**		
Dairy cows	DCOW	D	30AV
Heifers breeding	HEIR	D	28AV + MIN(26AV,28AV)
Raising male calves	CAMR	D	MAX(0,(24AV-28AV))
Raising female calves	CAFR	D	MIN(28AV,24AV)
Other cows	SCOW	D	32AV
Heifers fattening	HEIF	D	29AV + MAX (0,26AV-28AV)
Male adult cattle	BULF	D	25AV + 27AV
Fattening male calves	CAMF	D	0.5*23AV
Fattening female calves	CAFF	D	0.5*23AV
Pigs	**APIG**		
Pig fattening	PIGF	D	45AV + 46AV
Pig breeding	SOWS	D	44AV
Goats and sheep	**ASAG**		
Milk ewes and goats	SHGM	D	38AV + 40AV
Sheep and goat fattening	SHGF	D	39AV + 41AV
Other animals	**AOAN**		
Laying hens	HENS	D	48AV/1 000
Poultry fattening	POUF	D	(47AV + 49AV)/1 000
Other animals	OANI	D	50AV

Source: Authors' compilation based on the FADNTOOL project.

Table 6 shows the rules used to derive the proportions of young animals (e.g. calves, heifers, bulls) associated with each rearing animal component. These proportions are used for modelling herd demography for livestock rearing systems.

Table 6. Definition of herd demography coefficients for raising systems

Production activity	IFM-CAP acronym	Dimension	FADN Table	Extraction rule
Dairy cows	DCOW	Share	D	30AV/(30AV + 32AV)
Suckler cows	SCOW	Share	D	32AV/(30AV + 32AV)
Raising male calves	CAMR	Share	D	Max(0, (24AV-28AV))/(30AV + 32AV)
Raising female calves	CAFR	Share	D	MIN(28AV,24AV)/(30AV + 32AV)
Heifers raising	HEIR	Share	D	28AV + MIN(26AV,28AV)/(30AV + 32AV)
Goats	GOAT	Share	D	(38AV + 39AV)/(38AV + 39AV + 40AV + 41AV)
Sheep	SHEEP	Share	D	(40AV + 41AV)/(38AV + 39AV + 40AV + 41AV)

The set of livestock outputs modelled in IFM-CAP are the following: beef, cow's milk (for feeding and sales), milk from sheep and goats (for feeding and sales), meat from sheep and goats, poultry meat, pork and young animals (male/female calves and piglets). Young animals are produced by rearing processes and are used as inputs in the other animal processes.

Table 7 presents the list of livestock outputs and the rules used to define their coefficients. For some outputs, such as for cow's milk and beef, the coefficients are derived by dividing production by activity levels, and for some other outputs these coefficients are computed using animal numbers such as young animals.

Table 7. Definition of output coefficients for livestock activities

Production activity	IFM-CAP acronym	Dimension	Extraction rule
Female calves produced/dairy cow	DCOW	YCAF	0.5*N24SN*(DCOW /(DCOW + SCOW))/DCOW
Male calves produced/dairy cow	DCOW	YCAM	0.5*N24SN*(DCOW /(DCOW + SCOW))/DCOW
Female calves produced/suckler cow	SCOW	YCAF	0.5*N24SN*(SCOW /(DCOW + SCOW))/SCOW
Male calves produced/suckler cow	SCOW	YCAM	0.5*N24SN*(SCOW /(DCOW + SCOW))/SCOW
Piglets produced/sow	SOWS	YPIG	(D43AV/D44AV)
Beef produced/dairy cow	DCOW	BEEF	(N30SN/D30AV)*CW
Beef produced/suckler cow	SCOW	BEEF	(N32SN/D32AV)*CW
Beef produced/bull	BULF	BEEF	(N25SN + N27SN)/(D25AV + D27AV)*CW
Beef produced/heifer fattening	HEIF	BEEF	((N29SN/ D29AV) + MAX(0,N26SN – N28SN)/MAX(0,D26AV – D28AV)*CW
Beef produced/calf fattening	CAMF/CAFF	BEEF	0.5*(N23SN)/(D23AV)*CW
Milk for sale produced/dairy cow	DCOW	COMI	(K162QQ)/(D30AV)
Milk for feeding produced/dairy cow	DCOW	COMF	(K162QQ/ D30AV)*MC
Milk for feeding produced/suckler cow	SCOW	COMF	(K162QQ)/(D32AV)*MC*5
Pork produced/sow	SOWS	PORK	(44SN/D44AV)*CW
Pork produced/pig fattening	PIGF	PORK	(N45SN + N46SN)/(D45AV + D46AV)*CW
Meat produced/sheep and goat for milk production	SHGM	SGMT	(N38SN + N40SN)/(D38AV + D40AV)*CW
Meat produced/sheep and goat for fattening	SHGF	SGMT	(N39SN + N41SN)/(D39AV + D41AV)*CW
Milk for sale produced/sheep and goat for milk production	SHGM	SGMI	(K164QQ + K165QQ)/(D164AV + D165AV)
Milk for feeding produced/sheep and goat	SHGM	SGMF	(K164QQ + K165QQ)/(D164AV + D165AV)*MC
Poultry meat produced/poultry fattening	POUF	POUM	(N47SN + N49SN)/(D47AV + D49AV)*CW

Notes: CW: carcass weight at MS level derived from Eurostat; MC: proportion of COMF/COMI and SGMF/SGMI at NUTS 2 level from CAPRI; FADN reports the value of milk suckled by calves (however, it is given in terms of value and therefore a price should be assumed). We have preferred at this stage to use the proportion of COMF/COMI derived from CAPRI.

6.2. Feed availability and feed requirements

Most of the applied mathematical programming models in the literature represent the interaction between crop and animal activities through feed supply and demand balances. The feed balances guarantee that animal-specific nutrient demands (requirements) are met from farm-grown or purchased feed (e.g. forage, grains, concentrates). The balancing between feed supply (availability) and demand (requirements) is done through nutrient values. The physical quantities of feed and the animals' feed requirements are expressed in nutrient values such as energy, dry matter, protein, fibre and lysine. The feed demand depends on the feed requirement per animal and the number of animals; the feed supply depends on the nutrient content of each feed component and its available (farm-grown and/or purchased) quantity (e.g. Alford et al., 2004; Arata et al., 2013; Britz and Witzke, 2012; Crosson et al., 2006; De Cara and Jayet, 2000; De Cara et al., 2005; Heckelei et al., 2012).

In keeping with the literature, we have developed a specific module within IFM-CAP for endogenously matching feed availability and feed requirements on each farm with livestock. The structure of this feed module is depicted in Figure 4. It consists of two main components: feed availability and feed requirements. Feed availability represents the supply of different types of feed such as grass, fodder, cereals and concentrates. The list of individual feed products considered in IFM-CAP and their corresponding feed category is shown in Table 8. Feed requirements depend on livestock type and are determined, among others things, by animal productivity (e.g. weight, milk production), duration of the animal activity and farm herd size.

Feed availability and feed requirements are, then, converted into nutrient values and balanced by animal category at farm level. Table 9 lists the set of nutrients considered in IFM-CAP. Feed availability has to meet the protein (CRPR) and energy (ENNE) needs of each animal category (i.e. supply equals demand for CRPR and ENNE). In addition, for certain animal categories, additional minimum and/or maximum intake constraints are introduced. Maximum intake constraints concern dry matter (DRMX) and fibre (FIDI, FICO, FICT, FISM, FISF, FILG), while the minimum constraints are set for dry matter (DRMN) and lysine (LISI).

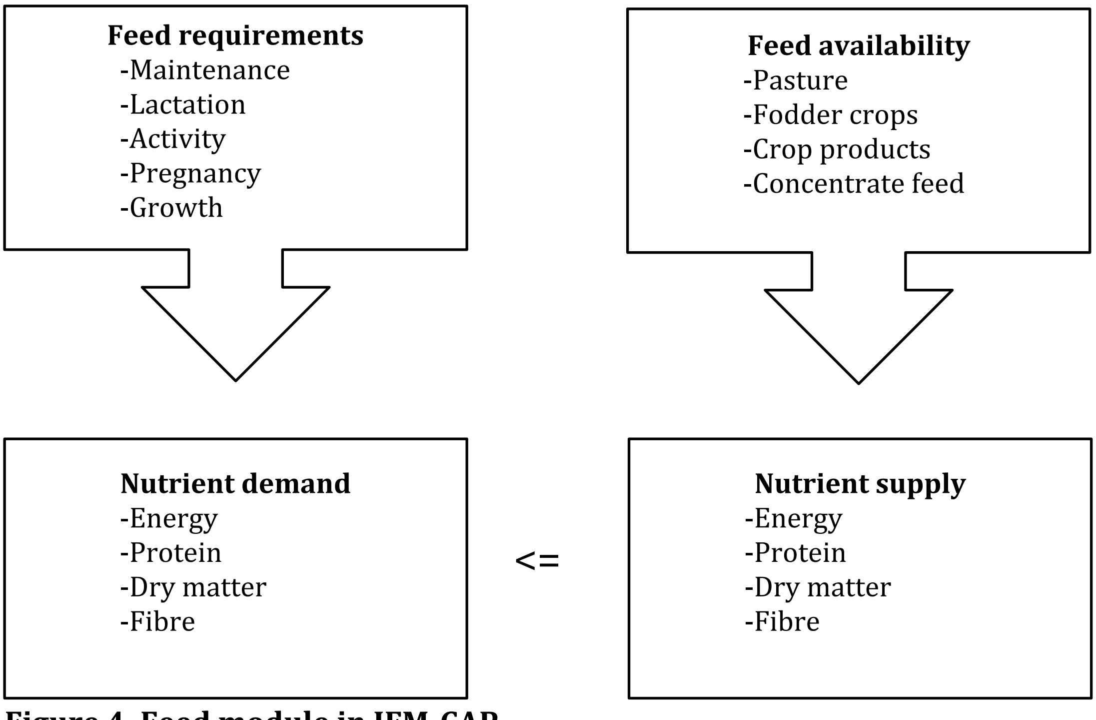


Figure 4. Feed module in IFM-CAP

Moreover, minimum and maximum thresholds of feed groups (e.g. cereals, fodder) in animal diets expressed in dry matter are defined for each animal category. These thresholds are reported in Table A 10 in Annex A. The thresholds ensure that the allocation of feed does not result in over- or underuse of certain feed groups.

Table 8. List of feed products in IFM-CAP

Feed (IFM-CAP acronym)	Aggregated feed grouping (IFM-CAP acronym)	Name	Feed category			
			Fodder crops	Concentrate feed	On-farm produced feed	Purchased feed
SOYC	FPRO	Soya cake		×		×
RAPC	FPRO	Olive cake		×		×
SUNC	FPRO	Sunflower cake		×		×
FRMI	FMIL	Fresh milk products		×		×
SMIP	FMIL	Skimmed milk powder		×		×
WMIO	FMIL	Whole milk powder		×		×
WHEP	FMIL	Whey powder		×		×
CASE	FMIL	Casein		×		×
RAPO	FPRO	Rapeseed oil		×		×
SOYO	FPRO	Soya oil		×		×
SUNO	FPRO	Sunflower oil		×		×
SUGA	FOTH	Sugar		×		×
DDGS	FPRO	Distillers dried grains with solubles		×		×
COMF	FCOM	Milk for feeding			×	×
STRA	FSTR	Straw	×		×	×
ROOF	FROO	Fodder root crops	×		×	×
OFAR	FOFA	Fodder other on arable land	×		×	×
MAIF	FMAI	Fodder maize	×		×	×
GRAS	FGRA	Pasture	×		×	×
POTA	FOTH	Potato			×	
SUNF	FOTH	Sunflower			×	×
SOYA	FOTH	Soya			×	×
RAPE	FOTH	Rapeseed			×	×
SWHE	FCER	Soft wheat			×	×
DWHE	FCER	Durum wheat			×	
RYEM	FCER	Rye and meslin			×	×
BARL	FCER	Barley			×	×
OATS	FCER	Oats			×	×
MAIZ	FCER	Grain maize			×	×
RICE	FCER	Rice			×	
OCER	FCER	Other cereals			×	

FPRO: Feed rich protein; FMIL: Feed from milk products; FOTH: Feed other; FCOM: Milk for feeding; FSTR: Straw; FROO: Fodder root crops; FOFA: Fodder other on arable land; FMAI: Fodder maize; FGRA: Grass; FCER: Feed cereals.

FADN data does not contain all the information needed to parameterise the feed module in IFM-CAP. FADN contains farm aggregated economic data on feed availability and costs. However, disaggregated feed data by activity (e.g. feed use by animal category), prices and yields of certain feeding stuffs, the nutrient content of feed and animal requirements are not available in FADN. In order to fill this gap, we supplement FADN data with external sources such as other official statistical sources (e.g. Eurostat, FSS), the scientific literature or other models (e.g. CAPRI). The external sources utilised in the current version of the model are documented below. The disadvantage of using external data is that they may be inconsistent with FADN data and may provide unreliable information, in particular when MS or regional data are used at farm level. To reduce this problem we employ the HPD approach to estimating farm-level data in which external data are used only as input information in the estimation approach. The estimation approach combines these different data sources by taking into consideration minimisation of feed costs, balancing between feed requirements and availability and data constraints to ensure that activity feed costs add up as closely as possible to the aggregated cost values reported in FADN (see section 4.2).

Feed availability is represented by the physical quantity of feed and its nutrient content and costs (prices). Farms can use feed from their own production or feed that is purchased on the market. The on-farm production of feed during the base year is reported as a monetary value in FADN. We have divided this monetary value by its respective price (described in section 3.3) to obtain the quantity (in tonnes) of feed ([28]). For straw production, we assumed a yield equivalent to 0.78 tonnes per tonne of grain (SWHE, DWHE, RYEM, BARL and OATS). The data on production and on-farm use of fodder crops (OFAR, GRAS, ROOF and MAIF) is not well reported in FADN. We have used Eurostat fodder crop yields (see Table A 11) and fodder crop area from FADN to calculate fodder crop production.

Feed prices are derived from FADN, except for fodder and concentrates, which come from CAPRI.

Table 9. List of nutrients in IFM-CAP

Nutrient acronym	Description (unit)
ENNE	Net energy (MJ/kg)
ENMR	Metabolisable energy ruminants (MJ/kg)
ENMC	Metabolisable energy chicken (MJ/kg)
ENMH	Metabolisable energy horses (MJ/kg)
ENMP	Metabolisable energy pigs (MJ/kg)
DRMN	Minimum dry matter (kg/kg)
DRMX	Maximum dry matter (kg/kg)
CRPR	Crude protein (kg/kg)
LISI	Lysine (kg/kg)
FIDI	Fibre (kg/100 kg)
FICO	Fibre dairy cows (Fill unit system)
FICT	Fibre cattle (Fill unit system)
FISM	Fibre sheep and goat milk (Fill unit system)
FISF	Fibre sheep and goat fattening (Fill unit system)
FILG	Fibre long

For the *nutrient content of feed* we rely exclusively on external sources, as this type of data is not available in FADN. In the literature, nutrient values (e.g. regional averages) are most often taken from technical books and/or are based on expert knowledge. For example, Arata et al. (2013) in their FADN-based farm model for Emilia-Romagna (Italy) collect nutrient content data from regional rule books and from personal communications from a local animal nutritionist. Similarly, De Cara et al. (2005) and De Cara and Jayet (2000) extract nutrient data from the literature (i.e. Jarrige, 1988, 1989), as well as using expert knowledge for their FADN-based representative EU farm model. The CAPRI model relies on nutrient contents from INRA (the French National Institute for Agricultural Research) and the SPEL/EU-Base Model (Wolf, 1995). In the current version of the IFM-CAP model, we use the nutrient content of feed from CAPRI.

([28]) Note that FADN reports for crop activities the total production value and the value of production used on farm. The total production value was used to derive crop prices, as described in section 3.3. These derived prices are used in the feed module to calculate the proportion of feed used on farm by dividing the value of production used on farm by its price.

The *feed requirements* are critical for an accurate representation of crop–animal interactions. It describes how much nutrients (energy, crude protein, fibre, dry matter) each animal activity requires for its main biological functions. The full set of underlying data needed to calculate feed requirements (nutrients and physical quantities) is not available in FADN. To overcome this lack of data, we use the so-called requirement functions combined with FADN and external data, as is usually done in the literature (e.g. Arata et al., 2013; De Cara and Jayet, 2000; De Cara et al., 2005). More precisely, we use the requirement functions implemented in CAPRI (Britz and Witzke, 2012; IPCC, 2006; Nasuelli et al., 1997) in order to calculate an approximate value for animal requirements. These values are then used as prior information to estimate the final nutrient requirements by animal category, which guarantees that feed availability is equal to feed requirement at farm level in both physical and nutrient terms (see section 7.2).

A detailed calculation of prior information for requirement functions is provided in Annex B. They are determined by predefined coefficients and animal productivity parameters. The predefined coefficients are extracted from CAPRI (Britz and Witzke, 2012; IPCC, 2006; Nasuelli et al., 1997). The main productivity parameters that determine the nutrient requirements include: live weight of animal, rearing period, milk and/or meat production, daily animal growth rate, finishing and start weight of animal, and carcass proportion. They are either obtained from FADN or their values are assumed to be as in CAPRI. For example, live animal weight for dairy cows is assumed to be 600 kg (as in CAPRI), whereas the live weight of fattening cattle is calculated based on meat production, daily weight increase and start weight. Meat production is calculated based on FADN data (animals sold at farm level for each animal category) and Eurostat data (carcass weight at MS level for each animal category), as described in Table 7, whereas daily weight increase, start weight and carcass proportion are extracted from CAPRI.

7. Model calibration

The aim of the calibration process is to ensure that the observed (crop and animal) activity levels, as well as the 'observed' ([29])feed quantities allocated to livestock activities during the base year period, are exactly reproduced by the optimal solution in the programming model.

7.1. Activity levels

Over the last decade, several PMP approaches have been developed to derive the parameters of the behavioural functions (**d** and **Q**) and to accurately calibrate

([29]) Because there is no information available on the observed allocated feed quantities on each farm, we first apply a HPD approach to estimate feed quantities by livestock that covers the animals' requirements (in physical units and nutrient values) with the minimum feed costs (see section 6.2) and then we use these estimated feed quantities as the observed ones to calibrate the model at this point.

programming models [30]. However, as the number of observations is usually not enough to allow for the traditional econometric estimation ('an ill-posed' problem), most of the proposed approaches go without any type of estimation by setting all off-diagonal elements of **Q** to zero and calculating the remaining parameters using ad hoc assumptions. In order to reduce the arbitrary parameter specifications and estimate more reliable behavioural functions covering all the parameters, the more recent applied programming models have either (i) used exogenous information on supply elasticities (Britz and Witzke, 2012; Mérel and Bucaram, 2010) or/and on shadow prices of resources (Henry de Frahan et al., 2007), or (ii) estimated programming model parameters in an econometric sense using either cross-sectional data (Arfini et al., 2008; Buysse et al., 2007a; Heckelei and Britz, 2000; Heckelei and Wolff, 2003) or time series data (Jansson and Heckelei, 2011).

In this analysis, we use both multiple observations (cross-sectional data) and prior information on supply elasticities ($\overline{\boldsymbol{\varepsilon}}$) and on dual values of constraints ($\overline{\boldsymbol{\rho}}$) to calibrate the model. Supply elasticities are taken from available econometric studies at the NUTS 2 level (Jansson and Heckelei 2011). Prior information on dual values of resources is derived from FADN.

We calibrate the model for the base year 2007–2009. Thus, the calibration problem in this case consists of selecting the set of parameters ($\mathbf{d}, \mathbf{Q}, \boldsymbol{\rho}$) so that the optimisation model, (1) and (2), replicates exactly the observed farm production structure ($\mathbf{x}^0$) in the base year and reproduces, as closely as possible, the given farm shadow values ($\overline{\boldsymbol{\rho}}$) and the aggregated supply responses at the NUTS 2 level ($\overline{\boldsymbol{\varepsilon}}$).

To perform the estimation we derive the first-order conditions (FOCs) of the optimisation model, (1) and (2), which is assumed to approximate farmer behaviour (Heckelei, 2002), and then we apply the HPD method to estimate the unknown parameters ($\mathbf{d}, \mathbf{Q}, \boldsymbol{\rho}$).

The use of the HPD approach for parameter estimation is carried out under the following assumptions:

- The HPD model minimises, in each NUTS 2 region, the weighted sum of normalised squared deviations of estimated regional own-price (diagonal) supply elasticities and of farm dual values of constraints from the prior subject to a set of data consistency (FOC) constraints. The normalised squared deviations of farm dual values are weighted with the proportion of the farm in the NUTS 2 region to obtain a weighted average normalised squared deviation at the NUTS 2 level. The normalised squared deviations of regional supply elasticities are normalised and weighted with the proportion of observed activity level in total regional land to allow activities with a high proportion of the area to dominate.
- Prior information on dual values of land (arable and grassland) are set to land rental prices, those of sugar beet quota restriction are set to the gross margin differential between sugar beet and the next best alternative crop, and those of set-aside obligations are set to arable land rental prices (i.e. knowing that the only constraints in the base year for crops are land, sugar beet quota and

[30] For a review of PMP models, see Heckelei and Britz (2005), Heckelei et al. (2012)), Henry de Frahan et al. (2007), Mérel and Bucaram (2010) and Paris (2010).

obligatory set-aside). Large standard deviations for prior information are used to allow the data to dominate.

- The calibration to the exogenous supply elasticities is performed in a non-myopic way, i.e. we take into account the effects of changing dual values on the simulation response (Heckelei, 2002; Mérel and Bucaram, 2010).
- The estimation procedure is applied only to arable crops, keeping livestock and permanent grassland fixed during this step. Moreover, to simplify the already complex estimation problem, the inequality on set-aside and quota restrictions is replaced with equality (i.e. both restrictions are assumed to be binding).
- The estimated B matrix related to the Q matrix (see further) is common across farms belonging to the same region and the same farm type (grouped based on production specialisation). However, the Q matrix is crop and farm specific owing to the farm-specific scaling factors, as suggested in Heckelei and Britz (2000), i.e. we exploit information contained in the cross-sectional sample to specify (farm-specific) quadratic activity functions with cross-effects for crop activities.
- B matrix estimation relies only on observed activities on each farm, meaning that the well-known self-selection problem is not explicitly handled in this estimation. To cope with this problem, we adopted the following ad hoc modelling decisions in the simulation phase: in each NUTS 2 region, the gross margin of the non-observed activities is equal to the farm-type average gross margin, the activity's quadratic function parameter is equal to the activity's average quadratic function parameter within the farm type, and the linear term's quadratic function is derived from the difference between the gross margin and the dual values of constraints.
- The exchange of production factors and production rights between farms is not allowed (i.e. there are no land or quota markets).

The general formulation of the corresponding HPD problem is now straightforward ([31]):

$$\mathbf{Min}\left[\boldsymbol{\psi}_{\mathbf{f}}'\frac{(\boldsymbol{\rho}_{\mathbf{f}}-\bar{\boldsymbol{\rho}}_{\mathbf{r}})^2}{(\boldsymbol{\sigma}_{\mathbf{r}}^{\boldsymbol{\rho}})^2}+\hat{\mathbf{x}}_{\mathbf{r}}'\frac{(\boldsymbol{\varepsilon}_{\mathbf{r}}-\bar{\boldsymbol{\varepsilon}}_{\mathbf{r}})^2}{(\boldsymbol{\sigma}_{\mathbf{r}}^{\boldsymbol{\varepsilon}})^2}\right] \tag{23}$$

$$\mathbf{y'}_{\mathbf{f}}\,\mathbf{p}_{\mathbf{f}}+\mathbf{s}_{\mathbf{f}}-\mathbf{C}_{\mathbf{f}}-\mathbf{d}_{\mathbf{f}}-\mathbf{Q}_{\mathbf{f}}\mathbf{x}_{\mathbf{f}}^{\mathbf{0}}-\mathbf{A}_{\mathbf{f}}\boldsymbol{\rho}_{\mathbf{f}}=\mathbf{0} \tag{24}$$

$$\mathbf{b}_{\mathbf{f}}-\mathbf{A}_{\mathbf{f}}\mathrm{x}_{\mathbf{f}}^{\mathbf{0}}=0 \tag{25}$$

$$\boldsymbol{\varepsilon}_{\mathbf{f}}=\left[\mathbf{Q}_{\mathbf{f}}^{-1}-\mathbf{Q}_{\mathbf{f}}^{-1}\mathbf{A}_{\mathbf{f}}(\mathbf{A}_{\mathbf{f}}'\mathbf{Q}_{\mathbf{f}}^{-1}\mathbf{A}_{\mathbf{f}})^{-1}\mathbf{A}_{\mathbf{f}}'\mathbf{Q}_{\mathbf{f}}^{-1}\right]\frac{\mathbf{gm}_{\mathbf{f}}}{\mathbf{x}_{\mathbf{f}}^{\mathbf{0}}} \tag{26}$$

$$\boldsymbol{\varepsilon}_{\mathbf{r}}=\frac{\sum_{\mathbf{f}}\boldsymbol{\varepsilon}_{\mathbf{f}}\mathbf{x}_{\mathbf{f}}^{\mathbf{0}}\mathbf{w}_{\mathbf{f}}}{\sum_{\mathbf{f}}\mathbf{x}_{\mathbf{f}}^{\mathbf{0}}\mathbf{w}_{\mathbf{f}}} \tag{27}$$

([31]) Indices *f* and *r* are introduced here to distinguish between variables defined at farm level and those at regional (NUTS 2) level.

$$\mathbf{Q_f} = \boldsymbol{\delta}_\mathbf{f} \mathbf{B} \boldsymbol{\delta}'_\mathbf{f} \quad (28)$$

$$\mathbf{B} = \mathbf{L'L} \quad (29)$$

where **f** indexes farm, **r** indexes NUTS 2 region, $\boldsymbol{\psi}$ is the (F × 1) vector of farm weight within the NUTS 2 region ($\Psi_f = w_f \Big/ \sum_f w_f$), $\mathbf{w_f}$ is the (F × 1) vector of farm weighting factor, $\mathbf{x^0}$ is the (N × 1) vector of non-negative observed activity level (i.e. hectares) for each of **N** agricultural activities, $\hat{\mathbf{x}}_\mathbf{r}$ is the (N × 1) vector of the *normalised* weight of observed activity level for each activity *i* in the NUTS 2 region ($\hat{x}_{r,i} = N_r x^0_{r,i} \Big/ \sum_{i=1}^{N} x^0_{r,i}$), **p** is the (N × 1) vector of product prices, **y** is the (N × 1) vector of yields, **s** is the (N × 1) vector of production subsidies (coupled and decoupled payments), **C** is the (N × K) matrix of unit input cost for **K** input categories estimated separately using the HPD approach, **d** is the (N × 1) vector of the linear part of the behavioural activity function, **Q** is the (N × N) symmetric, positive (semi-) matrix of the quadratic part of the behavioural activity function, **A** is the (N × M) matrix of coefficients for M resource and policy constraints, **b** is the (M × 1) vector of available resources and upper bounds to the policy constraints, and $\boldsymbol{\rho}$ is the vector of their corresponding shadow prices, $\bar{\boldsymbol{\varepsilon}}$ is the (N × N) matrix of exogenous supply elasticities at NUTS 2 level (Jansson and Heckelei, 2011) and represents the centre of the elasticity prior, $\boldsymbol{\varepsilon}$ is the (N × N) matrix of estimated supply elasticities at farm and NUTS 2 levels, $\boldsymbol{\delta}$ is a scaling factor ($\delta_{f,i} = \sqrt{1 \big/ x^0_{f,i}}$), **B** is a (N × N) parameter matrix related to the **Q** matrix (**B** is common across farms belonging to the same farm type (grouped based on production specialisation)), $\frac{\mathbf{gm}}{\mathbf{x^0}}$ is the gross margin ($\mathbf{gm}$) divided by the observed activity level ($\mathbf{x^0}$).

Prior information on dual values of resources is assumed to be normally distributed with the following means ($\bar{\boldsymbol{\rho}}$) and standard deviations ($\boldsymbol{\sigma}^{\boldsymbol{\rho}}_\mathbf{r}$) calculated at NUTS 2 level using the farm weights. The standard deviation of NUTS 2 elasticities ($\boldsymbol{\sigma}^{\boldsymbol{\varepsilon}}_\mathbf{r}$) is assumed to be 50 % of the mean NUTS 2 elasticities.

The constraints (24) and (25) represent the FOCs of the optimisation model, (1) and (2), with equality constraints (i.e. data consistency constraints). Equations (26) and (27) compute supply elasticities at farm and NUTS 2 levels. Equation (28) calculates the farm-specific Q matrix. Equation (29) is the Cholesky's decomposition, which ensures that the quadratic part of the activities' implicit cost function is a symmetric, positive (semi-) definite matrix.

The estimated parameters (**d, Q,** $\boldsymbol{\rho}$) in equations (24)–(29) guarantee the reproduction of the observed production structure when the model, (1) and (2), is run for the base year ([32]).

([32]) A detailed mathematical description of the calibration module is given in Table A 2.

7.2. Feed module

The feed module aims to balance feed requirements and feed availability at farm level, as described in section 6.2. It describes how many kilograms of certain feed categories (cereals, protein-rich, energy-rich, feed based on dairy products, other feed, etc.) or single feeding stuff (fodder maize, grass, fodder from arable land, straw, milk for feeding) are used per animal activity level (cows, heifers, calves, etc.). It also ensures that the total energy, protein, dry matter and fibre requirements of animals are met by the farm-grown and purchased quantities of feed. The feed requirements can be covered by roughage produced on farm or purchased (hay, straw, silage, etc.) and farm-grown or purchased concentrates.

The modelling of feed allocation to livestock activities is performed in two steps:

Step 1: Assuming that the feed contents are accurately known, the objective is to estimate, for given animal herd sizes and prices, the quantity of feeding stuffs needed to cover the animals' requirements (in physical units and nutrient values) with the minimum feed costs. In addition, it assures the minimum relative squared deviation between estimated animal requirements and prior information and the minimum relative squared deviation between estimated feed produced on farm, purchased feed/sold, other feed uses and feed costs and their respective observed values in FADN data. This is performed with the HPD approach using information on feeding costs and feed produced on farm reported in the FADN database, feed content from CAPRI, feed prices from FADN or CAPRI ([33]), prior information on animal requirements functions reported in Annex B, and a set of constraints for balancing feed requirement and feed availability (energy, crude protein, fibre, dry matter).

The model results provide estimates on nutrient requirements and physical quantity of feed for each feed and each animal activity, as well as the quantities of feed purchased, sold and put to other uses. These feed estimates are used in step 2.

A simplified formulation of the HPD estimation model can be summarised as follows:

$$\mathbf{Min}\left[\frac{(\mathbf{R}_{\mathbf{f},\mathbf{nut}} - \overline{\mathbf{R}}_{\mathbf{r}})^2}{\boldsymbol{\sigma}_{\mathrm{r}}^{\mathrm{R}}} + \frac{(\mathbf{p}_{\mathbf{f}}\mathbf{u}_{\mathbf{f}})^2}{2}\frac{1}{\mathbf{v}_{\mathbf{f}}} + \frac{(\mathbf{u}_{\mathbf{f},\mathbf{own}} - \mathbf{u}^0_{\mathbf{f},\mathbf{own}})^2}{(\mathbf{u}_{\mathbf{f}})^2} + \frac{(\mathbf{t}_{\mathbf{f},\mathbf{sale}} - \mathbf{t}^0_{\mathbf{f},\mathbf{sale}})^2}{(\mathbf{t}_{\mathbf{f}})^2} + \frac{(\mathbf{e}_{\mathbf{f}})^2}{(\mathbf{u}_{\mathbf{f}})^2} + \frac{(\mathbf{dc}^{\mathbf{P}}_{\mathbf{f}})^2}{2} + \frac{(\mathbf{dc}^{\mathbf{T}}_{\mathbf{f}})^2}{2}\right] \tag{30}$$

$$\mathbf{R}_{\mathbf{f},nut}\mathbf{x}^{\mathbf{0}}_{\mathbf{f}} = U_{\mathbf{f}}\, g_{nut} \qquad \text{for nut = energy and protein} \tag{31}$$

$$\mathbf{R}_{\mathbf{f},\mathbf{nut}}\mathbf{x}^{\mathbf{0}}_{\mathbf{f}} \geq \mathbf{U}_{\mathbf{f}}\,\mathbf{g}_{\mathbf{nut}} \qquad \text{for nut = dry matter and fibre} \tag{32}$$

$$\mathbf{dc}^{\mathbf{P}}_{\mathbf{f}} + \mathbf{u}_{\mathbf{f},\mathbf{own}}\mathbf{p}_{\mathbf{f}} = \mathbf{P}^{\mathbf{0}}_{\mathbf{f}} \tag{33}$$

$$\mathbf{dc}^{\mathbf{T}}_{\mathbf{f}} - \mathbf{t}_{\mathbf{f},\mathbf{purc}}\mathbf{p}_{\mathbf{f}} = \mathbf{T}^{\mathbf{0}}_{\mathbf{f}} \tag{34}$$

([33]) CAPRI feed prices are used for fodder crops and concentrated feeds.

$$\mathbf{q_f} = \mathbf{t_f} + \mathbf{u_f} + \mathbf{e_f} \tag{35}$$

$$\mathbf{MinShr_{f,F_n}} \mathbf{R_{f,DRMA}} \mathbf{x_f^0} \leq \mathbf{U_f} \mathbf{F_n} \mathbf{g_{DRMA}} \tag{36}$$

$$\mathbf{MaxShr_{f,F_n}} \mathbf{R_{f,DRMA}} \mathbf{x_f^0} \geq \mathbf{U_f} \mathbf{F_n} \mathbf{g_{DRMA}} \tag{37}$$

$$\mathbf{u_f} = \mathbf{x_f^{0'}} \mathbf{U_f} \tag{38}$$

where **f** indexes farm, **r** indexes NUTS 2 region, superscript **0** indexes for observed value of a given variable, **F** is a set of feed activities ($F \in N$), $\mathbf{x^0}$ is the (N × 1) vector of non-negative observed activity level (i.e. animal number) for each of ***N*** animal activities, $\mathbf{R_{nut}}$ is the (N × N) diagonal matrix of animal nutrient (nut) requirements for **nut** = energy, protein, dry matter and fibre, $\mathbf{R_{DRMA}}$ is the (N × N) diagonal matrix for dry matter requirements, $\mathbf{g_{nut}}$ is the (F × 1) vector of nutrient contents of feed for **nut** = energy, protein, dry matter and fibre, $\mathbf{g_{DRMA}}$ is the (F × 1) vector for dry matter content of feed, **p** is the (F × 1) vector of feed prices, **q** is the (F × 1) vector of produced feed quantities, **t** is the (F × 1) vector of sales/purchases quantities of feed, $\mathbf{t_{purc}}$ includes only negative values (feed purchases) of the vector **t**, $\mathbf{t_{sale}}$ includes only positive values (feed sales) of the vector **t**, **u** is the (F × 1) vector of used quantities for feeding (by feed), **e** is the (F × 1) vector of losses and on-farm non-feed use for seeds, **U** is the (N × F) matrix of quantities used for feeding by animal activity, and $\mathbf{F_n}$ is the (F × F) matrix defining different feed groups ([34]), where $\mathbf{F_1}$, $\mathbf{F_1}$, …, $\mathbf{F_n} \in \mathbf{F}$. $\mathbf{P^0}$ and $\mathbf{T^0}$ represent the total value of observed costs in FADN for farm-grown and purchased feed, respectively, $\mathbf{dc_f^P}$ and $\mathbf{dc_f^T}$ are the error terms of the estimated costs relative to the costs reported in FADN for farm-grown and purchased feed, respectively, **MinShr** and **MaxShr** are the (N × N) diagonal matrixes of minimum and maximum proportions of feed in total feed consumption, respectively, $\mathbf{v_f}$ is the rescaling factor for the feed cost component of the objective function given as the animal production value, $\mathbf{u_{f,own}}$ is the estimated value of feed produced on farm, where $\mathbf{u_{f,own}} = \mathbf{u_f} + \mathbf{t_f}$ if $\mathbf{t_f} < 0$ and $\mathbf{u_{f,own}} = \mathbf{u_f}$ if $\mathbf{t_f} \geq 0$, and $\mathbf{u}^0_{f,own}$ is the observed value of feed produced on farm in FADN. Prior information on animal requirements is assumed to be normally distributed with the following means ($\overline{\mathbf{R}}$) and standards deviations ($\boldsymbol{\sigma}_r^{\mathbf{R}}$) calculated at NUTS 2 level using the farm weighting factor.

The first component of the objective function (30) is linked to the minimisation of normalised squared deviation of estimated animal requirements from the prior, the second one ensures cost minimisation of feed consistent with the IFM-CAP income maximisation function (1) and the next three components of the objective function minimise the relative squared deviation between the estimated farm-grown feed, purchased/sold feed and other uses of feed and their respective observed values in FADN. The final two components minimise the relative squared error of the estimated feed costs from the FADN recorded feed costs. Because all components of the objective

([34]) For example, fodder, concentrates, high protein feed, etc.

function are expressed as deviations except for the cost minimisation element, we scale the latter by the production value of livestock (v_f).

Equations (31) and (32) balance the feed requirement with the feed availability in nutrient values. Equations (33) and (34) constrain the estimated costs of farm-grown and purchased feed to equal their observed values in FADN. Equation (35) ensures that the physical quantity of feed is balanced at the farm level. The minimum share constraint (36) ensures that a given feeding stuff (or group of feed) represents at least a certain amount in total feed consumption (measured in dry matter), whereas the maximum share equation (37) constrains a given feeding stuff (or group of feed) not to exceed a certain limit in the total feed consumption for a given animal activity. These two constraints ensure certain feed management practices and prevent over- or underuse of certain feed. Equation (38) sums the feed use over all animal activities.

During estimation, upper and lower bounds are set for feed requirements at two standard deviations in order to reduce computation time and to avoid unreasonable estimated results. However, these bounds are widened in the event of infeasibilities. The same holds for variables capturing the deviation of the estimated feed costs relative to the FADN feed costs, $d\mathbf{c}_f^{\mathbf{P}}$ and $d\mathbf{c}_f^{\mathbf{T}}$, equations (33) and (34). The bounds for these variables are set to ±25 % of the FADN value to ensure plausible estimates and/or bind estimates to the original data. These bounds are relaxed in the event of infeasibilities implying that, when they occur, we are not able to exactly replicate costs values in FADN.

Table 10 compares the estimated IFM-CAP costs with the actual FADN costs at MS level based on correlation analysis using the OLS regression. We compare the following there categories of costs: costs of purchased feed, costs of purchased fodder, and costs of own feed. We report the slope and the R^2 coefficient for the estimated linear model between the IFM-CAP costs and the FADN costs. A slope value equal to one implies that on average the estimated IFM-CAP costs correspond to the FADN costs across farms in a given MS. A slope value less than one implies that the estimated costs are on average lower than the FADN costs. As the table shows, the estimated costs are on average between 44 % and 100 % of the FADN value. The average correlation across the EU between the estimated and the FADN costs is highest for the cost of purchased fodder (at 98 %) followed by farm-grown feed (93 %) and purchased feed (77 %). As the slope values are less than one for most MSs, we underestimate the FADN costs. The use of external data and regional aggregates for feed requirements and particularly for nutrient feed content, feed prices and fodder yields may lead to differences between the estimated and the observed costs. The nutrient feed content, feed purchase prices and fodder yields probably vary strongly across farms in reality and thus may depart from the regionally aggregated values causing the discrepancy. Furthermore, the imposition of cost minimisation of feed mix may lead to feed cost understatement, given that, in reality, strict cost minimisation may not always hold, particularly in the presence of market imperfections (e.g. transaction costs).

The R^2 coefficient indicates the goodness of fit of the OLS regression. The R^2 coefficient equals one if the fit is perfect, implying that the variance in costs is explained fully by the linear regression model. In other words, if the R^2 coefficient is high, then the estimated IFM-CAP costs are close to the FADN costs for most farms at the rate determined by the slope. In the reverse case, with a low R^2 coefficient, the estimated costs vary considerably from the average explained rate given by the slope. According to results in Table 10, the R^2 coefficient is greater than 85 % for most MSs, implying that the deviation of estimated IFM-CAP costs from the average explained rate is relatively low across farms.

Table 10. Estimated FADN costs versus IFM-CAP costs: OLS regression results by MS

MS	Costs of purchased feed		Costs of purchased fodder		Costs of farm-grown feed	
	Slope	R^2	Slope	R^2	Slope	R^2
Belgium-Lux. (BL)	0.75	0.90	0.93	0.92	0.90	0.88
Denmark (DK)	0.79	0.86	0.99	0.99	0.95	0.98
Germany(DE)	0.86	0.94	0.72	0.74	0.98	1.00
Greece (EL)	0.80	0.85	1.00	1.00	0.94	0.98
Spain (ES)	0.91	0.97	1.00	1.00	0.97	0.99
France (FR)	0.79	0.91	0.98	0.98	0.94	0.96
Ireland (IR)	1.00	1.00	0.99	0.99	0.77	0.93
Italy (IT)	0.88	0.97	1.00	1.00	0.94	0.98
Netherlands (NL)	0.64	0.74	0.99	0.99	0.85	0.80
Austria (AT)	0.58	0.63	0.99	1.00	0.91	0.97
Portugal (PT)	0.90	0.99	1.00	1.00	0.97	0.99
Sweden (SE)	0.96	0.99	1.00	1.00	0.95	0.99
Finland (FI)	0.72	0.82	0.99	1.00	0.92	0.97
United Kingdom (UK)	0.77	0.86	0.97	0.97	0.94	0.98
Cyprus (CY)	0.88	0.98	1.00	1.00	1.00	1.00
Czeck Republic (CZ)	0.78	0.90	0.94	0.99	0.87	0.98
Estonia (EE)	0.84	0.99	0.98	1.00	0.99	1.00
Hungary (HU)	0.81	0.87	1.00	1.00	1.00	1.00
Lithuania (LT)	0.72	1.00	1.00	1.00	1.00	1.00
Latvia (LV)	0.94	1.00	0.98	1.00	0.95	0.99
Malta (MT)	0.82	0.94	1.00	1.00	0.92	0.97
Poland (PL)	0.51	0.64	1.00	1.00	0.94	0.97
Slovenia (SI)	0.81	0.83	0.96	0.98	0.97	0.99
Slovaquia (SK)	0.70	0.94	0.97	0.98	0.83	0.92
Bulgaria (BG)	0.50	0.74	1.03	0.99	0.71	0.94
Romania (RO)_	0.44	0.82	0.98	1.00	0.98	1.00
EU-27	**0.77**	**0.89**	**0.98**	**0.98**	**0.93**	**0.97**

Note: OLS regression results for the linear model where IFM-CAP estimated costs = slope × FADN costs + error.

Step 2: The purpose of the second step is to calibrate the feeding stuffs in IFM-CAP to the estimated ones in step 1, which is assumed to be the observed one because it guarantees the feed balance at farm level and resulting plausible feed costs. Using only feed prices/costs generated from the previous step cannot ensure reproducing the observed feeding stuffs and, thus, calibrating the model to the base year. Calibration can be guaranteed only by including PMP calibration terms for feeding defined by the joint combination of agricultural and livestock activity. This is achieved by following the approach of Helming et al. (2001), which consists of using dual values for the calibration constraint of the PMP first step, as well as exogenous own-price elasticities for deriving the parameters of the quadratic feed cost function according to the following formulas:

$$Q'_{f,i,j} = p_i / \varepsilon_i u^0_{f,i,j} \quad (39)$$

$$d'_{f,i,j} = -(\lambda_{f,i,j} + Q'_{f,i,i,j} \, u^0_{f,i,j} x^0_{f,i}) / x^0_{f,i} \quad (40)$$

where ***i*** and ***j*** indexes crop and animal activities/products (including feeds), **d'** is the linear part of the (implicit) animal feeding cost function, **Q'** is the quadratic part of the (implicit) animal feeding cost function (all off-diagonal elements of **Q'** are set to zero), **p** is the product (including feed) prices, **ε** is own-price feed demand elasticities taken from CAPRI (an elasticity of −10 is used when no elasticity is available), $\mathbf{x^0}$ is the observed animal activity level, $\mathbf{u^0}$ is the quantities used for feeding per animal and year, estimated in the previous step, and **λ** is the dual value of the calibration constraint of the PMP first step (for more detai,l see equation 8 in Table A 1 in Annex A).

8. Evaluation of model behaviour/performance

The model was calibrated for the EU-27. We report the results of three MSs as examples: Belgium-Luxembourg, Ireland and Denmark. The regional supply elasticities estimated by Jansson and Heckelei (2011) are used as prior information in this application. Elasticities of 1 and 0.1 are used for annual crops and permanent crops, respectively, when prior information is unavailable.

Apart from reproducing exactly the observed activity level, the main outcome of this calibration approach is that the estimated own-price elasticities are very close to the prior for all crops and for all three MSs (Table 11). This is, however, not surprising, as one component of the model's objective function is the minimisation of normalised squared deviation between estimated and given elasticities (prior).

To evaluate the performance of the calibrated model, we run some simulation experiments assuming a price increase of 10 % for single products and we calculate the aggregated regional percentage change in production related to the price change. Table 11 compares our simulated elasticities with both the prior elasticities (Jansson and Heckelei, 2011) and the estimated ones for the main crops at MS level.

The results show that the simulated own-price elasticities are in a plausible range and, for most crops, they are very close to the prior. Our elasticities are lower than the prior in around 60 % of the cases and higher or equal in the remaining cases. However, in the majority of cases the difference is very small.

Moreover, for the crops with the greatest proportion of cropped land, such as soft wheat, barley, maize and potatoes, the elasticities are mostly in agreement with the prior. For crops small proportions of cropped land, such as other cereals and oats, the results may be quite different ([35]).

([35]) A comparison between our simulated point elasticities and other studies from the literature will be performed in further steps to re-evaluate the model's behaviour.

Table 11. Comparison between simulated and estimated own-price elasticities and the prior

Crop	Belgium-Luxembourg (BL00) n = 1 417				Denmark (DK00) n = 1 144				Ireland (IR00) n = 982			
	Proportion of land	Prior	Estimated	Simulated	Proportion of land	Prior	Estimated	Simulated	Proportion of land	Prior	Estimated	Simulated
Soft wheat	0.151	0.844	0.844	0.782	0.276	0.860	0.860	0.713	0.0143	2.735	2.735	1.378
Rye and meslin	0.001	1.000	0.992	1.120	0.010	3.950	3.950	3.396		–	–	–
Barley	0.044	2.256	2.256	1.708	0.257	0.757	0.757	0.628	0.0418	1.945	1.945	0.588
Oats	0.004	2.763	2.763	4.376	0.023	2.672	2.672	2.116	0.0032	3.233	3.233	4.707
Maize	0.044	1.252	1.252	1.037	0.001	1.000	1.000	0.898		–	–	–
Other cereals	0.008	1.303	1.303	2.647	0.015	1.498	1.498	1.328	0.0004	7.287	7.287	3.509
Rape	0.010	0.760	0.760	0.917	0.069	1.357	1.357	1.480	0.0009	8.107	8.107	4.097
Sunflower	0.000	1.000	1.000	0.372		–	–	–		–	–	–
Pulses	0.001	1.000	1.000	0.941	0.003	5.781	5.781	4.259	0.0005	4.393	4.393	2.165
Potatoes	0.041	0.589	0.589	0.888	0.020	1.611	1.611	1.875	0.0010	8.485	8.485	9.541
Apples	0.013	0.100	0.087	0.096	0.013	0.100	0.100	0.131	0.0000	0.100	0.100	0.908

n = number of farms.
Source: Model results.

At farm level, the picture is also quite homogeneous among farms. As shown in Figure 5, which reports the distribution of own-price elasticities for wheat and barley in the selected three MSs, in 95 % of cases the simulated farms' elasticities are ranged between 0 and 6 (Figure 5) and in more than 50 % of cases they are less than 0.8. This means that more than two-thirds of the farmers will have a similar response to price changes. The large number of farms with very low elasticities is explained by the fact that, in this experiment, switching is allowed only between observed crops (i.e. in many farms only one arable crop is grown in the base year). Whether or not the farm results are plausible is not straightforward to judge, as, to the best of our knowledge, there are no other studies available in the literature that report farm-level elasticities.

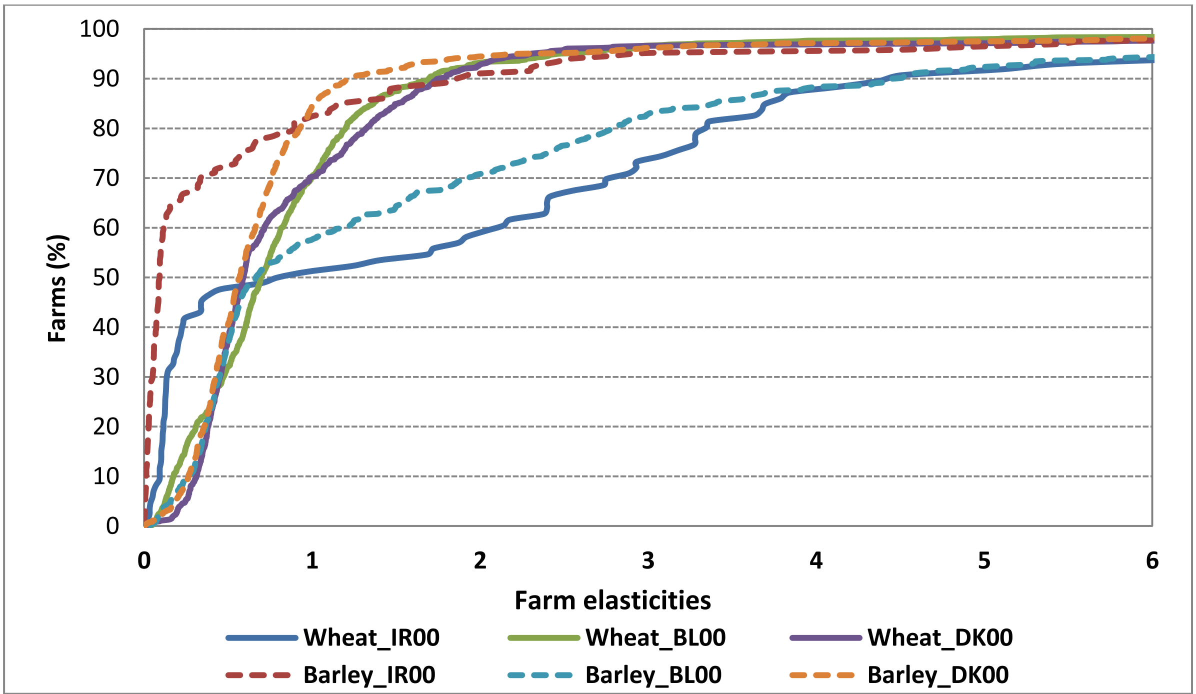


Figure 5. Distribution of simulated farm own-price elasticities for wheat and barley in the selected MSs

9. Graphical user interface for IFM-CAP

IFM-CAP has been linked to a graphical user interface (GUI) to support users to build and prepare the database, run the model and exploit the results. Written in Java, this GUI was targeted at users who would like to apply IFM-CAP without having an in-depth knowledge of the GAMS programming language. It is an update of the CAPRI-GUI developed by the Institute for Food and Resource Economics, University of Bonn (Britz, 2011).

The current GUI version is still at the trial stage and has a limited number of functionalities that are organised into work steps and tasks (see Figures 6 to Figure 11). The left-hand panel allows the selection of the different IFM-CAP work steps and their corresponding tasks. The right-hand side offers controls depending on the properties of the task. Each work step may comprise several tasks, which are shown in the second panel, below the work step panel. The content of the panel may change when the user selects a different work step. Only one work step and one task can be activated at a time. In each task the user can compile (test whether or not the program compiles without errors), start (execute the program) or stop the GAMS program. The user can also load and visualise the results generated from the task.

Three work steps can be performed through the IFM-CAP GUI: Generate base year, Generate baseline, and Run policy scenario.

'Generate base year' work step: This consists of four tasks: data preparation, feed module, input allocation, and base year calibration.

- In the data preparation task (Figure 6), the user can build the database and generate the dataset for the selected countries. By running the GAMS program in this task, all the input data needed by IFM-CAP for the base year (three-year average around 2008) and for the selected countries are generated and stored in gdx files. The user can run the program for a single country, a set of countries or the entire EU-27 countries. This task is controlled by the 'DataPrep.gms' GAMS file.

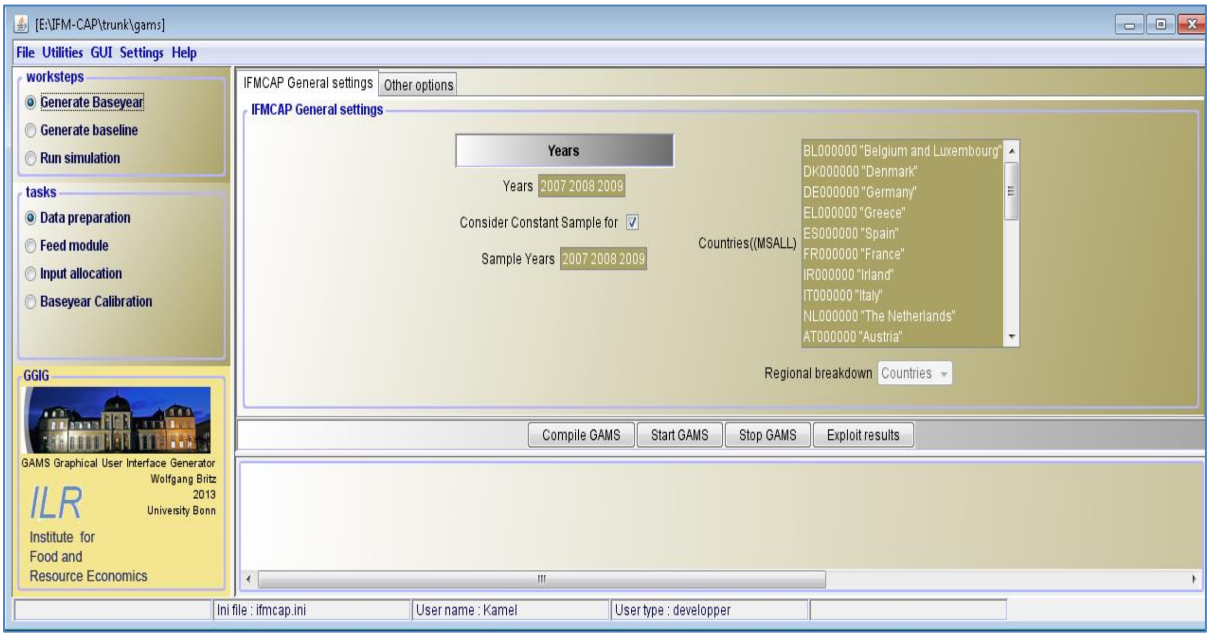


Figure 6. Task panel for running 'Data preparation module' in IFM-CAP GUI

- The feed module panel allows (Figure 7) the estimation of nutrient requirements and physical quantity of feed for each feed and for each animal activity, as well as quantity of purchased, sold and other uses of feed using the HPD approach. By running the program ('feed_module.gms') for the selected countries, the results at the single farm unit are generated and stored in gdx files 'results_feed.gdx'.

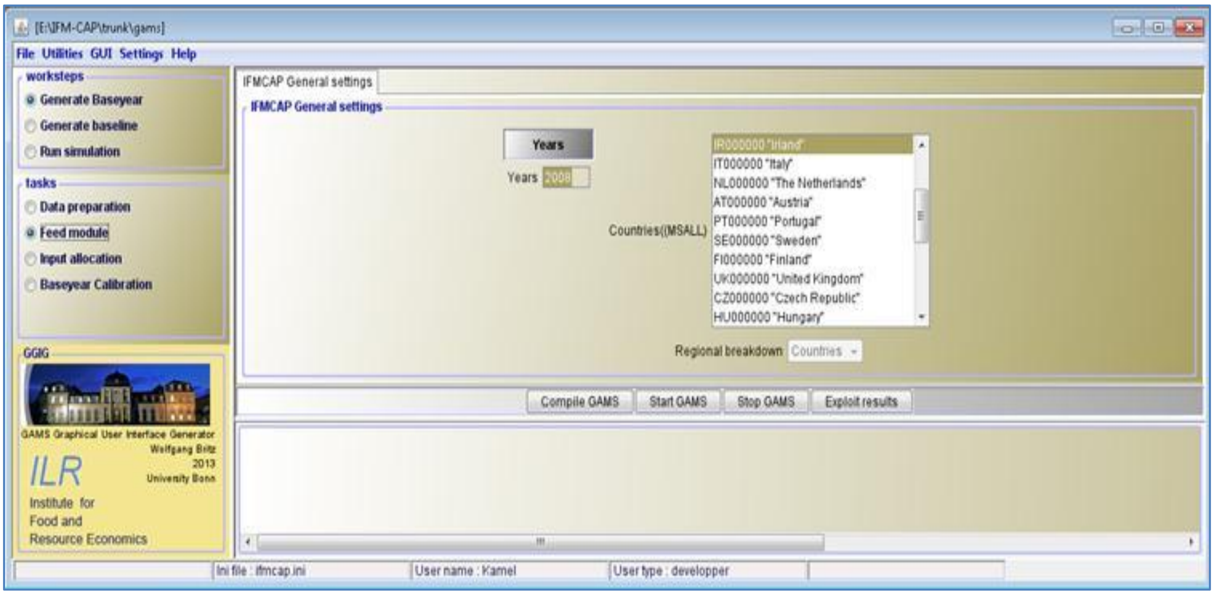


Figure 7. Task panel for running 'Feed module' in IFM-CAP GUI

- The input allocation panel (Figure 8) allows the estimation of unit input costs of agricultural activities using the HPD approach. By running the program for the selected countries, the set of input–output coefficients and the unit input costs by activity, at single farm and at NUTS 2 level, are generated and stored in gdx files. This task is controlled by the so-called 'InputAlloca_HPD_IFM.gms' GAMS file.

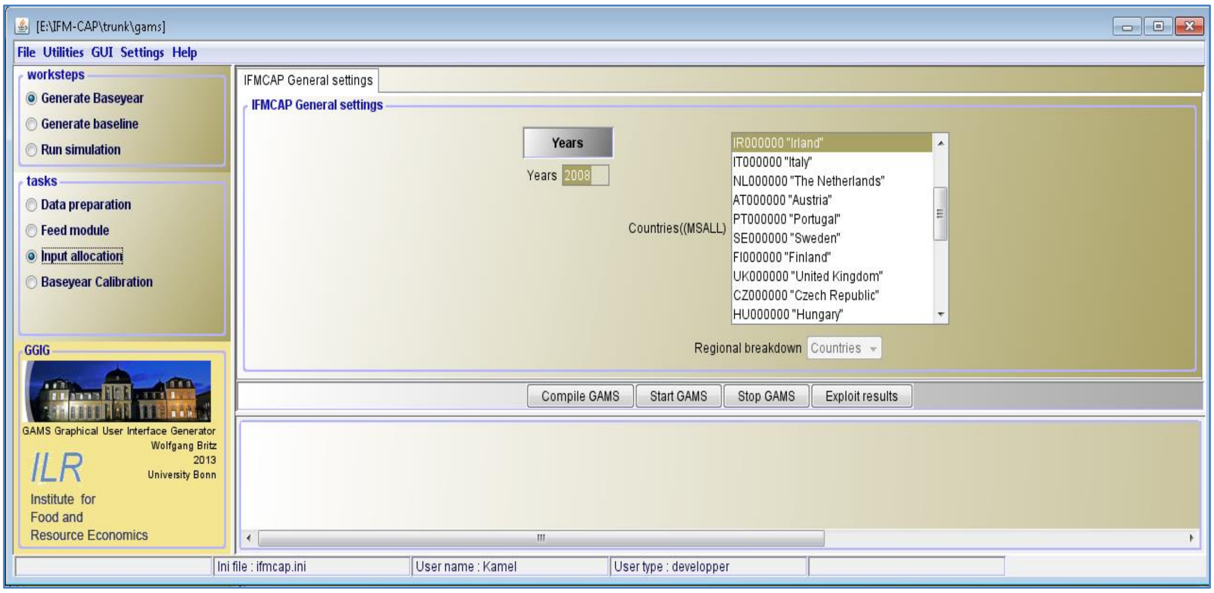


Figure 8. Task panel for running 'Input allocation module' in IFM-CAP GUI

- The base year calibration panel (Figure 9) allows the running of IFM-CAP for the base year period for the selected countries either using data already stored in gdx files or by running the 'data preparation program' explained previously. After running the GAMS program in this task, the user can check model calibration and evaluate model performance by visualising the results, stored as gdx files, accessible from the 'exploit results' button. The 'IFMCAP_baseyear.gms' GAMS file is used for controlling/running this task.

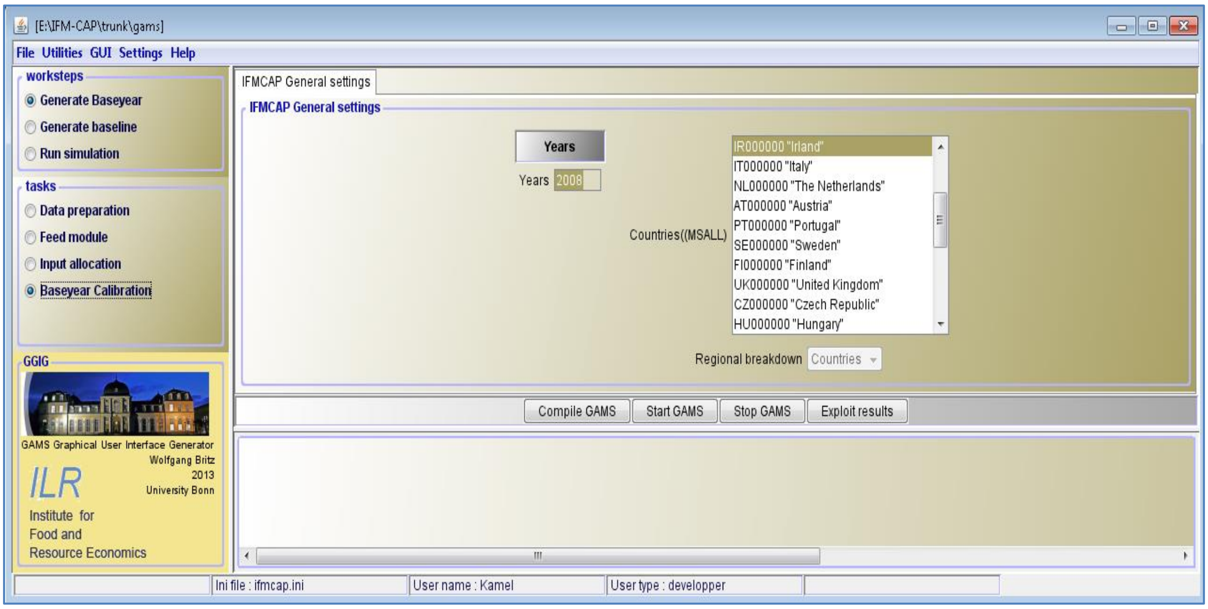


Figure 9. Task panel for running 'Base year calibration module' in IFM-CAP GUI

'Generate baseline' work step: This work step involves two tasks.

- In the 'Generation trend projection' task (Figure 10), the results from the trend projection taken from the CAPRI model are used to generate the IFM-CAP baseline prices and yields. As the CAPRI growth rates of yields and prices are defined at NUTS 2 level, we impose the same growth rate on all farms belonging to the same NUTS 2 region.
- In the 'Run baseline' task (Figure 10), the user runs the IFM-CAP baseline using the base year data (inflating the costs and the PMP terms to the chosen simulation year) and the trend projection on yield and prices generated in the previous task. The generated baseline (i.e. reference run) scenario is used as a reference for comparing simulated policy scenarios.

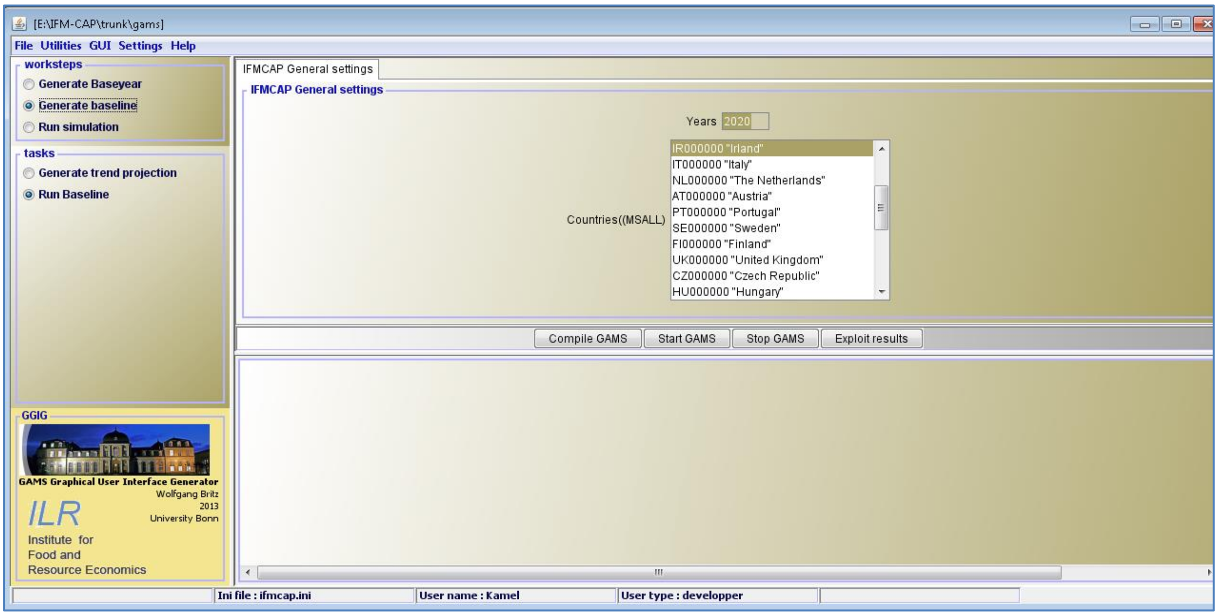


Figure 10: Task panels for running 'Generation trend projection' and for 'Run Baseline' in IFM-CAP GUI

'Run simulation' work step: Two different tasks can be performed under this work step.

- Through the 'Define policy scenario' task (Figure 11), the user may build up a policy scenario that specifies an assessment exercise. A policy scenario is characterised by a name and a short description of the problem that it tries to solve or to study, and it incorporates at least one experiment. Through a single policy scenario, several experiments can be investigated and compared. At this stage only a small number of experiments can be simulated using a predefined (i.e. prebooked) GAMS file that comprises the settings for policy variables for a simulation.
- In the 'Run policy scenario' task (Figure 11), the user runs the policy experiment selected in the previous step.

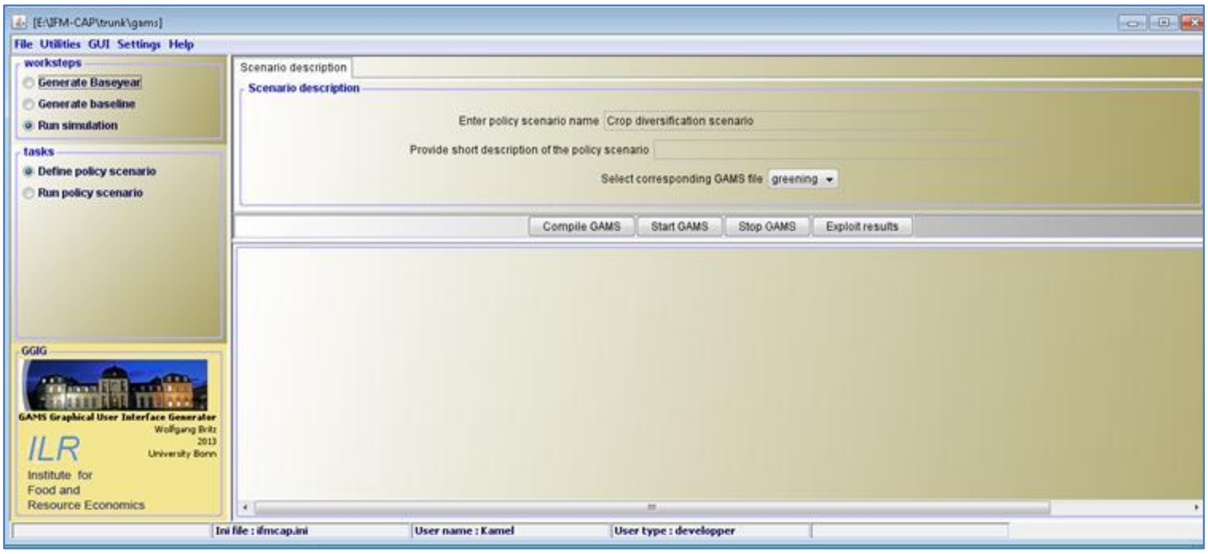


Figure 11. Task panels for 'Define policy scenario' and 'run policy scenario'

A post-modelling routine is under development to facilitate the management and use of model results. Specifically, this routine aims the to do the following:

- report model outputs such as activity levels, production, on-farm use, sales/purchases, sales within quota, etc., both for individual production activities and for single farms;
- report different income and environmental indicators at farm level such as farm income, revenues, variable costs, premiums, PMP terms, etc.;
- calculate activity-specific income indicators (revenues, variable costs, premiums, gross margins and PMP terms per hectare or head) for single farms and any relevant aggregation by farm specialisation, farm size, NUTS 2/NUTS 3/FADN/ regions, sociodemographic characteristics (e.g. age), MSs and EU;
- aggregate model outputs such as activity level, production, revenues, income, etc. at farm-type, NUTS 2 and national levels (and other classifications relevant for the policy maker) using farm weights;
- visualize the results in maps, graphs and interactive charts.

10. Application of IFM-CAP to the crop diversification 'greening' measure

In this chapter we present an application of IFM-CAP to illustrate its capability for assessing policy impacts at farm level. We simulate the potential impacts of the crop diversification measure (one of the so-called CAP greening instruments), as adopted by the 2013 CAP reform. The CAP greening includes three measures that are obligatory for farmers who wish to receive the full direct payment: crop diversification; the maintenance of permanent pasture; and the allocation of land to Ecological Focus Areas (EFAs) (EU, 2013). We focus on crop diversification because it is the most challenging greening measure to model and its implementation and impacts are farm specific.

The greening measures in general and the crop diversification measure in particular target land allocation at farm level with the aim of supporting agricultural practices beneficial to the climate and the environment. The eligibility and uptake of these measures largely depend on farm-specific characteristics (size, cropping pattern, location etc.), posing challenges for policy evaluation and raising the need for new modelling tools. Empirical evidence of the environmental and socioeconomic impacts of the CAP greening measures are very limited, especially at EU level. While a number of studies have opened the debate on the effectiveness of greening measures (Matthews, 2012; Singh et al., 2014; Westhoek et al., 2013), the few available farm-level models contribute only partially to the ongoing debate because they are applied only to selected MSs/regions and/or for specific agricultural sectors. For example, Solazzo et al. (2014) evaluate the effect of greening on Italian farms in the tomato sector. Mahy et al. (2014), Heinrich (2012), Czekaj et al. (2013) and Brown and Jones (2013) provide case studies on the impact of the crop diversification measure for Flanders, Germany, Poland and the United Kingdom, respectively. None of these models allows for a comprehensive EU-wide analysis of CAP greening measures at farm level.

10.1. Baseline

The baseline scenario is interpreted as a projection over time covering the most probable future development in terms of technological, structural and market changes. It represents the reference for the interpretation and analysis of the selected policy scenario. As IFM-CAP is a comparative static supply model that does not take into account the dynamics of market developments and market inter-linkages (price feedbacks), the baseline construction relies on external information. More precisely, we use CAPRI projection ([36]) to construct the IFM-CAP baseline for 2020, taken as the time horizon for running simulations. One important feature of the CAPRI baseline is that it is developed in conjunction with the European Commission (EC) baseline. The EC constructs medium-term projections for the agricultural commodity markets on an annual basis. The projections present a consistent set of market and sectoral income prospects elaborated on the basis of specific policy and macroeconomic assumptions (Himics et al., 2013; Nii-Naate, 2011).

To construct the IFM-CAP baseline, three assumptions are adopted: (i) a continuation of the CAP Health Check up to 2020; (ii) an assumed inflation rate of 1.9 % per year; and (iii) an adjustment of baseline prices and yields using growth rates from the CAPRI baseline. As the CAPRI growth rates of yields and prices are defined at NUTS 2 level, we impose the same growth rates on all farms belonging to the same NUTS 2 region. All the other parameters (e.g. farm resource endowments and farm weighting factors) are assumed to remain unchanged up to 2020.

The generated baseline scenario is used as a reference point for the comparison of the effects of the crop diversification scenario.

10.2. Crop diversification scenario

The 2013 CAP reform introduces explicit measures to remunerate the provision of public goods by farmers, the so-called 'greening payment' (EU, 2013). Under the CAP greening measures, 30 % of direct payments is conditional on complying with three mandatory requirements: (i) crop diversification for arable crops; (ii) maintenance of permanent grassland; and (iii) allocation of 5 % of land to EFAs. In this application we focus only on the crop diversification measure.

The implementation of the scenario in the model closely follows the adopted EU regulations (i.e. EU 2013, 2014). The crop diversification requirement applies only to farms with an arable area greater than 10 hectares. Farms with more than 75 % of their total eligible land covered by grassland and farms with 75 % of their arable area cultivated with forage are not subject to the crop diversification measure ([37]). Furthermore, there are stricter requirements for farms having more than 30 hectares of arable land (group 2) compared with farms with arable land between 10 and 30 hectares (group 1). The latter farms need to have at least two different crops and the

([36]) For more information, refer to Blanco-Fonseca (2010), Britz and Witzke (2012) and Himics et al. (2013) and (2014).

([37]) Organic producers and farmers in the 'small farmers' scheme' are exempted from the greening obligations. Also, MSs can opt to define practices (certification or specific agri-environmental schemes) that yield a level of benefit for the climate and the environment that is equivalent to or higher than the three greening obligations. These exemptions are not implemented in this simulation.

main crop should not exceed 75 % of the arable land. The former farms are required to have at least three crops and the main crop should not cover more than 75 % of the arable land and the two main crops together should not cover more than 95 % of the arable land (Table 12).

Farms not complying with these requirements are subject to a reduction in direct payments (i.e. the greening payment) corresponding to the non-compliant area plus a penalty. The penalty depends on the proportion of non-compliant area but is applied at an increasing rate. For example, if the proportion of non-compliant area is lower than 3 % of the total eligible area, then the penalty is zero. However, if this proportion is more than 50 %, then the penalty corresponds to a reduction in the greening payment of 25 %. Hence the total eligible area minus the non-compliant area and minus the penalty represents the total area that can benefit from the greening payment (see Table 12).

Table 12. Crop diversification measures as implemented in IFM-CAP

	Exempt farms	**Farms group 1**	**Farms group 2**
Arable land (AL)	< 10 ha*	10–30 ha	≥ 30 ha
Minimum number of cultivated crops	–	2	3
Maximum proportion of main crop in *AL* (%)	–	75 %	
Maximum proportion of two main crops in *AL* (%)	–	–	95 %
Non-compliant area (*W*)		$W = \min(1,(X75/25\ \% + X95/5\ \%))*AL*0.50$	
Proportion of non-compliant area (*sh*)		$sh = W/(EL - W)$	
Penalty (*P*)	–	$sh \leq 3\ \% \Rightarrow P = 0$ $3\ \% < sh \leq 20\ \% \Rightarrow P = (2*W)/4$ $20\ \% > sh < 50\ \% \Rightarrow P = (EL-W)/4$ $sh > 50\ \% \Rightarrow P = EL/4$	
Area eligible for receiving the greening payment (*GP*)	–	$GP=EL - W - P$	

Notes: *X75*: percentage area of main crop going beyond the 75 % threshold; *X95*: percentage area of two main crops going beyond the 95 % threshold; *EL*: Eligible Land (Basic Payment Scheme/Single Area Payment Scheme).
*Excluded are also those farms where (i) fodder area + fallow area ≥ 75 % of *AL*, (ii) *AL* – (fodder + fallow) < 30 ha, (iii) grassland + other herbaceous fodder crops > 75 % UAA, or (iv) *AL* – other herbaceous crops < 30 ha.
In the event that the farmer is not-compliant for three years the calculation of the penalty (*P*) and non-compliant area (*W*) differs. However as IFM-CAP is not a dynamic model, this issue cannot be considered and thus the simulations may underestimate the penalties.
Source: Compiled based on the Regulation No 1307/2013 (EU, 2013) and the Delegated Regulations No 639/2014 and No 640/2014 (EU, 2014).

10.3. Results

In this section we report the simulation results for the crop diversification scenario for the EU-27. We focus the analysis on the income and land use effects of the crop diversification measure and provide results at MS and EU aggregate level, by farm specialisation and farm size and for the full distribution of individual farms.

Out of the five million commercial farms represented in IFM-CAP for the EU-27 ([38]), only 31 % are subject to the crop diversification measure (i.e. concerned farms); the remainder (69 %) are exempted from the measure. The latter include non-arable farms, farms with a small arable area (less than 10 ha) or farms with a large proportion of land planted with fodder crops. The MSs with the largest proportion of concerned farms include Denmark (90 %), Slovakia (88 %), Germany (73 %), Sweden (72 %), Finland (70 %), the Czech Republic (67 %), Belgium-Luxembourg (64 %) and France (60 %). These MSs have a farm structure dominated by large farms and/or by specialised farms and/or have a large arable sector. On the other hand, the smallest proportion of concerned farms is found in Malta (1 %), Ireland (7 %), Slovenia (10 %), Romania (12 %), Bulgaria (13 %), Cyprus (13 %), Portugal (13 %) and Greece (14 %). Many of these MSs have a high proportion of small commercial farms in the total commercial farm population, which are exempted from the diversification measure. The remaining MSs have a proportion of concerned farms between 20 % and 60 % (Table 13).

In the baseline scenario, the proportion of farms not complying with the diversification measure represents around 15 % of concerned farms in the EU-27. This proportion varies between 0 % in Malta and 51 % in Cyprus. The non-compliant farms represent a hypothetical situation in breach of the diversification requirement before the implementation of the measure. It corresponds to the minimum proportion of farms that would need to adjust their land allocation in order to comply with the diversification measure. Otherwise, these non-compliant farms would face a reduction in subsidy (i.e. lower greening payments).

Under the diversification scenario, the proportion of non-compliant farms in the EU-27 falls to less than 10 %. In most MSs the proportion of non-compliant farms is lower (except for Slovakia, where it remains unchanged) than in the baseline (Table 13). Note that this proportion represents farms that do not fully comply with the diversification measure. This means that they may have partially adjusted the area to the requirements, but still a proportion of their area is non-compliant ([39]). According to the results reported in Table 13, most of the non-compliant farms increased their compliance level in the diversification scenario relative to the baseline. Out of 10 % of non-compliant farms in the EU-27 in the diversification scenario, 8 % are more compliant than in the baseline. The rest (2 % of concerned farms) have the same non-compliance level in both scenarios. This implies that approximately 80 % of non-compliant farms reduce their non-compliance level in response to the introduction of diversification measures relative to the baseline, whereas 20 % do not change their non-compliance level.

([38]) Note that we assume no structural change in the model, therefore the number of farms is fixed in the base year, the baseline and the diversification scenario.

([39]) For example, if the non-compliant area is less than 3 %, the administrative penalty (*P*) is not imposed, implying that some farms may choose this level of non-compliance.

Table 13. Farms affected by the crop diversification measure (% of farms)

MS	Exempt farms (% of total farms)	Concerned farms (% of total farms)	Baseline: Compliant (% of concerned)	Baseline: Non-compliant (% of concerned)	Diversification: Compliant (% of concerned)	Diversification: Non-compliant (% of concerned): All	Diversification: Non-compliant (% of concerned): Farms that increased compliance level relative to baseline
BL	35.6	64.4	88.6	11.4	91.1	8.9	7.9
DK	9.8	90.1	85.6	14.4	90.2	9.8	8.2
DE	26.1	73.4	92.7	7.3	97.2	2.8	2.4
EL	86.2	13.8	74.7	25.3	79.9	20.1	13.5
ES	71.8	28.2	63.8	36.2	75.2	24.8	16.2
FR	39.8	60.2	93.1	6.9	96.3	3.7	3.5
IR	93.2	6.8	54.0	46.0	72.6	27.4	24.9
IT	79.4	20.6	79.5	20.5	88.0	12.0	9.4
NL	70.8	29.2	64.5	35.5	72.2	27.8	20.2
AT	51.1	48.9	95.3	4.7	98.2	1.8	1.8
PT	87.5	12.5	74.4	25.6	82.9	17.1	14.2
SE	27.8	72.2	90.7	9.3	95.9	4.1	3.5
FI	23.3	69.7	80.4	19.6	92.5	7.5	7.1
UK	55.8	44.1	84.7	15.3	92.2	7.8	6.2
CY	86.7	13.3	48.8	51.2	70.2	29.8	16.6
CZ	32.7	67.2	95.7	4.3	96.9	3.1	2.5
EE	46.7	53.3	92.9	7.1	96.9	3.1	3.1
HU	50.1	49.8	90.0	10.0	92.0	8.0	7.4
LT	38.9	61.1	96.5	3.5	98.6	1.4	1.2
LV	61.0	38.8	93.4	6.6	94.7	5.3	4.3
MT	99.0	1.0	100.0	0.0	100.0	0.0	0.0
PL	59.9	40.1	86.7	13.3	90.1	9.9	8.6
SI	90.3	9.7	96.0	4.0	98.2	1.8	1.8
SK	9.8	88.4	94.9	5.1	94.9	5.1	1.9
BG	87.4	12.6	75.1	24.9	82.6	17.4	4.6
RO	87.6	12.4	97.6	2.4	97.8	2.2	1.9
EU-27	**68.9**	**31.0**	**84.7**	**15.3**	**90.1**	**9.9**	**7.6**

Source: model results

Table 14 reports the income effects of the crop diversification scenario at MS level. The results show that the potential decrease in income caused by the implementation of the crop diversification measure is small. The overall income loss represents less than 1 % compared with the baseline. The largest decrease in income is observed in Finland, but its magnitude is still small (about 0.2 %). The results by farm production specialisation and farm size aggregated over all MSs reveal more sizable income effects for certain farm specialisations, but they are still below 1 % (Table 15, Table 16). However, at MS level the income change decreases up to 6.5 % for certain farm specialisations and up to 1.5 % for certain farm sizes (Table 15, Table 16).

The most affected are farms specialising in cereals, oilseeds and protein crops and in general field cropping. The decrease in income of these farm types varies across the MSs, but it reaches up to 6.5 % compared with baseline for certain MSs (Table 15). This is in line with expectations, given that the crop diversification measure targets arable farming. These farm types are followed by farms specialised in cattle rearing and fattening and sheep and goats. These farm types tend to have a less diversified production structure on their arable land, given that their main activity is not necessarily linked to arable cropping. They are more likely to breach the crop diversification requirement. For the remaining farm specialisations the maximum decrease in income across the MSs is very small: less than −0.5 % compared with the baseline (Table 15).

By farm size, the most affected are farms in the middle class (between 8 and 16 European size units (ESUs)) followed by large ones. Small farms are marginally affected by the crop diversification measure (Table 16). This is in line with expectations, given that small farms (i.e. those with less than 10 ha of arable land) are exempted from the crop diversification measure and/or are subject to less strict diversification requirements (i.e. farms with arable land between 10 and 30 ha).

Table 14. Income effect of the crop diversification measure by MS (% change relative to baseline)

MS	Change relative to baseline (%)
BL	−0.001
DK	−0.001
DE	−0.002
EL	−0.007
ES	−0.006
FR	−0.001
IR	−0.013
IT	−0.004
NL	−0.002
AT	−0.002
PT	−0.005
SE	−0.004
FI	−0.216
UK	−0.003
CY	−0.012
CZ	0.000
EE	−0.003
HU	−0.002
LT	0.000
LV	−0.015
MT	0.000
PL	−0.002
SI	−0.002
SK	0.000
BG	−0.001
RO	−0.008
EU-27	**−0.003**

Source: model results

Table 15. Income effect of the crop diversification measure by farm specialisation in the EU-27 (% change relative to baseline)

Farm specialisation	Average	Min.	Max.
Cereals, oilseeds and protein crops	−0.016	−6.58	0.00
General field cropping	−0.003	−1.69	0.00
Horticulture	−0.004	−0.07	0.00
Vineyards	0.000	0.00	0.00
Fruit	0.000	−0.01	0.00
Olives	−0.005	−0.01	0.00
Permanent crops	−0.001	−0.05	0.00
Dairy farms	−0.005	−0.03	0.00
Sheep and goats	−0.023	−0.86	0.00
Cattle rearing and fattening	−0.001	−2.15	0.00
Pigs and poultry	0.000	0.00	0.00
Mixed crops	−0.005	−0.12	0.00
Mixed livestock	−0.002	−0.18	0.00
Mixed crops and livestock	−0.002	−0.12	0.00

Source: model results

Table 16. Income effect of the crop diversification measure by farm size in the EU-27 (% change relative to baseline)

Farm size	Average	Min.	Max.
< 2 ESU	0.000	0.00	0.00
2 to < 4 ESU	0.000	0.00	0.00
4 to < 6 ESU	−0.001	−0.02	0.00
6 to < 8 ESU	−0.004	−0.02	0.00
8 to < 12 ESU	−0.004	−1.41	0.00
12 to < 16 ESU	−0.005	−0.92	0.00
16 to < 40 ESU	−0.005	−0.15	0.00
40 to < 100 ESU	−0.004	−0.12	0.00
100 to < 250 ESU	−0.003	−0.58	0.00
≥ 250 ESU	−0.001	−0.01	0.00

Source: model results

The aggregate impacts reported in Table 14, Table 15 and Table 16 may hide sizeable effects for individual farms. To gain further insight, Figure 12 shows the distribution of the percentage change in farm income relative to the baseline for all EU-27 MSs (i.e. the total number of farms in the EU-27 is equal to 100). This figure is constructed by sorting, in ascending order, all of the farms according to the size of the income change until all farms (100 %) are reported. As shown in this figure, only a small proportion of farms is affected by the diversification measure. Although the income change of some farms is substantial (more than a 10 % decline), the total proportion of farms affected by the measure represents only around 5 % of the total farm population in the EU-27. Thus, about 95 % of the farm population is not affected at all, either because they are already complying in the baseline or because they are not concerned by the crop diversification measure (i.e. they are exempt farms).

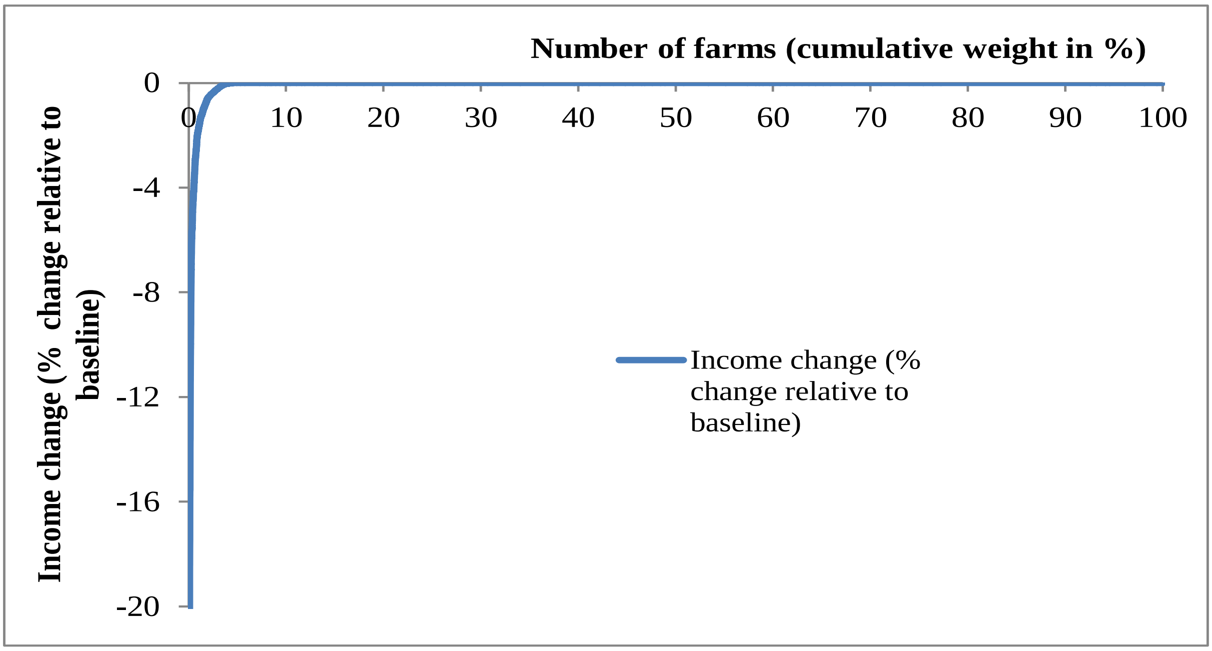


Figure 12. The distribution of the income change for the crop diversification scenario by individual farm (all farms, % change relative to baseline)

The low income effect reported above is largely explained by the limited impact of the crop diversification measure on land allocation. Table 17 illustrates the degree of non-compliance of land allocation in the baseline and crop diversification scenario. Similar to above, the non-compliant area in the baseline scenario represents a hypothetical area in breach of the diversification requirement before the implementation of the measure. It corresponds to the minimum area that farms would need to adjust in order to comply fully with the diversification measure and to avoid a reduction in their greening payments. As reported in Table 17, the arable area not complying with the diversification measure in the baseline is 0.6 % of the utilised agricultural area (UAA) in the EU-27. It ranges from 0 % to 5.4 % of UAA across different MSs (Table 17, panel a). Note that the degree of non-compliance can be slightly higher if calculated per concerned arable area. The concerned arable area is equal to the total arable area at MS level minus the arable area of farms exempted from the diversification measures. As reported in Table 17, panel b, the proportion of non-compliant area in the total concerned arable area is 1 % in the baseline in the EU-27 and it varies between 0 % and 6.5 % at MS level. Non-compliance is mostly related to the 75 % threshold imposed for the main crop cultivated on the farm. The area that does not comply with the 95 % threshold is significantly less important, representing less than 0.14 % of UAA and 0.21 % in the concerned arable area (Table 17, panels a and b). This result could also partly be explained by the fact that the 75 % threshold applies to all farms with an arable area greater than 10 hectares, whereas the 95 % threshold applies only to farms with an arable area greater than 30 hectares.

In the crop diversification scenario, the non-compliant area is reduced significantly compared with the baseline (Table 17, panels a and b). The proportion of non-compliant area in both UAA and concerned arable area is reduced by more than 50 % under the diversification scenario in the EU-27. This is explained by the relatively high subsidy reduction that would be imposed on farms if they did not comply. The (hypothetical) average subsidy reduction per hectare of non-compliant area is EUR 451 in the baseline in the EU-27 and varies between EUR 127 in Poland and EUR 758 in the Netherlands in the baseline (Table 18) ([40]). As penalties are expressed as a proportion of the direct payments, their value depends strongly on the value of direct payments per hectare, which varies across the MSs. MSs with a lower level of direct payments (e.g. BG, PL, SK, RO) also have smaller greening payments (and also a potential reduction in subsidy) than MSs with higher direct payments (e.g. DK, FR, NL). Note that although the non-compliant area is significantly reduced, the total affected area is small (less than 0.5 % of UAA).

Farms types with the greatest non-compliant area in the concerned area in the diversification scenario are specialised in permanent crops, horticulture, pigs and poultry and mixed crops (Table 19, panel a). For farm size, the most affected are middle-sized farms between 6 and 16 ESU followed by large farms (Table 19, panel b).

Table 17. Total area not complying with the diversification measure by MS

a) Proportion in UAA (%)

MS	Baseline			Diversification		
	Total	75% threshold	95% threshold	Total	75% threshold	95% threshold
BL	0.50	0.44	0.06	0.28	0.27	0.01
DK	0.58	0.47	0.11	0.28	0.28	0.00
DE	0.68	0.56	0.12	0.32	0.28	0.03
EL	1.62	1.44	0.17	1.13	1.07	0.06
ES	1.66	1.22	0.44	0.81	0.71	0.10
FR	0.21	0.17	0.05	0.06	0.06	0.00
IR	0.27	0.23	0.04	0.10	0.09	0.01
IT	0.96	0.74	0.22	0.49	0.45	0.05
NL	1.56	1.41	0.14	0.98	0.92	0.06
AT	0.28	0.26	0.02	0.05	0.05	0.00
PT	1.45	1.28	0.17	0.59	0.55	0.04
SE	0.54	0.37	0.17	0.15	0.13	0.02
FI	1.40	1.10	0.30	0.37	0.35	0.02
UK	0.23	0.15	0.08	0.11	0.10	0.01
CY	5.42	4.28	1.14	3.83	3.35	0.49
CZ	0.07	0.05	0.02	0.03	0.02	0.01
EE	0.29	0.23	0.06	0.15	0.15	0.00
HU	0.33	0.25	0.07	0.20	0.18	0.01
LT	0.26	0.19	0.08	0.07	0.07	0.01
LV	0.34	0.25	0.09	0.24	0.19	0.04
MT	0.00	0.00	0.00	0.00	0.00	0.00
PL	0.72	0.65	0.07	0.42	0.40	0.02
SI	0.05	0.04	0.01	0.02	0.02	0.00
SK	0.26	0.21	0.05	0.24	0.21	0.04
BG	0.55	0.43	0.12	0.38	0.34	0.03
RO	0.35	0.25	0.10	0.08	0.07	0.01
EU-27	**0.63**	**0.49**	**0.14**	**0.31**	**0.28**	**0.03**

([40]) In Malta the subsidy reduction is zero because all farms comply with the diversification measure.

b) Proportion in the concerned arable area (%)

MS	Baseline			Diversification		
	Total	75% threshold	95% threshold	Total	75% threshold	95% threshold
BL	0.85	0.75	0.10	0.47	0.45	0.02
DK	0.63	0.51	0.12	0.31	0.30	0.00
DE	0.94	0.77	0.17	0.44	0.39	0.05
EL	2.41	2.15	0.26	1.69	1.60	0.09
ES	2.92	2.15	0.77	1.43	1.25	0.18
FR	0.30	0.23	0.07	0.09	0.09	0.00
IR	2.18	1.83	0.35	0.81	0.75	0.06
IT	1.36	1.04	0.32	0.70	0.63	0.07
NL	3.47	3.15	0.32	2.19	2.05	0.14
AT	0.53	0.49	0.04	0.09	0.09	0.00
PT	2.39	2.10	0.29	0.97	0.90	0.07
SE	0.62	0.42	0.20	0.17	0.15	0.02
FI	1.43	1.13	0.31	0.38	0.36	0.02
UK	0.53	0.35	0.17	0.25	0.23	0.03
CY	6.45	5.10	1.36	4.56	3.98	0.58
CZ	0.10	0.07	0.03	0.04	0.02	0.01
EE	0.38	0.30	0.07	0.20	0.20	0.00
HU	0.40	0.31	0.09	0.24	0.22	0.01
LT	0.31	0.22	0.09	0.09	0.08	0.01
LV	0.47	0.34	0.13	0.33	0.27	0.06
MT	0.00	0.00	0.00	0.00	0.00	0.00
PL	0.89	0.80	0.09	0.52	0.50	0.02
SI	0.15	0.14	0.02	0.06	0.06	0.00
SK	0.37	0.30	0.07	0.35	0.29	0.05
BG	0.64	0.50	0.14	0.43	0.40	0.04
RO	0.41	0.29	0.12	0.10	0.09	0.01
EU-27	**0.98**	**0.76**	**0.21**	**0.47**	**0.43**	**0.04**

Source: model results

Table 18. Subsidy reduction per hectare of non-compliant area (EUR/ha)

MS	Baseline	Diversification
BL	539	298
DK	716	274
DE	523	258
EL	571	392
ES	363	178
FR	615	288
IR	574	372
IT	651	263
NL	758	426
AT	473	226
PT	331	206
SE	478	210
FI	741	322
UK	671	233
CY	331	137
CZ	245	219
EE	125	58
HU	244	123
LT	210	88
LV	181	87
MT	0	0
PL	127	91
SI	461	333
SK	139	80
BG	142	69
RO	187	64
EU-27	**451**	**218**

Source: model results

Table 19. Area not complying with the diversification measure by farm type in EU-27 (% of concerned arable area)

a) By farm specialisation

Farm specialisation	Baseline			Diversification		
	Average	Min.	Max.	Average	Min.	Max.
Cereals, oilseeds and protein crops	0.99	0.04	16.22	0.54	0.01	12.39
General field cropping	0.75	0.04	4.37	0.40	0.04	2.19
Horticulture	2.88	0.55	16.80	1.94	0.08	15.42
Vineyards	1.49	0.35	7.97	0.94	0.20	6.32
Fruit	1.08	0.34	22.77	0.69	0.04	10.97
Olives	1.51	0.16	2.78	1.17	0.65	2.28
Permanent crops	2.70	0.03	22.50	1.51	0.43	5.79
Dairy farms	0.90	0.04	7.08	0.28	0.00	4.13
Sheep and goats	1.40	0.22	11.80	0.48	0.01	9.45
Cattle rearing and fattening	0.76	0.05	14.62	0.20	0.02	3.41
Pigs and poultry	2.46	0.77	15.10	1.17	0.08	15.10
Mixed crops	1.53	0.03	4.94	0.96	0.00	3.22
Mixed livestock	1.02	0.07	7.54	0.45	0.01	5.45
Mixed crops and livestock	0.62	0.01	10.19	0.23	0.01	6.83

b) By farm size

Farm size	Baseline			Diversification		
	Average	Min.	Max.	Average	Min.	Max.
< 2 ESU	0.07	1.27	1.27	0.07	1.27	1.27
2 to < 4 ESU	0.32	0.09	3.86	0.25	0.23	3.82
4 to < 6 ESU	0.65	0.03	4.65	0.48	0.00	3.73
6 to < 8 ESU	1.67	0.15	11.52	1.23	0.06	10.66
8 to < 12 ESU	1.44	0.09	3.99	0.85	0.06	3.43
12 to < 16 ESU	1.57	0.00	10.42	0.86	0.02	10.42
16 to < 40 ESU	1.30	0.12	7.51	0.64	0.02	3.63
40 to < 100 ESU	0.91	0.02	4.53	0.38	0.00	2.37
100 to < 250 ESU	0.95	0.14	10.41	0.34	0.05	7.64
≥ 250 ESU	0.67	0.01	3.47	0.40	0.00	2.71

Source: model results

Figure 13 displays the distribution of non-compliant area across individual farms for the baseline and crop diversification scenarios. The horizontal axis is similar to that in Figure 12, with the exception that we cut the axis at 15 %, in order to better illustrate the changes for the affected farms. The remaining 85 % of farms that are not shown in the figure have no non-compliant area. The figure reveals that only a small proportion of farms (around 4.7 %) have a non-compliant area in the baseline. Under the diversification scenario, the proportion of farms that are not compliant drops to 3 %.

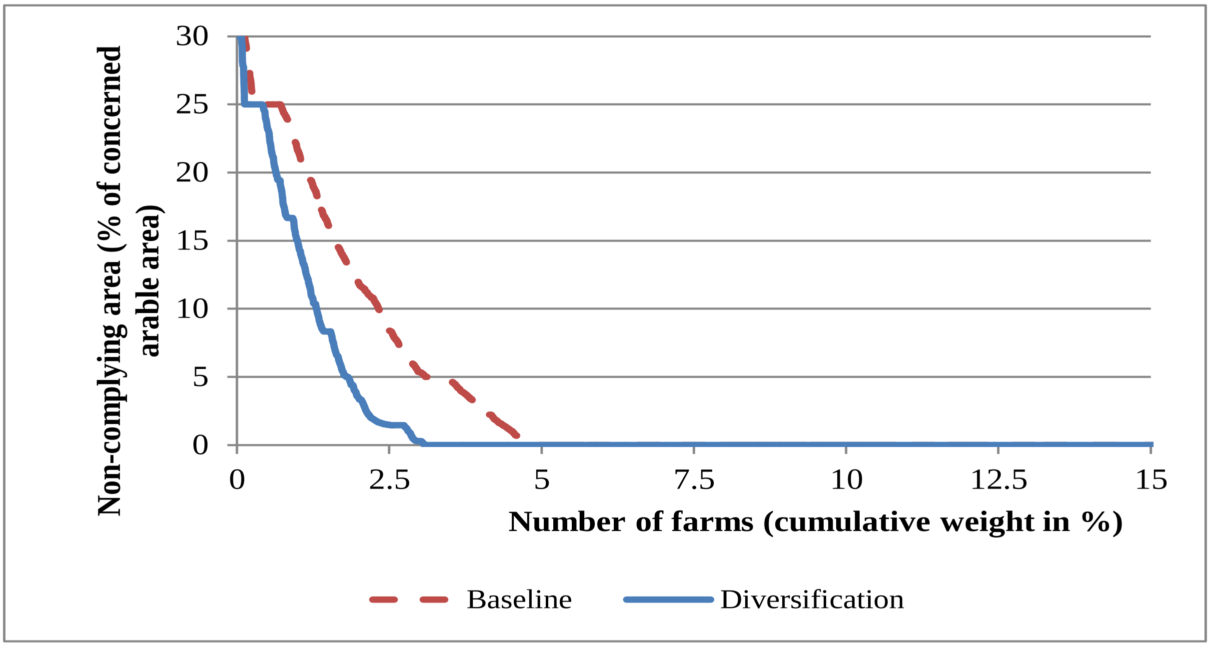


Figure 13 The distribution of non-compliant area by individual farm (% of concerned arable area)

10.4. Conclusions and discussion

In this application, the IFM-CAP model has been used to simulate the responses of EU farmers to the 2013 CAP reform, more specifically to the crop diversification measure. Out of five million farms represented in the IFM-CAP FADN data for the EU-27, 38 % are subject to the crop diversification measure (i.e. concerned farms), whereas the remainder (62 %) are exempted from the measure.

From a policy perspective, the main finding of this model application is that the effect of crop diversification on farm income is rather limited at the aggregate level. Agricultural income at MS level decreases by less than 1 %. At the individual farm level the impact could be more pronounced (more than −10 %), although the number of farms that is affected by the measure remains small (around 5 % of the total farm population). The proportion of reallocated area due to the diversification measure represents less than 0.5 % of the total agricultural area. The most constraining component of the diversification measure appears to be the 75 % threshold imposed for the main cultivated crop for farms with an arable area greater than 10 hectares. Another important outcome of the simulation analysis is that most non-compliant farms (80 %) choose to reduce their non-compliance level with the introduction of the diversification measure owing to the sizable subsidy reduction imposed.

These findings have to be considered, however, with some caution on account of the model's assumptions. First of all, the model is calibrated on the average values over the three years 2007, 2008 and 2009 instead of single year data. As the farm production plan of an average year is less specialised than that of a single year (i.e. the number of crops of an average year will most likely be higher than the number of crops in each single year), this implies that the crop diversification constraint will be less binding in our model than it is in reality. Therefore, our results will probably underestimate the non-compliant area in the baseline scenario and the overall effect of the crop diversification measure. A second potential caveat in our analysis is that we assume a fixed organisational structure, implying that land can be reallocated only within farms in response to the introduction of the crop diversification measure. In reality, farmers may reallocate land between farms or may decide to adjust other elements of farm organisation that are not necessarily linked to land allocation. For example, farms may enter into unofficial arrangements with neighbouring farms to rearrange claims for the greening payments in order to ensure compliance and, thus, to avoid the decrease in income related to potential land relocation. If this is the case, our results overestimate the overall effects. Third, we do not take market feedbacks (output price changes) into account in the model. The diversification measure will probably increase the overall output price level because of the productivity reduction effect. The price effects may thus offset some of the impacts (e.g. income change) simulated in the paper. Fourth, certain crops are defined in the model as an aggregation of a set of individual crops (e.g. fodder crops), which may also lead to a slight overestimation of the simulated impacts. Furthermore, given that the exact implementation of the 2013 CAP reform was not known at the time of preparation of this report, direct payments in the baseline are assumed to be at the level reported in FADN in the base year. In addition, not all the specificities regarding the 'greening' implementation are considered in the model. In the scenario analysis in particular, it is not considered either that organic producers and farmers in the 'small farmers' scheme' are exempted from the greening obligations or that MSs can opt to define practices that yield an equivalent or higher beneficial effect for the climate and the environment as the three 'greening' obligations. A careful analysis of each of these limitations to the current model is needed to test the robustness of these results and to provide a complete picture of the EU-wide impact of the crop diversification measure.

11. Current and future model developments

The development of IFM-CAP is part of the 'Integrated Modelling Platform for Agro-Economic Commodity and Policy Analysis' (IMAP) administrative arrangement between DG-AGRI and the Joint Research Centre (JRC).

Under the administrative arrangement, it is planned to deliver one JRC report every year describing updates to IFM-CAP. Below we mention the on-going model developments, as well as the activities planned for the second half of 2015 and for 2016.

The following IFM-CAP model developments are on-going:

- testing the application of yield trend projections using the FADN database;
- testing the application of flexible multi-input multi-output cost functions;
- an update of the livestock module (update of underlying data and recalibration);
- finalising the calibration of the improved combined livestock and arable modules;
- improvement/update of the baseline.;
- implementation of the CAP 2013 reform (CAP first pillar);
- a feasibility study on modelling permanent crops;
- a feasibility study on incorporating farmers' behaviour towards risk and uncertainty;
- a feasibility study on implementing a selection of environmental indicators in cooperation with JRC-IES;
- an update of the base year from the current 2007–2009 to the new 2010–2012 (checking new FADN data; identification and handling of outliers and missing values).

The following activities are planned for the second half of 2015 and for 2016.

- testing alternative approaches for modelling livestock activities;
- implementation of the permanent crops module;
- implementation of a selection of public goods and environmental indicators;
- linking farm supply and output market to capture price feedback;
- a feasibility study on the spatial allocation of FADN farms;
- yield endogenisation;
- allocation of labour input;
- a feasibility study on modelling CAP second pillar policies;
- implementation of linkage with farm structural change module (in the baseline);
- checking/improving the GAMS codes of the IFM-CAP modules;
- improvement of the IFM-CAP GUI.

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Annex A: Main model parameters and equations

Table A 1. Indexes, parameters, variables and equations in IFM-CAP

Indexes	Description
f	Farm
r	Region (NUTS 2)
i, i', j, j'	Agricultural (crop and livestock) activities and products ($i, i', j, j' \in N$)
k	Intermediate inputs (i.e. fertiliser, seeds, crop protection...) ($k \in K$)
m	Resource and policy constraints (agricultural land, quotas, set-aside ...) ($m \in M$)
ft	Farm types (TF14 grouping)
nut	Nutrient contents (i.e. energy, protein, dry matter...)
F	Feed activities ($F \in N$)
$F_1, F_2, \ldots, F_n$	Subset (sub-groups) of feed activities and products ($F_1, F_2, \ldots, F_n \in F$)

Parameters	Description (unit)
w_f	Farm weighting factor
Ψ_f	Farm weight within the NUTS 2 region ($\Psi_f = w_f \Big/ \sum_f w_f$)
$y_{f,i}$	Yield of activity i (tonne/ha or tonne/head)
$p_{f,i}$	Farm product prices (euros/tonne)
$p^q_{f,i}$	Farm in-quota prices (euros/tonne)
$s_{f,i}$	Subsidies (coupled and decoupled payments) (euros/ha or euros/head)
$C_{f,i,k}$	Accounting unit costs of input k per hectare of activity i (euros/ha)
$d_{f,i}$ & $Q_{f,i,i'}$	Behavioural functions' parameters (i.e. PMP parameters for activity levels) (euros/ha or euros/head)
$d'_{f,i,j}$ & $Q'_{f,i,i,j}$	PMP parameters for feeding (euros/tonne)
$A_{f,i,m}$	Matrix coefficients for resource and policy constraints (ha/ha or tonne/tonne)
$b_{f,m}$	Resource endowments and policy (quotas and other) rights (ha or tonne)
$R_{f,i,nut}$	Animal requirements (MJ/tonne or tonne or fill unit system)
$u^0_{f,i,j}$	Observed quantity used for animal feeding by animal category (tonne)
$\mathbf{g}_{\mathbf{f,i,nut}}$	Feed contents (MJ/tonne or tonne or fill unit system)
$\mathrm{MinShr}_{\mathbf{f,i,j}}$	Minimum proportion of feed in total feed consumption (in dry matter)
$\mathrm{MaxShr}_{\mathbf{f,i,j}}$	Maximum proportion of feed in total feed consumption (in dry matter)

Variables	Description (unit)
π_f	Farm expected income (euros)
$x_{f,i}$	Agricultural activity levels (i.e. land use and animal number) (ha or head)
$q_{f,i}$	Total production quantity (tonnes)
$t_{f,i}$	Selling and buying quantity (tonnes)
$q^q_{f,i}$	In-quota production quantity (tonnes)
$u_{f,j}$	Quantity used for animal feeding (tonnes)
$u_{f,i,j}$	Quantity used for animal feeding by animal category (tonnes)
$e_{f,i}$	Quantity lost or used for seeding (tonnes)

No	Equations	Description
(1)	$Max\,\pi_f = \sum_i t_{f,i} p_{f,i} + \sum_i q^q_{f,i}(p^q_{f,i} - p_{f,i}) + \sum_i s_{f,i} x_{f,i} - \sum_{i,k} C_{f,i,k} x_{f,i}$ $- \sum_{i,i'} (d_{f,i} + 0.5 Q_{f,i,i'} x_{f,i'}) x_{f,i}$ $- \sum_{i,j} (d'_{f,i,j} + 0.5 Q'_{f,i,i,j}\, u_{f,i,j}) u_{f,i,j} x_{f,j}$	Model objective function: maximise farm expected income
(2)	$\sum_i A_{f,i,m} x_{f,i} \le b_{f,m}$	Land and set-aside constraints
(3)	$\sum_i A_{f,i,m} q^q_{f,j} \le b_{f,m}$	Quota restrictions
(4)	$q_{f,i} = y_{f,i} x_{f,i}$	Total production
(5)	$q^q_{f,i} \le q_{f,i}$	In-quota production
(6)	$q_{f,i} = e_{f,i} + u_{f,i} + t_{f,i}$	Product balance
(7)	$\sum_j u_{f,i,j} x_{f,j} = u_{f,i}$	Feed allocation among animal activities
(8)	$u_{f,i,j} = u^0_{f,i,j}$	Fixed feed use (needed only for calibration step)
(9)	$x_{f,j} R_{f,j,nut} = \sum_i u_{f,i} g_{i,nut}$	Feed balance (energy, protein)
(10)	$x_{f,j} R_{f,j,nut} \ge \sum_i u_{f,i} g_{i,nut}$	Feed inequality (dry matter, fibre, etc.)
(11)	$MinShr_{f,j,F_n} x_{f,j} R_{f,j,DRMA} \le \sum_{i \in F_n} u_{f,i} g_{i,DRMA}$	Minimum feed proportion (by feed or group of feed)
(12)	$MaxShr_{f,j,F_n} x_{f,j} R_{f,j,DRMA} \ge \sum_{i \in F_n} u_{f,i} g_{i,DRMA}$	Maximum feed proportion (by feed or group of feed)

Table A 2. Parameters, variables and equations in calibration module

Parameters	Description (unit)
$(\bar{\rho}_{r,i,m}, \sigma^{\rho}_{r,i,m})$	Mean and standard deviation of regional land rental prices and in-quota prices used as prior
$(\bar{\varepsilon}_{r,i,i}, \sigma^{\varepsilon}_{r,i,i})$	Mean and standard deviation of regional own-price elasticities of supply used as prior
$x^0_{f,i}$	Observed activity level for activity *i* (ha)
$\delta_{f,i}$	Scaling factor $\delta_{f,i} = (\sqrt{1/x^0_{f,i}}\ )$ (ha)
$C_{f,i,k}$	Accounting unit costs of input *k* per hectare of activity *i* (euros/ha)
$gm_{f,i}$	Gross margin for activity *i* (euros/ha)
N_r	Number of observed crop activities (i.e. $x^0_{r,i}$ > 0) in each NUTS 2 region

Variables	Description (unit)
$d_{f,i}$ & $Q_{f,i,i'}$	Behavioural functions' parameters (euros/ha)
$\rho_{r,i,m}$	Dual values of land, set-aside and quota constraints (euros/ha or euros/tonne)
$\varepsilon_{f,i,i'}$	Farm own- and cross-price elasticities of supply
$\varepsilon_{r,i,i'}$	Regional own- and cross-price elasticities of supply
$B_{ft,i,i'}$	A quadratic parameter matrix – common across farms belonging to the same type of farming (using TF14 grouping based on production specialisation) and the same NUTS 2 region(r) – (euros/ha)

No	Equations	Description
(13)	$Min\,HPD_r = \left[\sum_{f,i,m} \psi_f \frac{(\rho_{f,i,m} - \bar{\rho}_{r,i,m})^2}{(\sigma^{\rho}_{r,i,m})^2} + \sum_i \frac{x^0_{r,i}(\varepsilon_{r,i,i} - \bar{\varepsilon}_{r,i,i})^2}{(\sigma^{\varepsilon}_{r,i,i})^2} \frac{N_r}{\sum_i x^0_{r,i}} \right]$	Model objective function
(14)	$\sum_k C_{f,i,k} + d_{f,i} + \sum_{i'} Q_{f,i,i'} x^0_{f,i'} + \sum_m A_{f,i,m}\rho_{f,i,m} = y_{f,i} p_{f,i} + s_{f,i}$	First-order condition for crop activities
(15)	$\sum_k C_{f,i,k} + d_{f,i} + \sum_{i'} Q_{f,i,i'} x^0_{f,i'} + \sum_m A_{f,i,l}\rho_{f,i,m} = y_{f,i} p^q_{f,i} + s_{f,i}$	First-order condition for sugar beet if out-of-quota production = 0
(16)	$b_{f,m} - \sum_i A_{f,i,m} x^0_{f,i} = 0$	First-order condition for constraints
(17)	$b_{f,m} - \sum_i A_{f,i,m} q^p_{f,i} = 0$	First-order condition for quota constraint
(18)	$\varepsilon_{f,i,i'} = \left[\begin{array}{l} Q^{-1}_{f,i,i'} - \\ \sum_m (\sum_j A_{f,j,m} Q^{-1}_{f,i,j} (\sum_{j,j'} A_{f,j,m} Q^{-1}_{f,j,j'} A_{f,j',m})^{-1} \sum_j A_{f,j,m} Q^{-1}_{f,j,i'}) \end{array} \right] \frac{gm_{f,i'}}{x^0_{f,i}}$	Farm elasticity calculation
(19)	$\sum_j Q_{i,j} Q^{-1}_{j,i'} = 1 \quad \forall i = i'$ $\sum_j Q_{i,j} Q^{-1}_{j,i'} = 0 \quad \forall i \neq i'$	Inverse of Q calculation
(20)	$\varepsilon_{r,i,i'} = \frac{\sum_f w_f x^0_{f,i} \varepsilon_{f,i,i'}}{\sum_f w_f x^0_{f,i}}$	Regional elasticity calculation
(21)	$Q_{f,i,i'} = \sum_{ft} \delta_{f,i} B_{ft,i,i'} \delta_{f,i'}$	Farm-specific quadratic parameter matrix of behavioural function
(22)	$B_{ft,i,i'} = \sum_j L_{ft,i,j} L_{ft,i',j} \qquad L_{i,i'} = 0 \quad for \;\; i' > i$	Cholesky decomposition

Table A 3. Parameters, variables and equations in input allocation module

Parameters	Description (unit)
$(\overline{H}_{ft,i,k}, \sigma^{H}_{ft,i,k})$	Mean and standard deviation of input–output coefficients used as prior
$(\sigma^{u}_{f,k})$	Standard deviation of error term used as prior
$x^{0}_{f,i}$	Observed activity level for activity *i* (ha)
$v_{f,i}$	Output value of activity *i* (euros)
$z_{f,k}$	Total value of input *k* at farm-level (euros)
Ψ_{f}	Farm weight within the NUTS 2 region ($\Psi_{f} = w_{f} \Big/ \sum_{f} w_{f}$)
F_{r}	Number of farms in each NUTS 2

Variables	Description (unit)
$H_{ft,i,k}$	Input–output coefficients – common across farms belonging to the same type of farming (using TF14 grouping based on production specialisation) and the same NUTS 2 region (r)
$u_{f,k}$	Error term (euros)
$\widetilde{H}_{f,i,k}$	Corrected input–output coefficients after full distribution of input costs
$C_{f,i,k}$	Accounting unit costs of input *k* per hectare of activity *i* (euros/ha)

No	Equations	Description
(23)	$Min\, HPD1_{r} = \left[\sum_{ft,i,k} \frac{(H_{ft,i,k} - \overline{H}_{ft,i,k})^2}{(2\sigma^{H}_{ft,i,k})^2} + \sum_{r,f,k} \psi_{f} \frac{(u_{f,k})^2}{(2\sigma^{u}_{f,k})^2} F_{r} \right]$	Model objective function
(24)	$z_{f,k} = \sum_{ft,i} H_{ft,i,k} v_{f,i} + u_{f,k} \quad \forall\ z > 0$	Data consistency constraint (Leontief production function)
(25)	$z_{f,k} > \sum_{ft,i} H_{ft,i,k} v_{f,i} + u_{f,k} \quad \forall\ z = 0$	
(26)	$\sum_{k} H_{ft,i,k} = 1$	Accounting restriction
(27)	$\widetilde{H}_{f,i,k} = \sum_{ft} H_{ft,i,k} \frac{z_{f,k}}{\sum_{i} H_{ft,i,k} v_{f,i}}$	Calculation of corrected input–output coefficient
(28)	$C_{f,i,k} = \widetilde{H}_{f,i,k} \frac{v_{f,j}}{x^{0}_{f,i}}$	Calculation of unit input cost per hectare
(29)	$z_{f,k} = \sum_{i} \widetilde{H}_{f,i,k} v_{f,i} = \sum_{i} C_{f,i,k} x^{0}_{f,i}$	Relation between total input costs, input–output coefficients and input costs per hectare

Table A 4. Extraction rules – land use activities (from FADN Table K)

Production activity	GAMS acronym for production activity	Extraction rule for area in ha (AA)	Extraction rule for output quantities (QQ) in tonnes	Extraction rule for total production value (TP) in euros
Cereals	**ACER**			
Soft wheat	SWHE	120AA	120QQ	120TP
Durum wheat	DWHE	121AA	121QQ	121TP
Rye and meslin	RYEM	122AA	122QQ	122TP
Barley	BARL	123AA	123QQ	123TP
Oats	OATS	124AA	124QQ	124TP
Grain maize	MAIZ	126AA	126QQ	126TP
Paddy rice	PARI	127AA	127QQ	127TP
Other cereals	OCER	125AA + 128AA	125QQ + 128QQ	125TP + 128TP
Oilseeds	**AOIL**			
Rape	RAPE	331AA	331QQ	331TP
Sunflower	SUNF	332AA	332QQ	332TP
Soya	SOYA	333AA	333QQ	333TP
Other oils	OOIL	334AA	334QQ	334TP
Other arable crops	**AOAC**			
Pulses	PULS	129AA	129QQ	129TP
Potatoes	POTA	130AA	130QQ	130TP
Sugar beet	SUGB	131AA	131QQ	131TP
Flax and hemp	TEXT	347AA + 364AA	347QQ + 364QQ	347TP + 364TP
Tobacco	TOBA	134AA	134QQ	134TP
Other industrial crops	OIND	133AA + 135AA – 347AA	133QQ + 135QQ – 347QQ	133TP + 135TP – 347TP
Other crops	OCRO	142AA + 143AA + 148AA + 156AA + 158AA + 159 AA	139QQ + 142QQ + 143QQ + 146QQ + 148QQ + 156Q Q + 158QQ + 159QQ + 160 QQ + 161QQ + 284QQ	139TP + 142TP + 143TP + 146TP + 148TP + 156TP + 158TP + 159TP + 160TP + 161TP + 284TP
Vegetables and permanent crops	**APER**			
Tomatoes	TOMA	337 AA	337QQ	337TP
Other vegetables	OVEG	136AA + 137AA + 138AA – 337AA – 341AA	136QQ + 137QQ + 138QQ – 337QQ-341QQ	136TP + 137TP + 138TP – 337TP – 341TP
Apples/peaches	APPL	349AA	349QQ	349TP
Other fruits	OFRU	350AA + 353AA + 351AA + 352AA + 341AA	152QQ – 349QQ + 341QQ	152TP-349TP + 341TP
Citrus fruits	CITR	354AA + 355AA + 356AA + 357AA	153QQ	153TP
Table grapes	TAGR	285AA	285QQ	285TP
Olives for oil	OLIV	282AA + 283AA	282QQ + 283QQ	282TP + 283TP
Table olives	TABO	281AA	281QQ	281TP
Table wine	TWIN	155AA – 285AA	155QQ-285QQ	155TP – 285TP
Nurseries	NURS	157AA	157QQ	157TP
Flowers	FLOW	If 140AA + 141AA > 0, then 140AA + 141AA, else 342AA + 343AA + 344AA	If 140QQ + 141QQ > 0, then 140QQ + 141QQ, else 342QQ + 343QQ + 344QQ	If 140TP + 141TP > 0, then 140TP + 141TP, else 342TP + 343TP + 344TP
Fodder activities	**AFOD**			
Fodder maize	MAIF	326AA	326QQ	326TP
Fodder root crops	ROOF	144AA	144QQ	144TP
Pasture	GRAS	150AA + 151AA	150QQ + 151QQ	150TP + 151TP
Fodder other on arable land	OFAR	147AA + 327AA + 328AA	147QQ + 327QQ + 328QQ	147TP + 327TP + 328TP
Set-aside and fallow land	**ASET**			
Set-aside	SETA	146OUAA		
Non-food set-aside	NONF	NFCAA		
Fallow land	FALL	146AFAA		

Source: Neuenfeldt and Gocht (2012).

Table A 5. Extraction rules for grants and subsidies per crop production activity

Total subsidies on crops	GAMS Abbr. for Subsidy positions		Activities or Categories of activities of crop production	Extraction rule for each category of subsidy and production activity
Compensatory payments per area	SUBCRO_COP	DPOILS	Oilseeds	M(603CP, 623CP)
		DPCER	Cereals	M(622CP, 625CP, 626CP)
		DPDWHE TR	Durum wheat	M(608CP, 618CP, 628CP, 638CP)
		DPSILA	Grass silage	M(611CP, 631CP)
		DPPULS	Pulses	M(604CP, 614CP, 624CP, 634CP)
		DPFODC	Fodder maize	M(607CP)
		DPTEXT	Flax and hemp	M(609CP, 610CP, 629CP)
		DPENERC RP	Energy crops	M(612CP, 613CP, 632CP, 633CP)
		DPOTHE	Other crops	M(609CP, 610CP, 629CP)
Compensatory payment set-aside	SUBCRO_SETA	DPSETA	Set-aside	M650CP
Other crops subsidies	SUBCRO_OTHER		Cereals:	
		JCSWHE	Soft wheat	JC120
		JCDWHE	Durum wheat	JC121
		JCRYEM	Rye and meslin	JC122
		JCBARL	Barley	JC123
		JCOATS	Oats	JC124
		JCMAIZ	Grain maize	JC126
		JCPARI	Paddy rice	JC127
		JCOCER	Other cereals	JC125 + JC128
			Oilseeds:	
		JCRAPE	Rape	JC331
		JCSUNF	Sunflower	JC332
		JCSOYA	Soya	JC333
		JCOOILS	Other oils	JC334
			Other arable crops:	
		JCPULS	Pulses	JC129 + JC330 + JC360 + JC361
		JCPOTA	Potatoes	JC130 + JC362 + JC363
		JCSUGB	Sugar beet	JC131
		JCTEXT	Flax and hemp	JC347 + JC364
		JCTOBA	Tobacco	JC134 + JC(365... 372)
		JCOIND	Other industrial	JC133 + JC135 + JC(345, 346, 348, 373, 374)
		JCOCRO	Other crops	JC(139, 142, 143, 146, 148, 149, 156, 158, 159, 160, 161, 284, 300, 301)
			Vegetables and permanent crops:	
		JCTOMA	Tomatoes	JC337
		JCOVEG	Other vegetables	JC136 + JC137 + JC138 + JC(335, 336, 338... 340)
		JCAPPL	Apples/peaches	JC339
		JCOFRU	Other fruits	JC(350...353) + JC341
		JCCITR	Citrus fruits	JC153 + JC(354... 357)
		JCTAGR	Table grapes	JCVINES
		JCOLIV	Olives for oil	JC154 + JC(282… 284)
		JCTABO	Table olives	JC281
		JWINES	Wine	JCWINE
		JCNURS	Nurseries	JC157
		JCFLOW	Flowers	JC140 + JC141 + JC(342... 344)
		JCFODC	Fodder activities	JC(144, 145, 147, 150, 151, 326, 327, 328, 329)
			Other crop subsidies:	
		JCOTHER	Other crop subsidies	JC952
Article 69	SUBART	JCART	Article 68	JC956

Table A 6. Eligible crops and livestock activities by subsidy type.

Subsidy code	Crops benefiting from the subsidy
DPSFP	All crop activities
DPSAP (2007)	SWHE, DWHE, RYEM, BARL, OATS, MAIZ, OCER, PARI, RAPE, SUNF, SOYA, OLIV, OOIL, P, ROOF, GRAS, MAIF, SETA, NONF, FALL PULS, POTA, SUGB, TEXT, TOBA, OIND, TABO, FLOW, OCRO, OFAR
DPSAP (2008)	SWHE, DWHE, RYEM, BARL, OATS, MAIZ, OCER, PARI, RAPE, SUNF, SOYA, OLIV, OOIL, PULS, POTA, SUGB, TEXT, TOBA OIND, APPL, OFRU, CITR, TAGR, TABO, NURS, FLOW, OCRO, OFAR, ROOF, GRAS, MAIF, SETA, NONF, FALL
DPSAP (2009)	CACT
DPAID	CACT
DPCER	CERE, MAIF, OFAR
DPFODC	MAIF, GRAS, OFAR
DPOILS	OILS
DPPULS	PULS
DPOTHER	CACT
DPENERCRP	NONF, RAPE,SUGB, SWHE, SUNF, MAIF, MAIZ, BARL, SOYA
DPDWHETR	DWHE
JCPARI	PARI
DPSILA	OFAR
DPTEXT	OIND
DPSETA	SETA, NONF, FALL
JCSUGB	SUGB
JCOLIV	OLIV, TABO
JCTABO	TABO
JCTOMA	TOMA
JCOVEG	OVEG
JCAPPL	APPL
JCOFRU	OFRU
JCCITR	CITR
JCTAGR	TAGR
JCNURS	NURS
JCFLOW	FLOW
JCWINE	WINE
JCTOBA	TOBA
JCPOTA	POTA
JCSWHE	SWHE
JCDWHE	DWHE
JCRYEM	RYEM
JCBARL	BARL
JCOATS	OATS
JCMAIZ	MAIZ
JCOCER	OCER
JCRAPE	RAPE
JCSUNF	SUNF
JCSOYA	SOYA
JCOOILS	OOILS
JCPULS	PULS, OFAR, GRAS
JCTEXT	TEXT
JCOIND.	OIND, TEXT
JCOCRO	OCRO
JCFODC	OFAR, GRAS, ROOF, MAI
JCOTHER	CACT
DPDCOW	DCOW
DPBULF	BULF
DPEXTENS	SCOW, BULF, HEIF, HEIR, CAMF, CAFF, CAMR, CAFR
DPSCOW	SCOW, HEIR, HEIF

Subsidy code	Crops benefiting from the subsidy
DPSL_ADCT	HEIF, BULF
DPSL_CALV	CAMF, CAFF
DPADDPNA	SCOW, BULF, HEIF, HEIR, CAMF, CAFF, CAMR, CAFR
JCHEIF	HEIF
JCHEIR	HEIR
JCOCAT	SCOW, CAMF, CAFF, CAMR, CAFR, BULF, HEIF, HEIR
JCCATT	SCOW, CAMF, CAFF, CAMR, CAFR, BULF, HEIF, HEIR, DCOW
JCCAR	CAMR, CAFR
JCSHGM	SHGM
JCSHGO	SHGM, SHGF
JCPIGF	PIGF
JCSOW	SOWS
JCHENS	HENS
JCPOUF	POUF
JCPOU	POUF, HENS
JCOANI	OANI
JCOTLI	All animal activities

Notes: If there is no year specified, the crops benefiting are the same for the three years (2007, 2008 and 2009). CACT: all the activities defined.

Table A 7. Key for allocating input costs developed by DG-AGRI

Cost item	IFM-CAP code	FADN code	Allocation key
Seeds and seedlings	SEED	SE290 (home-gown) + F72 (purchased)	Output of the crop analysed/Output of arable crops ([1])
Fertiliser	NITF	SE295	Output of the crop analysed/Output of crops and crop products ([1])
Crop protection	PLAP	SE300	Output of the crop analysed/Output of crops and crop products ([1])
Other crop specific costs	CSPE	SE305	Output of the crop analysed/Output of crops and crop products ([1])

([1]) In the event that the typology of the farm is classified as 'Mixed grazing' or 'Pure grazing', this ratio is multiplied by (1 – SE206/SE131), therefore (1 – Total output of livestock and livestock product/Total output). This ratio is used in the first stage of the model prototype, as it models only crop farms (with no livestock), and therefore it is assumed that the farms classified as 'Mixed grazing' and 'Pure grazing' have specific costs associated with the crop sector that at a later stage will be accounted for in the livestock sector. This classification is based on the variable SE120N (Grazing livestock) and KFORAA (Area of forage crops) and on the ratios between KFORTP (Total production of forage crops), KFORSA (Sales of forage crops) and KFORFU (Forage farm use).

Source: Authors' own elaboration.

Table A 8. Average estimated input costs per hectare for two selected regions

FR260000 (Bourgogne)				
Input	**Crops**	**Prior**	**Estimate**	**% dev.**
Fertiliser	DWHE	427.2	215.0	–49.7
	BARL	226.8	202.8	–10.6
	OATS	191.1	125.3	–34.4
	MAIZ	273.2	254.8	–6.7
	OCER	357.1	281.7	–21.1
	NURS	287.0	271.2	–5.5
	OCRO	3 504.5	1 780.8	–49.2
	MAIF	1 145.5	39.8	–96.5
	ROOF	367.8	73.2	–80.1
	OFAR	977.6	27.9	–97.1
	OFRU	260.9	604.8	131.8
Seeds	SWHE	75.2	64.3	–14.4
	DWHE	176.7	217.0	22.8
	RYEM	56.3	57.8	2.6
	BARL	62.3	36.5	–41.4
	OATS	50.5	45.4	–10.1
	MAIZ	108.6	104.8	–3.6
	OCER	88.7	68.2	–23.2
	RAPE	62.4	42.1	–32.5
	SUNF	54.0	59.8	10.7
	SOYA	83.2	89.1	7.1
	OOIL	71.0	63.9	–10.0
	OIND	83.4	98.1	17.6
	NURS	853.9	788.1	–7.7
	OCRO	9 399.0	4 234.4	–54.9
	MAIF	693.2	90.4	–87.0
	ROOF	112.5	34.7	–69.2
	OFAR	396.6	9.0	–97.7
	PULS	39.9	48.0	20.2
	POTA	529.4	1 052.1	98.7
	SUGB	134.6	182.0	35.3
	OVEG	0.1	0.4	206.0
	NONF	55.1	56.9	3.2
Plant Protection	DWHE	220.4	188.8	–14.3
	BARL	128.0	116.1	–9.3
	OATS	91.6	87.8	–4.2
	MAIZ	172.3	142.8	–17.1
	OCER	95.9	69.4	–27.6
	NURS	338.2	275.2	–18.6
	OCRO	309.4	376.3	21.6
	MAIF	610.1	51.5	–91.6
	ROOF	194.9	25.1	–87.1
	OFAR	438.4	14.4	–96.7
	OFRU	290.2	602.3	107.6

ES610000 (Andalucía)				
Input	**Crops**	**Prior**	**Estimate**	**% dev.**
Fertiliser	DWHE	74	77	4
	BARL	18	16	–10
	OATS	23	20	–13
	MAIZ	202	229	13
	OCER	53	53	0
	OCRO	16 547	16 516	0
	MAIF	293	351	20
	OFAR	31	81	159
	OFRU	746	409	–45
	CITR	0	289	-
Seeds	SWHE	283	250	–12
	DWHE	62	58	–7
	RYEM	17	21	27
	BARL	21	15	–27
	OATS	17	9	–45
	MAIZ	179	201	12
	OCER	42	47	12
	RAPE	22	25	10
	SUNF	58	51	–11
	OIND	391	327	–16
	OCRO	114 965	115 067	0
	MAIF	88	152	71
	OFAR	49	39	–19
	PARI	127	121	–4
	PULS	91	25	–72
	POTA	626	2 036	225
	SUGB	209	236	13
	TEXT	104	96	–7
	TOMA	1 995	2 005	0
Plant Protection	DWHE	54	40	–26
	BARL	11	8	–25
	OATS	9	6	–32
	MAIZ	131	112	–14
	OCER	44	39	–12
	OCRO	2 125	2 104	–1
	MAIF	99	100	0
	OFAR	35	32	–7
	OFRU	690	533	–23
	CITR	0	196	-

Table A 9. Average estimated input costs per hectare for two selected regions (continued)

FR260000 (Bourgogne)				
	Crops	**Prior**	**Estimate**	**% dev.**
Other specific costs	SWHE	21.6	13.0	−39.6
	BARL	17.2	9.8	−43.0
	OATS	21.1	37.2	75.8
	MAIZ	7.6	2.2	−71.2
	OCER	13.6	6.3	−53.7
	RAPE	7.6	5.8	−23.9
	SUNF	10.7	12.6	17.2
	OIND	11.7	9.5	−18.5
	OCRO	10 550.7	16 409.4	55.5
	MAIF	495.9	14.2	−97.1
	OFAR	352.3	1.5	−99.6
	POTA	29.8	12.8	−57.2
	SUGB	37.0	15.7	−57.5
	OVEG	0.0	117.6	–
	OFRU	90.4	290.6	221.6
	NONF	0.2	0.1	−35.9

ES610000 (Andalucía)				
	Crops	**Prior**	**Estimate**	**% dev.**
Other specific costs	SWHE	166	215	29
	DWHE	12	19	61
	BARL	7	1	−84
	OATS	4	4	−3
	MAIZ	11	5	−51
	OCER	9	11	18
	RAPE	5	14	184
	SUNF	6	11	88
	OCRO	35 225	35 223	0
	PARI	29	28	−5
	OLIV	36	8	−78
	PULS	3	5	55
	POTA	89	1 565	1 652
	SUGB	30	26	−13
	TEXT	15	17	10
	TOMA	1 585	1 647	4
	OVEG	0	4 421	–
	OFRU	910	738	−19
	CITR	0	125	–
	TABO	16	14	−17

Table A 10. Minimum and maximum feed thresholds

Activity	Feed group	Minimum threshold (%)	Maximum threshold (%)
NRUMI	FODDI		0
SOWS	FMAI		0.1
PIGF	FMAI		0.1
RUMI	FPRO		0.3
NRUMI	FPRO		0.2
NRUMI	FCER		0.6
DCOW, BULF, CALR, CALF	FCER	0.20	
HEIF, HEIR,SCOW	FCER	0.05	
OANI	FCER	0.50	
The rest of AACT	FCER	0.02	
DCOW, BULF, CALR, CALF	FPRO	0.10	
HEIF	FPRO	0.05	
The rest of AACT	FPRO	0.01	
AACT	FOTH	0.005	
SHGM	FOTH	0.001	
SHGF	FOTH	0.001	
SCOW	FOTH	0.001	
DCOW	FIRI	0.6	
SCOW	FIRI	0.9	
BULF	FIRI	0.5	
HEIF	FIRI	0.6	
CALR	FIRI	0.4	
CALF	FIRI	0.2	
SHGM	FIRI	0.8	
SHGF	FIRI	0.5	
RUMI	FSTR	0.01	0.05
SHGM, SHGF	Not FIRI		0.20
CALR, CALF	FMIL	0.05	
CALR, CALF	FCOM	0.10	
AACT	FCOM		0
ACATTLE	FCOM		0.01
AACT (except SHGF and SHGM)	FSGM		0
DCOW, SCOW	FCOM		0
CALF	FCOM		0.3
CALR	FCOM		1.0

Notes: FIRI = FOFA, FGRA, FMAI (used when there is GROF production on farm); AACT = all animal activities; ACATTLE = cattle activities; RUMI = ruminant activities; NRUMI = non-ruminant activities. For feed groups, see Table 8.

Table A 11. Yield of fodder crops

MS	MAIF	ROOF	GRAS	OFAR
BL	85.19	23.76	7.29	7.87
BG	12.82	7.29	7.24	10.44
CZ	35.96	22.85	8.49	13.52
DK	38.81	16.11	4.18	11.34
DE	45.67	45.67	7.24	8.15
EE	23.07	10.57	5.76	13.08
IR	33.87	23.76	7.24	10.44
EL	53.72	52.73	7.24	10.09
ES	42.69	18.03	7.24	13.11
FR	12.68	8.15	4.55	7.88
IT	51.87	24.42	6.62	28.51
CY	47.67	23.71	7.24	12.50
LV	21.71	12.41	4.40	11.78
LT	20.90	79.48	12.59	13.65
BL	17.25	17.25	8.65	9.69
HU	24.29	17.19	7.24	3.35
MT	33.87	7.07	7.24	10.44
NL	46.12	46.12	11.72	13.46
AT	47.49	60.86	3.20	6.80
PL	44.55	31.23	23.42	23.09
PT	33.87	23.76	7.24	10.44
RO	19.50	11.24	7.48	2.77
SI	33.87	23.76	7.24	10.44
SK	25.52	18.61	1.86	3.33
FI	33.87	23.76	7.24	9.15
SE	33.87	23.76	7.24	10.44
UK	40.03	32.72	7.24	10.44

Notes: OFAR = leguminous plants, clover, lucerne, other leguminous, temporary grazing and grasses; GRAS = permanent grasslands (pastures + meadows); ROOF = annual plants harvested green, other annual plants harvested green; MAIF = green maize.

Source: Eurostat.

Table A 12. Sugar/sugar beet information with EU coverage

Variable	Database	Scope
Sugar beet yield	FADN (derived)	Farm level
Sugar beet yield	FSS	MS level/NUTS 2 level
Sugar beet area	FADN	Farm level
Sugar beet area	FSS	MS level/NUTS 2 level
Sugar beet production	FSS	MS level/NUTS 2 level
Sugar beet specific cost	FADN (derived based on HPD estimator)	Farm level
Sugar quota	DG-AGRI	MS level
Sugar production	DG-AGRI	MS level

Table A 13. Sugar beet production, area and yields (FADN, FSS)

	Area (ha)			Production (tonnes)			Yield (tonnes/ha)		
MS	**FADN**	**FSS**	**% DIF**	**FADN**	**FSS**	**% DIF**	**FADN**	**FSS**	**% DIF**
AT	46 588	43 066	−8.2	3 249 684	2 943 566	−10.4	69.2	68.3	−1.3
BG	623	433	−44.0	7 243	5 466	−32.5	11.7	12.5	7.0
BL	81 389	62 700	−29.8	5 730 903	5 209 700	−10.0	67.5	82.7	18.3
CZ	61 688	52 400	−17.7	3 266 299	2 937 566	−11.2	50.6	56.1	9.8
DE	411 852	385 200	−6.9	26 387 175	24 686 900	−6.9	63.6	64.1	0.8
DK	35 355	37 933	6.8	2 116 963	2 113 566	−0.2	51.9	55.8	7.0
EE	9	0		104	0		14.3		
EL	19 123	17 333	−10.3	1 328 934	1 206 266	−10.2	68.4	70.3	2.7
ES	118 150	56 766	**−108.1**	8 847 800	4 435 366	**−99.5**	79.5	78.9	−0.8
FI	22 797	14 800	**−54.0**	931 365	566 700	**−64.3**	39.0	38.1	−2.3
FR	362 045	371 800	2.6	31 983 892	32 810 666	2.5	85.3	88.3	3.4
HU	19 283	21 533	10.4	910 041	1 001 000	9.1	41.9	51.4	18.4
IR	658	1 000	34.2	38 469	45 000	14.5	61.2	45.0	−36.0
IT	81 845	69 333	−18.0	4 428 203	4 109 200	−7.8	52.8	59.9	11.8
LT	13 168	13 566	2.9	636 262	607 000	−4.8	43.9	43.8	−0.3
LV	19	150	**86.9**	817	5 550	**85.3**	41.5	37.0	−12.2
NL	78 362	75 666	−3.6	6 186 516	5 488 333	−12.7	84.4	72.8	−16.0
PL	232 473	211 600	−9.9	12 161 980	10 748 633	−13.1	50.1	50.7	1.2
PT	1 704	1 533	−11.2	116 101	131 733	11.9	65.3	73.9	11.6
RO	77 076	23 466	**−228.4**	2 894 068	757 433	**−282.1**	31.3	33.0	5.3
SE	59 190	39 100	**−51.4**	3 237 760	2 172 800	**−49.0**	53.1	55.5	4.5
SI	9			616			63.9		
SK	16 070	15 300	−5.0	889 717	808 066	−10.1	49.5	54.2	8.7
UK	213 153	119 566	**−78.3**	13 156 155	7 610 333	**−72.9**	57.2	64.0	10.6
EU			−24.6			−26.1			2.4

(*) The values are highlighted in bold when the differences are greater than ±50%.

Annex B: Animal feed requirement functions in IFM-CAP

This annex presents the functions used in IFM-CAP to determine the nutrient requirement by animal category. These requirement functions are based on CAPRI (Britz and Witzke, 2012; IPCC, 2006; Nasuelli et al., 1997).

1. DAIRY COWS (DCOW) and SUCKLER COWS (SCOW)

The dry matter requirements for cows include minimum dry matter for lactation per year (*DRMN*) and maximum dry matter (*DRMX*):

$$DRMN_i = 305(0.0185\,LW_i + 0.305\,MC_i) + 60(0.0185\,LW_i)$$
$$DRMX_i = DRMN_i * 1.2$$

The energy requirements of cows are expressed as net energy for each of the main biological functions of the animal including lactation, maintenance, activity, pregnancy, and growth: net energy lactation (*NEL*); net energy maintenance (*NEM*); net energy activity (*NEA*); net energy pregnancy (*NEP*); and net energy for growth (*NEG*).

$$NEL_i = (0.4MC_i + 1.47)MPD_i LP_i$$
$$NEM_i = 0.17(0.386\,LW_i^{0.75})365$$
$$NEA_i = 0.17(0.386\,LW_i^{0.75})365 \quad \textit{if there is grassland on the farm,}$$
$$\textit{otherwise } NEA_i = 0$$
$$NEP_{DCOW} = (LW^{0.75} * 0.386) * 0.10 * 365$$
$$NEP_{SCOW} = (LW^{0.75} * 0.386) * 0.10 * CALV_{SC} / 1\,000$$

The total net energy (*ENNE*) is the sum of the above energy components:

$$ENNE_i = NEL_i + NEM_i + NEA_i + NEP_i$$

The crude protein requirement (*CRPR*) is calculated as follows:

$$CRPR_{DCOW} = \frac{14\,MC_{DCOW} + 28}{1\,000} MPD_{DCOW} LP_{DCOW} + \frac{117 + 0.6LW_{DCOW}}{1\,000} 365 + 1\,300 \cdot 42$$
$$CRPR_{SCOW} = \frac{14\,MC_{DCOW} + 28}{1\,000} MPD_{DCOW} LP_{DCOW} + \frac{1.27 + LW_{DCOW} + 127.3}{1\,000} 365 + 1\,300 \cdot 42$$

The requirements for fibre digestibility (*FIDI*), maximum fibre (*FICO*) and fibre long (*FILG*) are:

$$FIDI_i = DRMN_i(MC_i / 100 - 0.29 + 43.92 / 100)$$
$$FIDI_i = 0.7(0.14\,LW_i^{0.75})365$$
$$FILG_i = FIDI_i / 3$$

Where

Subscripts *DCOW*, *SCOW* stand for dairy cow and suckler cow, respectively, *i* = *DCOW*, *SCOW*; $CALC_{SG}$ (calves per cow); *MC* is adjusted milk production per day corrected by milk fat content (*MF*). *MF* is assumed to be 4 %. *MC* depends on the milk production per day (*MPD*), which it is derived from FADN; *COMI* and *COMF* is milk production for feeding and milk production (not for feeding), respectively, for suckler/dairy cows derived from FADN (in kg/day). The rearing period (*PD*) is 365 days (Table B 1), of which the duration of lactation (*LP*) is assumed to be 305 days for dairy cows and 125 days for suckler cows. The mean live weight (*LW*) is 600 kg and 550 kg for dairy cows and suckler cows, respectively.

$$MC_i = MPD_i (0.4 + 0.15 MF_i)$$
$$MPD_i = (COMI_{DCOW/SCOW} + COMF_{DCOW})/125$$

3. FATTENING OF CALVES (CAMF/CAFF)

Fattening of male calves (*CAMF*) and female (*CAFF*) is split in two categories: (*a*) light calves with final live weight less than 150 kg; and (*b*) heavy calves with final live weight greater than 150 kg. Heavy calves are further split into two phases: (*b1*) weight between 50 kg and 150 kg; and (*b2*) weight from 150 kg to final weight.

$$NEG_a = NEG_{b1} = NEG_{a/b1} = 22.02\left(\frac{LW_{a/b1}}{CGH} WF\right)^{0.75} DAILY^{1.097} FD_{a/b1}$$
$$NEG_{b2} = NEG_{b1} + 22.02\left(\frac{LW_{b2}}{CGH} WF\right)^{0.75} DAILY^{1.097} FD_{b2}$$
$$NEM_{a/b1} = 0.322\, LW_{a/b1}^{0.75} FD_{a/b1}; \qquad NEM_{b2} = NEM_{b1} + 0.322\, LW_{b2}^{0.75} FD_{b1}$$
$$NEA_{a/b1} = 0.17(0.322\, LW_{a/b1}^{0.75}) FD_{a/b1} \text{ if there is grassland on the farm,}$$
$$\text{otherwise } NEA_{a/b1} = 0$$
$$NEA_{b2} = NEA_{b1} + 0.17(0.322\, LW_{b2}^{0.75}) FD_{b2} \text{ if there is grassland on the farm,}$$
$$\text{otherwise } NEA_{b2} = 0$$
$$ENNE_i = NEG_{b2} + NEM_{b2} + NEA_{b2}$$

The minimum dry matter (*DRMN*), maximum dry matter (*DRMX*), crude protein requirements (*CRPR*) and fibre cattle (*FICT*) are calculated as follows:

$$DRMN_{a/b1} = 0.9(0.0271\, LW_{a/b1} - 0.433) FD_{a/b1}$$
$$DRMN_{b2} = DRMN_{b1} + 0.9(2.433 + 0.0166\, LW_{b2} + 0.0002\, DAILY) FD_{b2}$$
$$DRMN_i = DRMN_{b2}$$
$$DRMX_i = 1.5 * DRMN_i$$

$$CRPR_{a/b1} = (-0.00039\, LW_{a/b1} + 0.000628\, DAILY\, 1\,000 - 0.0193) FD_{a/b1}$$
$$CRPR_{b2} = CRPR_{b1} + (-0.00109\, LW_{b2} + 0.00022\, DAILY\, 1\,000 - 0.2027) FD_{b2}$$

$$CRPR_i = CRPR_{b2}$$
$$FICT_i = DRMX_i$$

Where:

Subscripts *a*, *b1* and *b2* stand for light calves with final live weight less than 150 kg, heavy calves weighing between 50 kg and 150 kg and heavy calves weighing from 150 kg to final weight, respectively; subscript *a*/*b1* implies that a given equation is valid for calves of category *a* and *b1* with corresponding consistency in parameters between the left-hand side and the right-hand side of the equation; *i* = *CAMF*, *CAFF*; *DAILY* is daily growth increase (kg/day) for *CAMF* and *CAFF* (Table B 1); *SW* is calf start weight (SW_i = 50); *BEEF* is beef production in kg/head ([41]), *CW* is percentage carcass proportion for *CAMF* and *CAFF* (*CW* = 0.6) (Table B 2); *CGH* is the coefficient parameter for calculation of energy for growth and is 1 and 0.8 for male and female calves, respectively (Table B 2); *WF* is average live weight of adult females in moderate body condition (assumed to be 550 kg).

The production days (*PD*), fattening days (*FD*) and live weights (*LW*) are given as follows:

$$PD_i = \frac{BEEF_i}{CW} - \frac{SW}{DAILY};$$

$$FD_a = PD_a; \qquad FD_{b1} = \frac{100}{DAILY}; \; FD_{b2} = \frac{PD_{b2} \cdot DAILY - 100}{DAILY}$$

$$LW_a = SW + \frac{PD \cdot DAILY}{2}; \qquad LW_{b1} = 100; \quad LW_{b2} = 150 + \frac{PD_{b2} \cdot DAILY - 100}{2}$$

4. RAISING OF CALVES (CAMR/CAFR)

Raising of male (*CAMR*) and female (*CAFR*) calves is split into three phases: (*p1*) first 49 days (between 50 kg and 80 kg live weight); (*p2*) next 125 days (between 80 kg and 150 kg); and (*p3*) the final phase (between 151 kg and 300 kg for heifers and 335 kg for males). The total rearing period for calves (*DAYS*) is assumed to be 353 days (Table B 1), resulting in 353 – 49 – 125 = 179 days for the last phase:

$$NEL_{p1} = 11.79 \cdot 0.1 - 49\frac{(2+2+5+6+7+8)}{7}; \; NEL_{p2} = NEL_{p3} = NEL_{p1}$$

$$NEG_{p2} = 22.02(LW_{p2} / CGH \cdot SW)^{0.75} * DAILY_{p2}^{1.097} + FD_{p2}$$

$$NEG_{p3} = NEG_{p2} + 22.02(LW_{p3} / CGW \cdot WF)^{0.75} DAILY_{p3}^{1.097} + FD_{p3}$$

$$NEM_{p2} = 0.322 LW_{p2}^{0.75} FD_{p2}$$

$$NEM_{p3} = NEM_{p2} + 0.322 LW_{p3}^{0.75} FD_{p3}$$

$NEA_{p3} = 0.17(0.322 LW_{p3}^{0.75}) FD_{p3}$ *if there is grassland on the farm,*

([41]) (23SN)/(23AV) × CW, where 23SN and 23AV are the number of sold and average calves derived from FADN.

$otherwise\ NEA_{p3} = 0$

$$ENNE_i = NEL_{p3} + NEG_{p3} + NEM_{p3} + NEA_{p3}$$

$$CRPR_{p1} = 0.35 \cdot 0.1 - 49 \frac{(2+2+5+6+7+8)}{7}$$

$$CRPR_{p2} = CRPR_{p1} + (-0.00039\ LW_{p2} + 0.000628\ DAILY_{p2} 1\,000 - 0.0193) FD_{p2}$$

$$CRPR_{p3} = CRPR_{p2} + (0.00109\ LW_{p3} + 0.00022\ DAILY_{p3} 1\,000 - 0.2027) FD_{p3}$$

$$CRPR_i = CRPR_{p3}$$

$$DRMN_{p1} = 0.93 * 0.1 - 49 \frac{(2+2+5+6+7+8)}{7}$$

$$DRMN_{p2} = DRMN_{p1} + 0.9(0.0271\, LW_{p2} - 0.433) FD_{p2}$$

$$DRMN_i = DRMN_{p3} = DRMN_{p2} + 0.9(2.433 + 0.0116\, LW_{p3} + 0.0002\ DAILY_{p3}) FD_{p3}$$

$$DRMX_i = 1.5 * DRMN_i$$

$$FICT_i = DRMX_i$$

Where:

$LW_{p2} = (80 + 150)/2$;

$DAILY_{p2} = (150 - 80)/125$;

$FD_{p2} = (150 - 80)/DAILY_{p2}$;

$LW_{p3} = 150 + (DAILY_{p3} FD_{p3})/2$

$DAILY_{p3} = (SW - 150)/FD_{p3}$

$FD_{p3} = DAYS_{p3} - 49 - 125$

$PD_{p3} = 49 + 125 + FD_{p3}$

Subscripts *p1, p2* and *p3* stand for the three phases of the calf-rearing process; *i* = *CAMR*, *CAFR*; $DAYS_{p3}$ = 179 days *CAMR* and *CAFR*; *CGH* is the coefficient parameter for calculation of energy for growth and is 1 and 0.8 for male and female male rearing calves, respectively (Table B 2); *SW* is the start live weight for the next stage of the fattening process (or the finishing weight for the calf-rearing process). The *SW* values for adult fattening cattle (i.e. the finishing weight of male rearing calves) is 335 kg and for heifers fattening cattle (i.e. the finishing weight of female rearing calves) is 300 kg (Table B 2). These values are used to calculate the daily growth in phase *p3*.

5. MALE ADULT CATTLE FATTENING (BULF)

$$NEG_i = 22.02 \left(\frac{LW_i}{CGW_i} WF \right)^{0.75} DAILY_i^{1.0977} FD_i$$

$$NEM_i = 0.370\, LW_i^{0.75} FD_i$$

$$NEA_i = 0.370\, LW_i^{0.75}\, 0.17\, FD_i \ \textit{if there is grassland on farm, otherwise}\ \ NEA_i = 0$$

$$ENNE_i = NEG_i + NEM_i + NEA_i$$

The requirements for *DRMN*, *CRPR* and *FICT* depend on the daily weight increase of male cattle:

$$DRMN_i = 0.8[(0.029 - 0.00001914\ LW_i)LW_i FD_i] \quad \text{if } DAILY < 1.1 \text{ kg}$$
$$DRMN_i = 0.8[(0.028 - 0.00001678\ LW_i)LW_i FD_i] \quad \text{if } 1.1 \text{ kg} < DAILY < 1.3 \text{ kg}$$
$$DRMN_i = 0.8[(0.0288 - 0.0000231\ LW_i)LW_i FD_i] \quad \text{if } DAILY > 1.3 \text{ kg}$$
$$DRMX_i = 1.5 DRMN_i$$

$$CRPR_i = (0.1602 - 0.0001228\ LW_i)DRMN_i \quad \text{if } DAILY < 1.1 \text{ kg}$$
$$CRPR_i = (0.1657 - 0.0001214\ LW_i)DRMN_i \quad \text{if } 1.1 \text{ kg} < DAILY < 1.3 \text{ kg}$$
$$CRPR_i = (0.1493 - 0.0004405\ LW_i)DRMN_i \quad \text{if } DAILY > 1.3 \text{ kg}$$

$$FICT_i = DRMX_i$$

Where

$$DAILY_i = 0.4 + 0.0016\ \frac{BEEF_i}{CW_i}$$ or $DAILY_i$ from Table B 1 (minimum value of the two)

$$FD_i = \frac{BEEF_i / CW_i - SW_i}{DAILY_i}$$

$$LW_i = SW_i + \frac{FD_i DAILY_i}{2}$$

$i = BULF$; $CW = 0.555$, $SW = 335$ kg (Table B 2); $PD_i = FD_i$. *WF* is the average live weight of an adult female in moderate body condition (assumed to be 550 kg); BEEF is beef meat production per animal ([42]) .

6. HEIFERS FOR MEAT (HEIF) and HEIFERS FOR BREEDING (HEIR)

HEIF heifers for meat and *HEIR* heifers for breeding:

$$NEG_{HEIF} = 22.02(LW_{HEIF} / CGH_{HEIF} WF)^{0.75} DAILY_{HEIF}^{1.097} + FD_{HEIF}$$
$$NEG_{HEIR} = 22.02(LW_{HEIR} / CGH_{HEIR} WF)^{0.75} DAILY_{HEIR}^{1.097} + 365$$
$$NEM_i = 0.322\, LW_i^{0.75} FD_i$$
$$NEA_i = 0.370\, LW_i^{0.75}\, 0.17\, FD_i$$ *if there is grassland on the farm, otherwise* $NEA_i = 0$
$$ENNE_i = NEG_i + NEM_i + NEA_i$$

$$DRMN_{HEIF} = [(0.029 - 0.00001914\ LW_{HEIF})LW_{HEIF} FD_{HEIF}]0.9$$
$$DRMN_{HEIR} = 0.9(1.777 - 0.0167\ LW_{HEIR})FD_{HEIR}$$

([42]) (25SN + 27SN)/(25AV + 27AV) × CW, where 25SN + 27SN and 25AV + 27AV are the number of sold and average bulls derived from FADN.

$$DRMX_i = 1.5 DRMN_i$$

$$CRPR_{HEIF} = (0.1602 - 0.0001228\ LW_{HEIF}) DRMN_{HEIF}$$
$$CRPR_{HEIR} = (0.00127\ LW_{HEIR} + 0.00024\ DAILY_{HEIR} 1\,000 + 1.1273) FD_{HEIR}$$

$$FICT_i = DRMX_i$$

Where

$$FD_{HEIF} = (BEEF / CW_{HEIF} - SW) / DAILY_{HEIF};\ FD_{HEIR} = 517$$
$$LW_{HEIF} = SW + \frac{(FD_{HEIF} DAILY_{HEIF})}{2};$$
$$LW_{HEIR} = \left(SW + \frac{600\,DCOW + 550\,SCOW}{DCOW + SCOW} \right) / 2$$

$$DAILY_{HEIF} = 0.8; \qquad DAILY_{HEIR} = (LW_{HEIR} - SW) / FD_{HEIR}$$

i = *HEIF*, *HEIR*; *BEEF* is beef meat production per animal (43); CW_{HEIF} = 0.55; *SW* = 300 kg; *DCOW* is number of dairy cows; *SCOW* is number of suckler cows; *CGH* = 0.8 (Table B 2); *WF* = 550 kg; *PD* = *FD*.

8. SOWS (SOWS)

$$ENMP_{SOWS} = (8\,219.75 + 3\,703.2 + YPIG_{SOWS} * 404.75) * k_{ENMP}$$
$$CRPR_{SOWS} = 101.71 + 46.5 + 5.7 YPIG_{SOWS}$$
$$DRMA_{SOWS} = 610.35 + 261 + 26.1 YPIG_{SOWS}$$
$$DRMN_{SOWS} = ENMP_{SOWS} / 14.82$$
$$DRMX_{SOWS} = ENMP_{SOWS} / 13.47$$
$$LISI_{SOWS} = 0.610 + 0.372 + 0.074 YPIG_{SOWS}$$

Where

ENMP is metabolisable energy for pigs; *YPIG* is number of piglets per sow derived from FADN (expressed in heads per 1 000 heads*)*; k_{ENMP} is the unit conversion factor for energy requirements (Table B 3); *PD* = 365 days.

9. FATTENING OF PIGS (PIGF)

Nutrients for fattening pigs are calculated by adding up the nutrient requirements over the growth period of pigs from the start weight (*SW*) up to the final live weight (*FLW*). The value of the nutrient requirements distinguishes between two types of pigs: light pigs with a final weight of 115 kg and heavy pigs with a final weight of 170 kg:

(43) (29SN)/(29AV)*CW, where 29SN and 29AV are the number of sold and average heifers for fattening derived from FADN respectively.

$$REQ_{PIGF} = \sum_{SW}^{FLW} REQ_{WP}$$

Where

$$FLW_{PIGF} = PORK_{PIGF} / CW_{PIGF}$$
$$SW_{PIGF} = 20$$

REQ_{PIGF} = *ENMP ,CRPR, LISI, DRMA, DRMN, DRMX*; *CW* = 0.78; REQ_{WP} is the value of a given nutrient for the live weight category of pig with live weight *WP,* which is in the interval between *SW* and *FLW*. The values of REQ_{WP} are reported in Table B 4, PORK is pork meat production ([44]) .

10. LAYING HENS (HENS)

$$ENMC_{HENS} = 365(0.46 LW_{HENS} + 0.57 EGGY_{HENS}) 1\,000\, k_{ENMC}$$
$$DRMA_{HENS} = ENMC_{HENS} / 12$$
$$DRMN_{HENS} = ENMC_{HENS} / 15$$
$$DRMX_{HENS} = ENMC_{HENS} / 8$$
$$CRPR_{HENS} = 0.14 \frac{ENMC_{HENS}}{11.1}$$
$$LISI_{HENS} = 0.0095\, EGGS_{HENS} + 1.9 \cdot 60$$

Where

$$EGGY_{HENS} = \frac{EGGS_{HENS} / 57}{365} \quad \mathrm{EGGY} = (\frac{\mathrm{EGGS}}{57})/365$$

ENMC is metabolisable energy for chickens; *EGGY* is number of eggs per laying hen per day assuming an average egg weight of 57 g and 365 production days; *EGGS* is egg production (in kg/1 000 head); k_{ENMC} is the unit conversion factor for energy requirements (Table B 3).

11. POULTRY (POUF)

$$DRMA_{POUF} = 1.6463 [(2 LW_{POUF})^{1.3023} 0.87] 1\,000$$
$$DRMN_{POUF} = 0.8 DRMA_{POUF}$$
$$DRMX_{POUF} = 1.2 DRMA_{POUF}$$
$$CRPR_{POUF} = (0.23 - 0.04 LW_{POUF} - 0.5) \frac{DRMA_{POUF}}{0.87} \quad \mathrm{CRPR} = \mathrm{DRMA} * 0.23/0.87$$
$$ENMC_{POUF} = 12.392 \frac{DRMA_{POUF}}{0.89} k_{ENMC}$$

([44]) (45SN + 46SN)/(45AV + 46AV) × CW, where 45SN + 46SN and 45AV + 46AV are the number of pigs sold and the average number of fattening pigs derived from FADN.

$$LISI_{POUF} = 0.011 CRPR_{POUF}$$

Where

$$LW = MAX\left(0.5\frac{POUM\ /1\,000}{CW};0.25\right)$$

$$PD = \left[\frac{MAX((POUM/1\,000)/CW),0.5)}{DAILY/1\,000}\right]$$

POUM is poultry meat per 1 000 animals ([45]), *CW*= 0.8 (Table B 2).

12. EWES AND GOATS FOR MILK (SHGM)

First, nutrient requirements are calculated for ewes (*EWES*) and goats (*GOAT*) separately, then the nutrient requirements for combined sheep and goat activity (*SHGM*) are obtained as the weighted average of *EWES* and *GOAT*.

12.1 Nutrient requirements for EWES and GOAT

$$NEM_i = 0.217\, LW_i^{0.75}\, 0.107\, PD_i$$

$NEA_i = 0.0107\, LW_i\ PD_i$ *if there is grassland on the farm,*

otherwise $NEA_i = 0.009\, LW_i\ PD_i$

$$NEL_i = 4.6 MPD_i 170$$

$$ENNE_i = NEM_i + NEA_i + NEL_i$$

$$\begin{aligned} CRPR_{\mathrm{EWES}} &= 135(0.026 + 0.0014\, LW_{\mathrm{EWES}}) \\ &+ 170(0.0634 + 0.0012\, LW_{\mathrm{EWES}} + 0.0895\, MPD_{\mathrm{EWES}}) \\ &+ [1.35(2.22 LW_{\mathrm{EWES}} - 19.88)60]/1000 \end{aligned}$$

$$\begin{aligned} CRPR_{GOAT} &= 305(12.66 + 0.8 LW_{GOAT}) \\ &+ 61 MPD_{GOAT} 170 + 60(1.425\, LW_{GOAT} + 14.666)/1000 \end{aligned}$$

$$\begin{aligned} DRMN_{\mathrm{EWES}} &= 135(0.36 + 0.023\, LW_{\mathrm{EWES}}) + 170(1.112 + 0.0187\, LW_{\mathrm{EWES}} + 0.279\, MPD_{\mathrm{EWES}}) \\ &+ 60(0.0268\, LW_{\mathrm{EWES}} - 0.24) \end{aligned}$$

$$DRMN_{GOAT} = 305(0.55 + 0.013\, LW_{GOAT}) + 0.3 MPD_{GOAT} 170 + 60(0.0122\, LW_{GOAT} + 0.5316)$$

Where

$$MPD_i = \frac{SGMI_i + SGMF_i}{170}$$

([45]) (47SN + 49SN)/(47AV + 49AV) × CW, where 47SN + 49SN and 47AV + 49AV are the number of poultry sold and the average number of poultry derived from FADN.

i = EWES, GOAT; *MPD* is sheep/goat milk production per day. The assumptions are: 170 milk production days; 135 days only maintenance; and 60 days of final mating. *SGMI* is milk production per sheep/goat; *SGMF* and SGMI are milk production for feeding and milk production (not for feeding), respectively, for sheep and goats derived from FADN (in kg/day); PD_i = 365; LW_{EWES} = 55; LW_{GOAT} = 60.

12.2 Nutrient requirements for sheep and goat activity (SHGM)

$$REQ_{SHGM} = sh_{EWES} REQ_{EWES} + sh_{GOAT} REQ_{GOAT}$$
$$DRMX_{SHGM} = 1.5 DRMN_{SHGM}$$
$$FISM_{SHGM} = 120 \frac{LW_{SHGM}^{0.75}}{1000} 365$$

Where

$$LW_{SHGM} = sh_{EWES} LW_{EWES} + sh_{GOAT} LW_{GOAT}$$

REQ = *ENNE*, *CRPR*, *DRMN*; *FISM* is fibre for sheep and goat; sh_{EWES} and sh_{GOAT} are the proportions of ewes and goats, respectively, in the total herd size derived from FADN.

<u>13. SHEEP AND GOATS FATTENING (SHGF)</u>

$$ENNE_{SHGF} = (0.1596\, LW_{SHGF} + 0.0303\, DAILY_{SHGF} - 0.56)(1 - 0.2) FD_{SHGF} k_{ENMR}$$
$$CRPR_{SHGF} = [(21.778 + 0.33 LW_{SHGF}) + 0.258\, DAILY_{SHGF} 1.35 FD_{SHGF} 1\,000\,]/1\,000$$
$$DRMN_{SHGF} = (0.038286\ LW_{SHGF} + 0.06381\,) FD_{SHGF}$$
$$DRMX_{SHGF} = 1.5 DRMN_{SHGF}$$
$$FISF_{SHGF} = 0.075 * LW_{SHGF}^{0.75} * FD_{SHGF}$$

Where

$$FD_{SHGF} = Min\left[320; Max\left(45; \frac{SGMT_{SHGF} / CW_{SHGF}}{DAILY_{SHGF}}\right)\right]$$
$$LW = \frac{Max[8; Min(25; SGMT_{SHGF})] / CW_{SHGF}}{2}$$

SGMT is meat production per animal ([46]); *CW* = 0.6; *DAILY* = 0.250 kg; k_{ENMR} is the conversion factor for metabolisable energy ruminants (*ENMR*) (Table B 1, Table B 2 Table B 3).

([46]) (39SN + 41SN)/(39AV + 41AV) × CW, where (39SN + 41SN) are the number of sheep and goats sold and (39AV + 41AV) are the average number of sheep and goats for fattening derived from FADN.

Table B 1. Rearing period and daily weight gain

Livestock activity	Rearing period (*DAYS*) (days)	Daily weight gain (*DAILY*) (kg/day)
HEIR	517	
CAMF	188	1.000
CAFF	188	1.000
CAMR	353	
CAFR	353	
PIGF	10	
SHGF	183	0.250
POUF	90	0.030
BULF	462	1.150
HEIF	370	0.800
DCOW	365	
SCOW	365	

Source: CAPRI

Table B 2. Carcass proportion, live start weight and coefficient of energy for growth

Livestock activity	Carcass to life weight (*CW*) (coeff. 0–1)	Live weight at start of fattening or raising process (*SW*) (kg)	Coefficient of energy for growth (*CGH*) (index)
BULF	0.555	335	1.2
HEIF	0.555	300	0.8
HEIR		300	0.8
CAMF	0.60	50	1.0
CAFF	0.60	50	0.8
CAMR		50	1.0
CAFR		50	0.8
SHGF	0.60	0	
POUF	0.80	0	
PIGF	0.78	20	
HENS	0.80		
SOWS	0.78		

Source: CAPRI

Table B 3. Conversion factors for energy requirements *(K_{ENMR}, K_{ENMC},K_{ENMH}, K_{ENMP})*

ENMR	ENMC	ENMH	ENMP
0.627	0.717	0.631	0.588

Source: CAPRI

Table B 4. Nutrient requirements for fattening pigs

Live weight (*WP*)	Fattening days (*FD*)	ENMP	CRPR	LISI	DRMA	DRMN	DRMX
Light pigs (final weight 115 kg)							
20.536–25.29	1–10	12.72	0.139	0.01	0.87	0.858	0.944
25.906–30.254	11–18	15.264	0.167	0.012	1.044	1.03	1.133
30.939–35.11	19–25	17.808	0.195	0.014	1.218	1.202	1.322
35.847–40.321	26–32	19.715	0.216	0.015	1.349	1.33	1.463
41.107–45.065	33–38	21.623	0.237	0.017	1.479	1.459	1.605
45.872–50.745	39–45	22.259	0.244	0.017	1.523	1.502	1.652
51.572–55.718	46–51	22.895	0.251	0.018	1.566	1.545	1.699
56.571–60.841	52–57	24.167	0.264	0.019	1.653	1.631	1.794
61.707–65.167	58–62	24.803	0.271	0.019	1.697	1.674	1.841
66.042–70.365	63–68	25.439	0.278	0.02	1.74	1.717	1.888
71.259–75.662	69–74	26.711	0.292	0.021	1.827	1.802	1.983
76.556–80.022	75–79	27.347	0.299	0.021	1.871	1.845	2.03
80.904–85.177	80–85	27.983	0.306	0.022	1.914	1.888	2.077
86.044–90.246	86–91	28.619	0.313	0.022	1.958	1.931	2.124
91.1–120.073	92–132	29.255	0.32	0.023	2.001	1.974	2.171
Heavy pigs (final weight 115 kg)							
20.44–25.34	1–12	12.72	0.14	0.01	0.87	0.86	0.94
25.91–35.55	13–30	19.08	0.21	0.01	1.31	1.29	1.42
36.18–45.47	31–46	22.26	0.24	0.02	1.52	1.5	1.65
46.13–55.35	47–61	25.44	0.28	0.02	1.74	1.72	1.89
56.09–65.47	62–75	30.53	0.33	0.02	2.09	2.06	2.27
66.22–75.1	76–88	33.07	0.32	0.02	2.26	2.23	2.45
75.88–85.69	89–102	35.62	0.34	0.02	2.44	2.4	2.64
86.44–95.3	103–115	36.89	0.35	0.02	2.52	2.49	2.74
96.05–105.42	116–129	38.16	0.37	0.02	2.61	2.57	2.83
106.14–115.26	130–143	39.43	0.38	0.02	2.7	2.66	2.93
115.96–159.53	145–216	40.7	0.39	0.02	2.78	2.75	3.02

Source: CAPRI

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