Economic impacts of CAP greening: application of an EU-wide individual farm model for CAP analysis (IFM-CAP)

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Abstract

This paper presents the EU-wide individual farm-level model (IFM-CAP) applied to assess the economic effects of CAP greening. IFM-CAP is a static positive programming model developed to capture the full heterogeneity of EU farms in terms of policy representation and impacts. Simulation results show that, although the proportions of farms and utilised agricultural area (UAA) subject to CAP greening are sizeable (55 per cent of all farms and 86 per cent of UAA) at EU-27 level, the reallocated area caused by CAP greening represents only 4.5 per cent of UAA. Farm income and total production both decrease by 1 and 0.9 per cent, respectively. In total, around 29 per cent of the farm population is affected by CAP greening in the EU-27.

Keywords: Common Agricultural Policy, CAP greening, farm model, positive mathematical programming model, EU, IFM-CAP

JEL classification: C55, Q12, Q18

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 farm-specific measures attempting to enhance the environmental performance of the EU agricultural sector. This became evident with the introduction of farm-specific decoupled direct payments (i.e. the Single Payment Scheme) in 2004. A particularly strong shift towards farm-specific policy instruments occurred with the adoption of the so-called greening measures in the 2013 CAP reform. CAP greening includes measures that are

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obligatory for farmers who wish to receive full direct payments (EU, 2013; Erjavec and Lovec, 2017).

The greening measures target land allocation at farm level with the aim of supporting ‘agricultural practices that are beneficial to the climate and the environment’. The eligibility and uptake of these measures depend largely on farm-specific characteristics (size, specialisation, location, etc.), posing challenges for policy evaluation and raising the need for new modelling tools. Most EU-wide models are aggregate models (based on farm typologies, regions, countries) that are not fully able to model policies targeted at farm level without imposing strong assumptions on farmers’ behaviour (Lansink and Peerlings, 1996; Gocht and Britz, 2011; Cantelaube et al., 2012). Farm-specific policies can be handled only by models that operate at the level of the individual farm to account for farm heterogeneity in terms of policy representation and impacts. The more local and farm-specific interventions are, the more important modelling at the individual farm level becomes (Buysse et al., 2007).

There is a growing literature attempting to quantify the socio-economic effects of CAP greening. However, farm-level empirical evidence is relatively limited. While a number of studies have opened up a debate on the effectiveness of greening measures (Matthews, 2012; Westhoek et al., 2013; Singh et al., 2014), the few available farm-level studies provide limited insights because they cover only selected Member States (MSs)/regions, specific agricultural sectors and/or a specific greening measure. For example, Solazzo et al. (2014), Cimino et al. (2015) and Vosough-Ahmadi et al. (2015) evaluated the effect of CAP greening on Italian tomato farms, Italian arable farms and Scottish beef and sheep farms, respectively. Heinrich (2012), Brown and Jones (2013), Czekaj et al. (2013), Mahy et al. (2015) and Solazzo and Pierangeli (2016) provide regional or country case studies on the impact of CAP greening in, respectively, Germany, North Cornwall (UK), Poland, Flanders and Northern Italy. None of these models allows for a comprehensive EU-wide analysis of CAP greening measures at farm level. To the best of our knowledge, only Van Zeijts et al. (2011) and Gocht et al. (2017) provide estimates of the EU-wide impact of CAP greening. Both these studies use the representative (average) farm model CAPRI (Common Agricultural Policy Regionalised Impact). Given that the implementation and impacts of CAP greening are very specific to individual farm characteristics (e.g. land use, farm size), these studies suffer from aggregation bias. The main reason for this situation and the lack of detailed empirical insights is with the computational complexity of solving an individual farm-level model at the scale of the EU. These types of models are also very data intensive (and this may not be available or easily accessible) as well as demanding in terms of parameterisation and calibration compared with representative farm models (e.g. Van Zeijts et al., 2011; Gocht et al., 2017).

This paper aims to contribute to the literature by extending the current modelling approaches in two respects. First, we present an EU-wide individual farm-level model, IFM-CAP (Individual Farm Model for Common Agricultural Policy Analysis), which (i) allows a flexible assessment of a wide
range of farm-specific policies; (ii) reflects the full heterogeneity of EU commercial farms in terms of policy representation and impacts; (iii) covers all main agricultural production activities in the EU; (iv) captures the behaviour of different farming systems; (v) employs econometric estimation to derive behavioural parameters for farms; and (vi) estimates the distributional impacts of policies across the farm population. Second, the model’s capability is illustrated with an analysis of the impacts of CAP greening for the EU-27.1

The paper is structured as follows: Section 2 describes the IFM-CAP model specification, calibration process and data processing. Section 3 presents the baseline and the CAP greening scenarios simulated in this paper. Section 4 analyses the results of the model application to CAP greening measures. Finally, Section 5 presents the main conclusions and policy implications.

2. The IFM-CAP model

2.1. Model specification and mathematical structure

IFM-CAP is a farm-level model designed for economic and environmental analysis of the European agricultural sector. Rather than providing forecasts or projections, the model aims to generate scenarios, or ‘what if’ analyses. It simulates how a given scenario, for example a change in prices, in farm resources or environmental and agricultural policy, might affect a set of performance indicators considered important to decision makers and stakeholders. Performance indicators include, for example, crop allocation, input use, crop and animal production, farm income, livestock density and CAP expenditures. In contrast with representative farm models, which estimate only average policy impacts, IFM-CAP can estimate both average and distributional effects of policies.

IFM-CAP is a static positive programming model applied to each individual farm (83,292 farms) in the Farm Accountancy Data Network (FADN) to guarantee the highest possible representativeness of the EU agricultural sector. It assumes that farmers maximise expected utility given yield levels, product prices and production subsidies, subject to resource endowments (arable land, grassland and feed) and policy constraints, such as CAP greening restrictions. Farmers’ expected utility is defined following the mean-variance (E-V) approach (Markowitz, 2014) with a constant absolute risk aversion (CARA) specification (Pratt, 1964). Following this approach, it is assumed that farmers select a production plan that minimises the variance in income caused by a set of stochastic variables for a given expected income level (Hazell and Norton, 1986).

The computational advantage of the E-V approach with a CARA specification was one of the main reasons for using it in the IFM-CAP framework. The resulting optimisation problem is still a quadratic programming problem, one for which the literature provides several solution methods. Utility

1 Croatia is not included in the analysis, as data are not available in the FADN database for this country for the period used for the model calibration (i.e. for 2012). Belgium and Luxembourg are combined into one entity.
functions with other theoretical properties often have expected values that are
difficult to evaluate numerically and higher order polynomials that might lead
to non-convex programming problems (Hazell and Norton, 1986).

Farmer’s expected income is defined as the sum of expected gross margins
minus a non-linear (quadratic) activity-specific function. The gross margin is
the total revenue from sales of agricultural products and direct payments
coupled and decoupled payments) minus the accounting variable costs of
production activities. Total revenue is calculated using expected prices and
yields assuming adaptive expectations (based on the previous three observa-
tions with declining weights). The accounting costs include the costs of
seeds, fertilisers and soil improvers, crop protection, feeding and other spe-
cific costs. The quadratic activity-specific function is a behavioural function
introduced to calibrate the farm model to an observed base-year situation, as
usually done in positive programming models. This function intends to cap-
ture the effects of factors that are not explicitly included in the model, such
as farmers’ perceived costs of capital and labour, or model misspecifi-
cations (Paris and Howitt, 1998; Heckelei, 2002; Henry de Frahan et al., 2007).

Regarding income variance, most of the models in the literature incorpor-
ate uncertainty in the gross margin per unit of activity (see Cortignani and
Severini, 2009; Jansson et al., 2014) or in the revenues per unit of activity
(see Coyle, 1999; Paris and Arfini, 2000; Sckokai and Moro, 2006; Arata
et al., 2013; Petsakos and Rozakis, 2015). The former models assume that
prices, yields and costs are stochastic. The latter models either consider that
costs are non-random because they are assumed to be known when decisions
are made (Antle, 1983; Petsakos and Rozakis, 2015), or are less stochastic
than revenues from the farmer’s perspective. Thus, the variance in the gross
margin can be approximated by the variance in revenues (Jansson et al.,
2014). In the IFM-CAP framework, we opted for the second approach, con-
sidering uncertainty only in prices and yields (i.e. revenues) without differenti-
tiating between sources of uncertainty (Arribas et al., 2017).

An identical model structure was applied to all modelled FADN farms to
ensure uniformity (i.e. the same structure of equations and variables, but
farm-specific model parameters). No cross-farm constraints or relationships
were assumed in the current version of the model. The exception is in the
estimation phase of the behavioural function parameters (see Section 3), in
which all individual farms in each region are used to simultaneously estimate
these parameters.

The general mathematical formulation of the expected utility maximisation
problem of farm $f$ ($f = 1, 2, \ldots, F$) is as follows:

$$
\max_{x_{f,i} \geq 0} \ E (U)_f = \sum_i \ E [g_{m_{f,i}}] x_{f,i} + e_f t_{f} - \sum_i d_{f,i} x_{f,i} \\
- 0.5 \sum_{i,i'} x_{f,i} Q_{f,i,i'} x_{f,i'} - 0.5 q_f \sum_{f,t,i,i'} x_{f,i} x_{f,i'}
$$

subject to
\[ \sum_i A_{f,i,m} x_{f,i} \leq b_{f,m} [\rho_{f,m}] \] (2)

where indices \( i, i' = 1,2,\ldots, I \) denote the agricultural (crop and livestock) activities\(^2\); and \( m = 1,2,\ldots, M \) denote the resource and policy constraints (e.g. agricultural land, CAP greening restrictions and animal feeding). \( E(U)_f \) is the expected utility of farm \( f \) to be maximised, \( x_{f,i} \) is the non-negative level (i.e. hectares, heads) of activity \( i \), \( E[g_{mf,i}] \) denotes the expected gross margin for activity \( i \) (EUR/ha) (with \( g_{mf,i} = p_{f,i} y_{f,i} + s_{f,i} - \sum_k C_{f,i,k} \)), \( p_{f,i} \) denotes expected product prices (including for feed and young animals), \( y_{f,i} \) are expected yields, \( s_{f,i} \) are coupled payments, and \( k = 1,2,\ldots, K \) are intermediate inputs (i.e. fertiliser, seeds, crop protection, etc.), \( C_{f,i,k} \) are accounting variable costs for intermediate input \( k \) and activity \( i \), \( e_f \) are the decoupled payments, \( t_f \) is the eligible area for decoupled payments,\(^3\) \( d_{f,i} \) is the linear part of the behavioural activity function, \( Q_{f,i,i'} \) is the quadratic part of the behavioural activity function, \( \phi_f \) is the farmer’s CARA coefficient and \( \Sigma_{f,i,i'} \) is the farm-type symmetric, positive (semi-)definite matrix of the covariance activity revenues per hectare or per head. \( A_{f,i,m} \) are coefficients for resource and policy constraints (land, obligation set-aside, CAP greening restrictions and animal feeding), \( b_{f,m} \) are available resource levels and upper bounds to the policy constraints, and \( \rho_{f,m} \) are their corresponding shadow prices.

### 2.2. Model calibration

The aim of the calibration process is to ensure that the observed (crop and animal) activity levels during the base year are exactly reproduced by the optimal solution of the programming model. The process consists of recovering the set of unknown parameters \( (d, Q, \rho, \phi \text{ and } \Sigma) \) so that the optimisation model equations (1) and (2) replicates exactly the observed activity levels \( (x^0) \) during the base year (2012).

Over the previous decade, several positive mathematical programming (PMP) approaches have been developed to derive the parameters of the behavioural functions \( (d \text{ and } Q) \) and to accurately calibrate programming models.\(^4\) As the number of observations is usually not sufficient to allow traditional econometric estimation (an ‘ill-posed’ problem), most of the proposed approaches set all off-diagonal elements of \( Q \) to zero and calculate the remaining parameters using \textit{ad hoc} assumptions. To reduce arbitrary parameter specifications and estimate more reliable behavioural functions covering all the parameters, PMP models have either (i) used exogenous information

2 To simplify mathematical notations, we assume one product per activity so that indices for activity and product are identical.

3 The eligible area in MSs implementing the Single Payment Scheme is equal to the amount of the farm’s entitlements, whereas in MSs that implement the Single Area Payment System it is equal to the total agricultural area.

on supply elasticities (Mérel and Bucaram, 2010; Britz and Witzke, 2014) and/or on shadow prices of resources (Henry de Frahan et al., 2007) or (ii) estimated programming model parameters in an econometric sense using cross-sectional data (Heckelei and Wolff, 2003; Buysse et al., 2007; Artini et al., 2008; Garnache et al., 2017) or time series data (Jansson and Heckelei, 2011).

In this paper, we use both multiple observations (cross-sectional data) and prior information on (i) NUTS2\(^5\) supply elasticities \((\overline{\varepsilon}_r)\), (ii) dual values of constraints \((\rho_{f,m})\) and (iii) a farm-type covariance matrix of activity revenues \((\overline{\Sigma}_{ft,i,i})\) to calibrate the model to the 2012 condition. Supply elasticities for crops are taken from available econometric studies at the NUTS2 level (Jansson and Heckelei, 2011).\(^6\) Supply elasticities for livestock activities are taken from CAPRI. Prior information on dual values of resources and on the farm-type covariance matrix of activity revenues is derived from FADN.

The use of multiple observations (i.e. cross-sectional data) allows the full set of \(Q\) coefficients for crop and livestock activities to be estimated and the model specification to be based on observed differences in behaviour. More specifically, with the proposed calibration method we aim not only to exactly reproduce the observed activities in the base year (2012), \(x^0\)——as most PMP methods do——but also to ensure that (i) the estimated farm dual values \((\rho_{f,m})\), farm-type covariance matrix of revenues \((\overline{\Sigma}_{ft,i,i})\) and NUTS2 own-price supply elasticities \((\overline{\varepsilon}_r)\) are as close as possible to the prior information, and (ii) the estimated farmers’ constant absolute \((\phi_f)\) and relative risk aversion coefficients are consistent with the range indicated in the literature.

To perform the estimation, we derive the first-order conditions (FOCs) of the optimisation model equations (1) and (2), which are assumed to approximate farmer behaviour (Heckelei, 2002) and, then, apply the highest posterior density (HPD) method (Heckelei et al., 2005)\(^7\) to estimate the unknown parameters \((d, Q, \rho, \phi\) and \(\Sigma)\). The use of the HPD approach for parameter estimation is carried out under the following assumptions:

- The HPD model minimises, in each NUTS2 region, the weighted sum of normalised squared deviations of estimated (i) regional own-price (diagonal) supply elasticities, (ii) farm-type covariance matrix of activity revenues per hectare or per head, and (iii) farm dual values from the prior information subject to a set of data consistency (FOC) constraints.

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\(^5\)NUTS2 refers to regions belonging to the second level of the EU’s Nomenclature of Territorial Units for Statistics.

\(^6\)Note that IFM-CAP considers land allocation elasticities with respect to gross margins, as in Heckelei (2002) and Heckelei and Wolff (2003). IFM-CAP assumes fixed yields, meaning that land allocation elasticities correspond to supply elasticities. The use of supply elasticities from Jansson and Heckelei (2011) was motivated by the fact that they provide estimates of land allocation elasticities at EU regional level.

\(^7\)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 prior information and a clearly defined estimation objective.
• The normalised squared deviations of farm dual values are weighted with the proportion of the farm in the NUTS2 region, $\omega_f^p = w_f / \sum_i w_f$, to obtain a weighted average normalised squared deviation at the NUTS2 level, where $w_f$ is the farm weighting factor reflecting the number of farms in the population that is represented by farm $f$.

• The normalised squared deviations of regional supply elasticities are weighted with the proportion of observed activity level on total regional land, $\omega_r^e = N_r x_{r,i}^0 / \sum_i x_{r,i}^0$, to allow activities with a large land share to dominate, where $N_r$ is the number of observed crop activities (for $x_{r,i}^0 > 0$) in NUTS2 region $r$.

• Prior information on dual values, $\bar{\rho}_{r,m}$, is set to the average land rental price at regional (NUTS2) level for arable land and grassland; to the gross margin differential between sugar beet and the next best alternative crop for the sugar beet quota restriction; and to arable land rental prices (where the only constraints in the base year for crops are land and sugar beet and milk quota obligations).

• 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 estimated $B_{ft,i,i'}$ parameters related to the $Q_{ft,i,i'}$ (see below) are common across farms in the same region and of the same farm type (group), $ft$. Farms are grouped based on 14 production specialisations, i.e. $ft = 1, 2, \ldots, 14$. However, the $Q_{ft,i,i'}$ parameters are activity- and farm-specific, owing to the farm-specific scaling factors, as suggested in Heckelei and Britz (2000). Thus, we exploit information contained in the cross-sectional sample to specify (farm-specific) quadratic activity functions with cross-effects for production (crop and livestock) activities.

• The inequality on quota restriction is replaced with equality to simplify the already complex estimation problem. Moreover, the non-negativity condition was omitted because of the heavy computational requirement. That is, all optimal activity levels are assumed to be positive. This implies that we overestimate the profitability of non-observed activities.

• The estimation of $B_{ft,i,i'}$ (and thus $Q_{ft,i,i'}$) parameters relies only on observed activities, 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 NUTS2 region, the gross margin of the non-observed activities is equal to the farm-type average gross margin, the activity’s

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8 We use the TF14 grouping, as available in FADN, which defines 14 distinct farm types specialising in (1) cereals, oilseeds and protein crops (COP); (2) other field crops; (3) horticulture; (4) wine; (5) fruit orchards; (6) olives; (7) various permanent crops combined; (8) milk; (9) sheep and goats; (10) cattle; (11) granivores; (12) mixed crops; (13) mixed livestock; and (14) mixed crops and livestock (FADN, 2015).

9 Different arbitrary assumptions were tested for setting the behavioural function’s parameters for the non-observed activities, such as the use of the highest $Q$ matrix, or the use of $B$ matrix, but the results were not conclusive. Finally, we opted for what is often done in the literature.
The quadratic function parameter is equal to the activity’s average quadratic function parameter within the farm type, and the quadratic function’s linear term is derived from the difference between the gross margin and the dual values of constraints.\(^{10}\)

- The estimation procedure is applied to both crop and livestock activities.
- The exchange of production factors and production rights between farms is not allowed (i.e. there are neither land nor entitlement markets).

The general formulation of the corresponding HPD problem is now straightforward:

\[
\begin{align*}
\text{Min } HPD_r &= \sum_i \alpha_i \left( \frac{(\bar{e}_{i,i} - \bar{e}_{i,i})^2}{(\sigma_{i,i})^2} \right) + \sum_{f, i, i'} \alpha_r \left( \frac{(\bar{e}_{f,i,i'} - \bar{e}_{f,i,i'})^2}{(\sigma_{f,i,i'})^2} \right) + \sum_{f, m} \alpha_f \left( \frac{(\bar{e}_{f,m} - \bar{e}_{f,m})^2}{(\sigma_{f,m})^2} \right) \\
E [gm_{f,i}] - d_{f,i} - \sum_i T_{f,i,i'} x_{f,i'}^0 - \sum_m A_{f,i,m} \rho_{f,m} &= 0 \quad (3)
\end{align*}
\]

\[
\begin{align*}
E [y_{f,i} p_{f,i}^q] + s_{f,i} - \sum_k E [C_{f,i,k}] - d_{f,i} \\
- \sum_i T_{f,i,i'} x_{f,i'}^0 - \sum_m A_{f,i,m} \rho_{f,m} &= 0 \quad (4)
\end{align*}
\]

\[
\begin{align*}
b_{f,m} - \sum_i A_{f,i,m} x_{f,i}^0 &= 0 \quad (5)
\end{align*}
\]

\[
\begin{align*}
b_{f,m} - \sum_i A_{f,i,m} q_{f,i}^p &= 0 \quad (6)
\end{align*}
\]

\[
\begin{align*}
T_{f,i,i'} &= Q_{f,i,i'} + \sum_{f} \phi_f \Sigma_{f,i,i'} \quad (7)
\end{align*}
\]

10 This approach does not allow farms to choose activities not observed in the same region and farm type, which may restrict choices and thus also the simulated results. However, the set of activities observed for farm type and region is indicative of the likely feasible options that a farm faces when choosing production structure. If an activity is not observed in other similar farms, it indicates that it is probably not economically feasible because of various unobserved factors (e.g. experience, farmer skills, environmental constraints) that are not accounted for in our model and which would make that activity unprofitable. Hence, our approach for modelling non-observed activities partially accounts for unobserved factors that may impact farms’ choices. A similar approach, but with more restrictive selection criteria, was used by Mahy et al. (2015). They selected the closest peers based on the total farm area, crop area allocation, number of crops, geographical distance between farms and permanent grassland.
\[
\begin{align*}
\varepsilon_{f,i,i'} &= \left[ T_{f,i,i'}^{-1} - \sum_m \left( \sum_j A_{f,j,m} T_{f,j,i}^{-1} \right) \right] \left[ \sum_j A_{f,j,m} T_{f,j,i'}^{-1} \right]^{-1} \sum_j A_{f,j,m} T_{f,j,i'}^{-1} \right] E[g_{m}, \lambda] x_{m,i}^0
\end{align*}
\]

\[
\varepsilon_{r,i,i'} = \frac{\sum_f w_f x_{f,i}^0 \varepsilon_{f,i,i'}}{\sum_f w_f x_{f,i}^0}
\]

\[
Q_{f,i,i'} = \sum_{f_t} \delta_{f,i} B_{f,t,i,i'} \delta_{f,i'}
\]

\[
B_{f,t,i,i'} = \sum_j Lb_{f,t,i,j} Lb_{f,t,i',j} \quad Lb_{f,t,i,i'} = 0 \quad \text{for} \quad i' > i
\]

\[
V_{f,t,i,i'} = \sum_j Lv_{f,t,i,j} Lv_{f,t,i',j} \quad Lv_{f,t,i,i'} = 0 \quad \text{for} \quad i' > i
\]

\[
\sum_i T_{f,i,i} T_{f,i,i'}^{-1} = 1 \quad \forall \quad i = i'
\]

\[
\sum_i T_{f,i,i} T_{f,i,i'}^{-1} = 0 \quad \forall \quad i \neq i'
\]

where indices \( r \) denote NUTS2 region and \( j, j' \) (similar to \( i, i' \)) the agricultural activities and products; \( p_{f,i}^q \) is the farm in-quota price (EUR/tonne); \( q_{f,i}^q \) is the farm in-quota production (tonnes); \( g_{m,i} \) is the expected gross margin for activity \( i \) (EUR/ha); \( T_{f,i,i'} \) are the farm-specific behaviour and risk parameters; \( \bar{\rho}_{r,m}, \sigma_{r,m}^f \) are the mean and standard deviation of the regional dual values of resource and policy constraints (land rental prices, in-quota prices), used as prior information; \( \bar{\varepsilon}_{r,i,i}, \sigma_{r,i,i}^f \) are the mean and standard deviation of regional own-price elasticities of supply, used as prior information (Jansson and Heckelei, 2011); and \( \delta_{f,i} \) is a scaling factor with \( \delta_{f,i} = \sqrt{1/x_{f,i}^0} \).

Prior information on dual values of constraints is assumed to be normally distributed with the means (\( \bar{\rho}_{r,m} \)) and standard deviations (\( \sigma_{r,m}^f \)) calculated at NUTS2 level using the farm weighting factors. The standard deviation of NUTS2 elasticities (\( \sigma_{r,i,i}^f \)) is assumed to be 50 per cent of the mean.

The endogenous variables of the HPD problem defined in equations (3)–(11) are the dual values of resource and policy constraints, \( \bar{\rho}_{r,m} \); the farm price elasticities of supply, \( \varepsilon_{f,i,i'} \); the regional price elasticities of supply, \( \varepsilon_{r,i,i'} \); the behavioural parameters, \( B_{f,t,i,i'} \); common across farms belonging to the same region and the same farm type (group), \( f_t \); the elements of the lower triangular Cholesky decomposition related to \( B_{f,t,i,i'} \) and \( \Sigma_{f,i,i'} \) parameters, \( Lb_{f,t,i,i'} \) and \( Lv_{f,t,i,i'} \); the farmers’ CARA coefficients, \( q_{f,i}^f \); the behavioural parameters,
Equations (4) and (5) represent the FOCs of the optimisation model for production activities and in-quota sugar beet production, respectively. Equations (6) and (7) represent the FOCs for land and quota constraints. Equation (8) calculates the farm-specific behaviour-risk $T_{f,i,i'}$. Equations (9) and (10) compute supply elasticities at farm and NUTS2 levels, respectively. Equation (11) calculates the farm-specific $Q_{f,i,i'}$ parameters of the cost behavioural function. Equations (12) and (13) are the Cholesky decomposition of the $B$ and $\Sigma$ matrices, respectively, which ensures appropriate curvature properties of the estimated quadratic cost function (i.e. convex in activity levels). Finally, equation (14) calculates the inverse of farm-specific parameters $T_{f,i,i'}$.

The estimated parameters ($d, Q, \rho, \varphi$ and $\Sigma$) guarantee the reproduction of the observed production structure when the model (equations (1) and (2)) is run for the base year.

2.3. Data

The primary data source used to parameterise IFM-CAP is individual farm-level data from the FADN database (FADN, 2015), complemented by other external EU-wide data sources such as the Farm Structure Survey (FSS), the CAPRI database and Eurostat (see Figure A in the online Appendix). Most of the latter external data sources serve as an input (i.e. prior information) in the estimations rather than for model parameterisation (for more details, see Louhichi et al., 2015).

All 83,292 farms represented in the FADN sample for the year 2012 are included in the model. To improve the model parameterisation, past observations (2007–2012) on yields, prices and input costs for these farms were also exploited. For each farm, the following variables are derived from the FADN: levels (hectares or number of animal heads), yields, product prices for all crop and animal activities, available farmland (utilised agricultural area (UAA), arable land and grassland), rental prices, and coupled and decoupled subsidies. Data on labour and capital costs are not included; they are implicitly captured by the behavioural activity function. Data on unit input costs of crops, animal feeding and sugar beet quota were estimated based on FADN data combined with external data sources using the HPD estimation approach. The advantage of the HPD approach in this context is that it allows a direct and transparent formulation of prior information and reduces significantly the computational time compared with

11 Note that this specification implies that farms may not necessarily be calibrated to the exogenous regional elasticity and allows for farm supply responses to deviate from the regional average to guarantee farm level heterogeneity.

12 Note that we correct outliers and address the missing values before using the FADN data in the IFM-CAP model (for more details, see online Appendix 1).
3. Baseline and the crop diversification scenario

3.1. Baseline

To construct the IFM-CAP baseline, we used CAPRI projections for the year 2025, which was taken as the time horizon for CAP greening scenario simulations. One important feature of the CAPRI baseline is that it is developed in conjunction with the European Commission baseline. The Commission 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 defined on the basis of specific policy and macroeconomic assumptions (Himics et al., 2013; Britz and Witzke, 2014).

Three assumptions were thus adopted: (i) a continuation of the current CAP up to 2025 without the greening restrictions; (ii) an assumed inflation rate of 1.9 per cent per year for input costs, as in the CAPRI baseline; and (iii) an adjustment of baseline prices and yields using growth rates from the CAPRI baseline. The regional yield growth attempts to capture both technical change and input intensification effects and the regional price growth represents a nominal price projection. As the CAPRI growth rates of yields and prices are defined at NUTS2 level, we imposed the same growth rate on all farms belonging to the same NUTS2 region. All the other parameters (e.g. farm resource endowments and farm weighting factors) are assumed to remain unchanged up to 2025.

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

3.2. CAP greening scenario

The 2013 CAP reform introduced specific measures to enhance the provision of public goods by farmers, the so-called greening measures (EU, 2013, 2014a, 2014b). Under the CAP greening measures, 30 per cent of direct payments are conditional on complying with three mandatory requirements: (i) crop diversification for arable crops, (ii) maintenance of permanent grassland and (iii) allocation of land to Ecological Focus Areas (EFAs).

The greening scenario includes the three greening measures, while keeping the direct payments and other policies unchanged relative to the baseline scenario. Following the EU regulation, we assume full compliance with the three greening measures without allowing farmers to trade-off between income reductions with full compliance versus direct payment reduction as a consequence of partial or full non-compliance. This assumption implies that our simulated results represent the highest potential impacts of CAP greening. Most studies in the literature model full compliance with CAP greening

13 For more details see online Appendix II and Louhichi et al. (2015).
requirements (e.g. Was et al., 2014; Cortignani and Dono, 2015; Mahy et al., 2015; Gocht et al., 2017), except for a few, which allow farmers to choose the level of (non-)compliance (e.g. Vosough-Ahmadi et al., 2015; Solazzo and Pierangeli, 2016; Cortignani et al., 2017).

As shown in Table 1, the crop diversification measure applies only to farms with an arable area greater than 10 ha. Farms with more than 75 per cent of their total eligible land covered by grassland and farms with 75 per cent of their arable area cultivated with forage are also not subject to the crop diversification measure. Furthermore, there are stricter requirements for farms having more than 30 ha of arable land (group 2) than for farms with between 10 and 30 ha of arable land (group 1). Farms in the latter group need to have at least two different crops, and the main crop should not exceed 75 per cent of the arable land. Farms in the former group are required to have at least three crops, the main crop should not cover more than 75 per cent of the arable land and the two main crops together should not cover more than 95 per cent of the arable land.

Under the maintenance of permanent grassland measure, the ratio of grassland to total agricultural area cannot decrease by more than 5 per cent compared with the reference ratio in 2015. Further, under this measure, farms are prevented from ploughing and converting permanent grassland in areas designated by MSs as environmentally sensitive.14

The calculation of the reference ratio can be applied at national, regional or sub-regional level: 23 MSs apply it at national level, 4 MSs do so at regional level, 1 MS does so at sub-regional level, and 1 MS is without permanent grassland (Malta). If the ratio of grassland to total agricultural area has decreased by more than 5 per cent at national or regional level (depending on the implementation), the obligation needs to be imposed at farm level (EU, 2013, 2014a, 2014b).

We take 2012 as the reference year for modelling the grassland measure, as this is the IFM-CAP base year. That is, we calculate the ratio of grassland to total agricultural area for 2012 and compare it with the ratio in the baseline (2025). If in an MS or region (depending on the implementation) the ratio decreases by more than 5 per cent in the baseline relative to the base year, we impose the obligation at farm level in the greening scenario.

Two categories of grassland are modelled in IFM-CAP: permanent grassland and rough grazing area. Permanent grassland is assumed to be fully substitutable with arable land if relative returns change, while rough grazing area is assumed to be fixed, as this type of land is usually of low quality. Both grassland categories are supposed to be subject to the grassland measure in the greening scenario.

For environmentally sensitive areas, we consider grassland located in a Natura 2000 area subject to the grassland measure of no conversion to arable land.

The EFA measure requires farms with more than 15 ha of arable land to allocate at least 5 per cent of that land (excluding areas under grassland) to

14 These areas could be located inside or outside Natura 2000 areas.
an EFA. The areas that qualify as EFAs include land left fallow, terraces, landscape features, buffer strips, agroforestry, areas with short rotation, afforested areas, catch crops and nitrogen-fixing crops (Table 2) (EU, 2013).

Table 1. Crop diversification measure as implemented in IFM-CAP

<table>
<thead>
<tr>
<th>Eligible area</th>
<th>Exempted farms</th>
<th>Farm group 1</th>
<th>Farm group 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arable land (AL)</td>
<td>&lt;10 ha(^a)</td>
<td>10–30 ha</td>
<td>≥30 ha</td>
</tr>
<tr>
<td>Minimum number of cultivated crops</td>
<td>–</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Maximum proportion of main crop in AL (%)</td>
<td>–</td>
<td>75%</td>
<td>No</td>
</tr>
<tr>
<td>Maximum proportion of two main crops in AL (%)</td>
<td>–</td>
<td>–</td>
<td>95%</td>
</tr>
</tbody>
</table>

Source: Compiled based on Regulation No. 1307/2013 (EU, 2013) and Delegated Regulations No. 639/2014 (EU, 2014a) and No. 640/2014 (EU, 2014b).

\(^a\)Farms are also excluded where (i) fodder area + fallow area ≥75 per cent of AL and AL – (fodder + fallow) <30 ha; (ii) grassland + other herbaceous fodder crops >75 per cent UAA and AL – other herbaceous crops <30 ha or (iii) organic farmers.

Table 2. Land elements eligible for EFA

<table>
<thead>
<tr>
<th>Eligible area</th>
<th>No. of implementing MSs</th>
<th>Conversion factor</th>
<th>Weighting factor</th>
<th>Modelling in IFM-CAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fallow land</td>
<td>26</td>
<td>n.a.</td>
<td>1</td>
<td>Yes</td>
</tr>
<tr>
<td>Terraces</td>
<td>8</td>
<td>2</td>
<td>1</td>
<td>No</td>
</tr>
<tr>
<td>Hedges or wooded strips</td>
<td>13</td>
<td>5</td>
<td>2</td>
<td>No</td>
</tr>
<tr>
<td>Isolated trees</td>
<td>13</td>
<td>20</td>
<td>1.5</td>
<td>No</td>
</tr>
<tr>
<td>Trees in line</td>
<td>16</td>
<td>5</td>
<td>1.5</td>
<td>No</td>
</tr>
<tr>
<td>Trees in groups</td>
<td>17</td>
<td>n.a.</td>
<td>1.5</td>
<td>No</td>
</tr>
<tr>
<td>Field margins</td>
<td>16</td>
<td>6</td>
<td>1.5</td>
<td>No</td>
</tr>
<tr>
<td>Ponds</td>
<td>12</td>
<td>n.a.</td>
<td>1.5</td>
<td>No</td>
</tr>
<tr>
<td>Ditches</td>
<td>15</td>
<td>3</td>
<td>2</td>
<td>No</td>
</tr>
<tr>
<td>Traditional stone walls</td>
<td>7</td>
<td>1</td>
<td>1</td>
<td>No</td>
</tr>
<tr>
<td>Other landscape features under GAEC or SMR</td>
<td>11</td>
<td>n.a.</td>
<td>1</td>
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<tr>
<td>Buffer strips</td>
<td>17</td>
<td>6</td>
<td>1.5</td>
<td>No</td>
</tr>
<tr>
<td>Agroforestry</td>
<td>11</td>
<td>n.a.</td>
<td>1</td>
<td>No</td>
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<tr>
<td>Strips along forest edges (no production)</td>
<td>9</td>
<td>6</td>
<td>1.5</td>
<td>No</td>
</tr>
<tr>
<td>Strips along forest edges (with production)</td>
<td>6</td>
<td>6</td>
<td>0.3</td>
<td>No</td>
</tr>
<tr>
<td>Areas with short rotation</td>
<td>20</td>
<td>n.a.</td>
<td>0.3</td>
<td>No</td>
</tr>
<tr>
<td>Afforested areas</td>
<td>14</td>
<td>n.a.</td>
<td>1</td>
<td>Yes</td>
</tr>
<tr>
<td>Catch crops or green cover</td>
<td>19</td>
<td>n.a.</td>
<td>0.3</td>
<td>Yes</td>
</tr>
<tr>
<td>Nitrogen-fixing crops</td>
<td>27</td>
<td>n.a.</td>
<td>0.7</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Source: Compiled based on EU Regulations (EU, 2014a).

Note: GAEC, Good Agricultural and Environmental Condition of Land; SMR, Statutory Management Requirement. n.a., not available.
Member States can choose which land elements they classify as eligible for EFA status. As reported in Table 2, land cultivated with nitrogen-fixing crops is the most common type of EFA-eligible area across MSs (in 27 MSs) followed by fallow land (26) and areas with short rotation (20 MSs). The eligible land elements have different weights in contributing to EFA levels (varying between 0.3 and 30), depending on their conversion and weighting factors.

The EFA measure is the most challenging measure to model, as there are no data available for capturing different eligible land elements. Because of missing data in FADN, only the following four elements of EFA are considered in IFM-CAP: fallow land (including voluntary set-aside), afforested area, catch crops and nitrogen-fixing crops. Fallow land and nitrogen-fixing crops are endogenous activities in the IFM-CAP model. Forests and catch crops are not endogenously modelled in IFM-CAP and, thus, their areas are set as equal to the base year level. The EU regulation specifies the list of crops that can be considered catch crops/green cover or nitrogen-fixing crops. Given that in the IFM-CAP model some minor activities are aggregated, they cannot be exactly mapped to this list of eligible crops. Thus, we assumed that all cereals and pulses can be considered catch crops and that pulses and soya can be considered nitrogen-fixing crops. MSs with more than 50 per cent of their land surface area covered by forest may decide that the EFA measure will not be applied in areas designated by those MSs in which more than 50 per cent of the land surface area at LAU-2 level (or other contiguous geographical area) is covered by forest and the ratio of forest land to agricultural land is higher than 3:1. This forest exemption is applied in Estonia, Finland, Latvia and Sweden. Given that in FADN (and IFM-CAP) there is no information on the LAU-2 level, the forest exemption is assessed at farm level, but only for farms located in NUTS3 regions in which the exemption is applied (European Commission, 2016).

It is important to note that MSs can change the elements that are eligible to be counted as EFAs on a yearly basis. Table 2 reports the notifications applied in 2016 and which correspond to our assumptions in the greening scenario.

4. Results

In this section, we report the simulation results for the greening scenario for the EU-27. We have focused the analysis on the land use, production and

15 As in the case of the crop diversification measure (Table 1), farms with more than 75 per cent of their total eligible land covered by grassland and farms with 75 per cent of their arable area cultivated with forage are not subject to the EFA measure.

16 Local administrative unit (LAU) is a low-level administrative division of an MS defined at two levels: LAU-1 and LAU-2.

17 The IFM-CAP model is programmed in GAMS (General Algebraic Modelling System) and solved using CONOPT and SBB (Standard Branch and Bound algorithm). CONOPT is applied to solve the non-linear programme in calibration and the baseline, while SBB is used to solve the mixed integer non-linear programme induced by the modelling of the CAP greening scenario.
income effects of the three greening measures combined. Results are provided at MS and EU-27 aggregate level, by farm specialisation and farm size and as a distribution across the farm population.

4.1. Baseline

Before presenting the greening scenario simulation results, we provide some statistics on the number of farms subject to CAP greening measures in the baseline. Of around 5 million commercial farms represented in IFM-CAP for the EU-27, around 55 per cent are subject to at least one CAP greening measure, while the rest (45 per cent) are exempt from all three measures. The MSs with the largest proportions of farms subject to CAP greening include Ireland (99 per cent), UK (93 per cent), Denmark (90 per cent), Slovakia (88 per cent), Germany (85 per cent), Belgium–Luxembourg (85 per cent), Sweden (82 per cent), France (81 per cent), Poland (80 per cent), Slovenia (80 per cent) and Finland (80 per cent). On the other hand, the smallest proportions of farms subject to CAP greening are found in Mediterranean countries—Malta (1 per cent), Cyprus (18 per cent), Greece (22 per cent) and Italy (27 per cent)—because they have relatively high proportions of small farms that are exempted from the diversification and EFA measures. The remaining MSs have proportions of farms subject to CAP greening ranging between 45 and 75 per cent (Table 3).

Although a significant proportion of farmers are subject to CAP greening (i.e. 55 per cent), not all of them are affected by CAP greening. In fact, the proportion of farms not complying with CAP greening, in the baseline scenario, represents only around 29 per cent of all the commercial farms in the EU-27. This proportion varies between 0.2 per cent in Malta and 84 per cent in Denmark (Table 3). In terms of the specific measures, the non-complying proportion of EU farms is 9 per cent for crop diversification, 13 per cent for EFA and 14 per cent for grassland measures. The non-compliant farms in the baseline scenario represent a hypothetical situation that is in breach of at least one greening measure. These farms need to adjust their land allocation to comply with the CAP greening measures if they do not want to face a reduction in subsidy (i.e. lower greening payments). The remaining 26 per cent (i.e. 55–29 per cent) of farms subject to CAP greening in the EU-27 are effectively not affected by CAP greening because their area allocation in the baseline complies with all greening requirements.

Table 4 reports the UAA subject to CAP greening and non-complying UAA with CAP greening requirements in the baseline scenario. Compared with the proportions of farms reported in Table 3 for the EU-27, the

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18 Note that the sum of non-complying farms by measure (i.e. 9 per cent + 13 per cent + 14 per cent) might not be equal to the figure reported for non-complying farms for all three measures combined (i.e. 29 per cent) because some farms may be in breach of more than one measure in the baseline.

19 These two indicators are calculated as the sum of UAA of farms subject to CAP greening and non-complying UAA with CAP greening requirements across all farms, respectively.
<table>
<thead>
<tr>
<th>Country</th>
<th>Exempted farms</th>
<th>Farms subject to CAP greening</th>
<th>Baseline</th>
<th>Complying farms (% of total farms)</th>
<th>Non-complying farms</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Greening (all)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Complying farms</td>
<td>CropDiv  EFA Grass</td>
</tr>
<tr>
<td>EU-27</td>
<td>45.1</td>
<td>54.9</td>
<td></td>
<td>70.8</td>
<td>29.2</td>
</tr>
<tr>
<td>Belgium and Luxembourg</td>
<td>14.8</td>
<td>85.2</td>
<td></td>
<td>63.6</td>
<td>36.4</td>
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<td>Bulgaria</td>
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<td>46.4</td>
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<td>60.0</td>
<td>40.0</td>
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<td>29.1</td>
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<td></td>
<td>46.9</td>
<td>53.1</td>
</tr>
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<td>89.8</td>
<td></td>
<td>15.6</td>
<td>84.4</td>
</tr>
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<td>Germany</td>
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<td>84.9</td>
<td></td>
<td>55.1</td>
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<tr>
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<td>26.2</td>
<td>73.8</td>
<td></td>
<td>70.9</td>
<td>29.1</td>
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<td>9.2</td>
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<td>36.8</td>
</tr>
<tr>
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<td>27.0</td>
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<td>41.5</td>
</tr>
</tbody>
</table>

**Source:** Model results.

**Note:** CropDiv: Crop diversification measure; EFA: Ecological Focus Area measure; Grass: Permanent grassland measure.
Table 4. Area non-compliant with CAP greening in the baseline (per cent of UAA)

<table>
<thead>
<tr>
<th>Region</th>
<th>Exempted UAA</th>
<th>UAA subject to CAP greening</th>
<th>Baseline</th>
<th>Non-complying UAA</th>
<th>Greening (all)</th>
<th>CropDiv</th>
<th>EFA</th>
<th>Grass</th>
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<tbody>
<tr>
<td>EU-27</td>
<td>14.2</td>
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<td>15.5</td>
<td>39.1</td>
<td>10.9</td>
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<td>Belgium and Luxembourg</td>
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<td>94.7</td>
<td>55.1</td>
<td>44.9</td>
<td>6.8</td>
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<td>65.5</td>
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<td>12.9</td>
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<td>Latvia</td>
<td>21.6</td>
<td>78.4</td>
<td>52.3</td>
<td>47.7</td>
<td>11.2</td>
<td>41.5</td>
<td>7.9</td>
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<td>Lithuania</td>
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</tr>
<tr>
<td>Hungary</td>
<td>4.6</td>
<td>95.4</td>
<td>24.0</td>
<td>76.0</td>
<td>32.2</td>
<td>67.2</td>
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<tr>
<td>Malta</td>
<td>95.9</td>
<td>4.1</td>
<td>98.7</td>
<td>1.3</td>
<td>0.4</td>
<td>1.1</td>
<td>0.0</td>
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</tr>
<tr>
<td>The Netherlands</td>
<td>11.9</td>
<td>88.1</td>
<td>62.5</td>
<td>37.5</td>
<td>19.6</td>
<td>34.3</td>
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<tr>
<td>Austria</td>
<td>32.5</td>
<td>67.5</td>
<td>78.6</td>
<td>21.4</td>
<td>1.8</td>
<td>20.2</td>
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<tr>
<td>Poland</td>
<td>9.3</td>
<td>90.7</td>
<td>49.6</td>
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<td>11.5</td>
<td>32.4</td>
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<tr>
<td>Portugal</td>
<td>24.2</td>
<td>75.8</td>
<td>49.1</td>
<td>50.9</td>
<td>18.6</td>
<td>15.1</td>
<td>28.7</td>
<td></td>
</tr>
</tbody>
</table>

(continued)
Table 4. (continued)

<table>
<thead>
<tr>
<th>Country</th>
<th>Exempted UAA</th>
<th>UAA subject to CAP greening</th>
<th>Baseline</th>
<th>Complying UAA</th>
<th>Non-complying UAA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Greening (all)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CropDiv</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>EFA</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Grass</td>
</tr>
<tr>
<td>Romania</td>
<td>19.1</td>
<td>80.9</td>
<td>31.0</td>
<td>69.0</td>
<td>12.1</td>
</tr>
<tr>
<td>Slovenia</td>
<td>16.9</td>
<td>83.1</td>
<td>40.4</td>
<td>59.6</td>
<td>1.9</td>
</tr>
<tr>
<td>Slovakia</td>
<td>9.8</td>
<td>90.2</td>
<td>17.3</td>
<td>82.7</td>
<td>17.7</td>
</tr>
<tr>
<td>Finland</td>
<td>16.8</td>
<td>83.2</td>
<td>46.5</td>
<td>53.5</td>
<td>20.1</td>
</tr>
<tr>
<td>Sweden</td>
<td>22.0</td>
<td>78.0</td>
<td>51.3</td>
<td>48.7</td>
<td>9.5</td>
</tr>
<tr>
<td>UK</td>
<td>7.3</td>
<td>92.7</td>
<td>61.7</td>
<td>38.3</td>
<td>11.4</td>
</tr>
</tbody>
</table>

Source: Model results.
proportions of UAA subject to CAP greening and non-complying UAA are significantly higher, reaching 86 and 49 per cent, respectively. By specific measure, the proportion of non-complying UAA in the EU-27 is 16 per cent for crop diversification, 39 per cent for EFA and 11 per cent for grassland measures. This implies that larger farms (in terms of area) tend to be more affected by greening than smaller farms. This result is expected, as many small farms are excluded from CAP greening (in particular from crop diversification and EFA measures).

A full comparison of the results reported in Tables 3 and 4 with literature findings is not always possible, as the studies are heterogeneous in terms of the methodologies used, data sources, geographical scope and farm coverage. In general, studies that use data covering the total farm population find smaller proportions of farms and areas subject to CAP greening and affected by CAP greening than our results suggest. This is expected, as we modelled only commercial farms, whereas total farm population data include small non-commercial farms, which are exempt from some greening measures. For example, the only EU-wide information available for the total farm population is the data on CAP greening implementation collected under the CAP regulation No. 640/2014 (EU, 2014a, 2014b). According to these data, 32 per cent of farms and 63 per cent of farm area were subject to CAP greening measures in the EU-28 in 2015. These figures are lower than our results of 55 per cent of farms and 86 per cent of area subject to CAP greening, respectively. Vanni and Cardillo (2013) used the total farm population data for Italy (i.e. the 2007 Agricultural Census) and estimated that CAP greening affects only around 7 per cent of Italian farms, which is lower than our estimate of 10 per cent.

The findings of studies based on farm sample data (e.g. FADN) depend on the regional coverage, but in general they tend to be similar in magnitude to our results. For example, Solazzo and Pierangeli (2016) estimated that the proportion of affected farms in three regions of Northern Italy varied between 10 and 24 per cent, compared with our estimate of 10 per cent for the whole of Italy. Was et al. (2014) reported that 23 per cent of farms in Poland were affected, compared with our estimate of 33 per cent. This difference could be partly explained by the fact that Was et al. (2014) considered only crop diversification and EFA measures, whereas we modelled all three greening measures.

4.2. Land use effects

Table 5 shows the areas reallocated as a result of CAP greening measures in the EU-27. The figures were calculated as the total area of crops that changed land allocation over all EU-27 farms, by farm specialisation and farm economic size. The total area reallocated as a result of CAP greening measures represents 4.5 per cent of the UAA in the EU-27. The standard deviation across MSs is about 2.4 per cent of UAA. As reported in Table 6, in relative terms, the area reallocated is mostly the result of the EFA measure (2.4 per
cent of UAA), followed by the crop diversification measure (1.8 per cent). The grassland measure leads to the reallocation of 1.5 per cent of UAA.\(^{20}\) In the case of the crop diversification measure, the 75 per cent threshold

\(^{20}\) Note that the sum of area changes due to the crop diversification, EFA and grassland measures reported in Table 6 may not equate to the aggregate reallocated areas reported in Table 5 because of the interactions between the measures, as some farms are affected by more than one measure. For example, under certain circumstances, the introduction of a new crop that is eligible under the EFA measure (e.g. pulses) in the greening scenario may simultaneously help farmers to comply with the diversification and EFA measures if they were in breach of these two measures in the baseline scenario.
imposed for the main crop cultivated on arable farms has the largest effect (1.4 per cent of UAA). At MS level, the contribution of the three measures to the total reallocated area is very heterogeneous. In several MSs, the EFA measure leads to a larger reallocated area than other measures (e.g. Denmark, Slovakia, Hungary), while in others the grassland measure has the strongest effect (e.g. Slovenia, Ireland).

As shown in Table 5, the farms with the largest proportion of reallocated UAA as a result of CAP greening measures are those that specialise in cereals, oilseed and protein crops (COP), other field crops, horticulture, cattle, sheep and goats, and mixed farms. Regarding farm economic size, the effects tend to be rather homogenous, although small and large farms report slightly greater reallocated areas than medium-sized farms, driven mainly by the EFA and crop diversification measures (Table 5). Note that many farms that have a small area but specialise in capital- and labour-intensive production activities (e.g. horticulture, pigs and poultry production) are categorised as middle economic size in FADN, which may explain the smaller CAP greening effect for this class.

Similar results are found in the literature, although it is not always straightforward to compare the farm classifications between studies. For example, Gocht et al. (2017) show that the land use effects of CAP greening in the EU are more sizeable for farms specialising in COP, cattle, sheep, goats and other grazing livestock, and mixed livestock holdings. Cortignani and Dono (2015), who used a farm-type model for an irrigated area in west-central Sardinia (Italy), found that CAP greening has a substantial impact on dairy farms, which specialise in arable fodder crops.

Figure 1 shows the distribution of the reallocated area across all individual farms represented in FADN for the EU-27 (i.e. the total number of farms in the EU-27 is equal to 100) compared with the baseline. This figure is constructed by sorting, in increasing order, all the farms according to the size of the reallocated area until all farms (100 per cent) are reported. The vertical axis in Figure 1 starts at 65 per cent to better illustrate the changes for the affected farms. Consistently with the aggregate results reported in Table 3, only 29 per cent of farms change land allocation as a result of CAP greening. The remaining 71 per cent of farms do not change land allocation at all, either because they already comply in the baseline or because they are not subject to CAP greening (i.e. they are exempted farms). As depicted in Figure 1, most of the affected farms (27 per cent all farms) reallocate between 1 and 50 per cent of their UAA as a result of CAP greening. However, around 1 per cent of farms reallocate more than 50 per cent of their total UAA. This large proportion of reallocated area is a consequence of the grassland measure, particularly on farms with a small UAA and a large proportion of grassland; these farms need to reconvert the land when greening is introduced. The other two measures have an impact on land allocation that is less than 50 per cent. By design, the diversification measure may result in a

21 Note that we apply FADN farm weights to represent the farm population in the figure.
reallocation of a maximum of 25 per cent of UAA, for example, in monocrop farms. The EFA measure may result in a reallocation of a maximum of 5 per cent of UAA in farms that have no EFAs in the baseline.

4.3. Production effects

The production effects of CAP greening follow similar tendencies to land use effects. They depend on the production structures of farms in the baseline and on the extent to which they are in breach of the greening measures. The production of crops that have a large land share in the baseline will tend to decrease, whereas the production of crops with a small land share will tend to increase as a result of the diversification measure. The production of crops eligible for EFA is expected to increase with the introduction of this measure. The grassland measure is expected to have a negative impact on arable crop production and it may stimulate livestock production.

Table 7 reports the production quantity effects of CAP greening for the EU-27. Results show that the production changes caused by CAP greening are relatively small. The total production change at EU-27 level represents a decline of around 0.9 per cent compared with the baseline. Total production declines because farms are required to adjust land allocation in line with the CAP greening requirements, which they would not do otherwise. At MS level, the total production change varies between 0 and −4.5 per cent (not reported in Table 7).

The production at sectoral level tends to decrease for major crops such as wheat, barley and rapeseed. The main causes of these effects are the EFA and grassland measures, which require farmers to reallocate land from main arable crops to EFA-eligible crops and grassland, respectively. As a result, the production levels of smaller crops that are EFA eligible will increase. For example, the production of pulses was simulated to increase by 20 per cent.
Table 7. Production quantity change caused by CAP greening for selected crops and total production in the EU-27 (per cent change relative to the baseline)

<table>
<thead>
<tr>
<th>Farm specialisation</th>
<th>Wheat</th>
<th>Barley</th>
<th>Rape</th>
<th>Pulses</th>
<th>Total production</th>
<th>Farm size (EUR)</th>
<th>Wheat</th>
<th>Barley</th>
<th>Rape</th>
<th>Pulses</th>
<th>Total production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specialist COP</td>
<td>−3.4</td>
<td>−6.9</td>
<td>−3.8</td>
<td>44.2</td>
<td>−2.2</td>
<td>&lt;2,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specialist other field crops</td>
<td>−1.1</td>
<td>−5.5</td>
<td>−3.2</td>
<td>59.3</td>
<td>−1.9</td>
<td>&gt;2,000 ≤4,000</td>
<td>−2.9</td>
<td>−3.7</td>
<td>−12.4</td>
<td>−41.0</td>
<td>−3.0</td>
</tr>
<tr>
<td>Specialist horticulture</td>
<td>6.3</td>
<td>4.0</td>
<td>−3.9</td>
<td>33.8</td>
<td>−1.6</td>
<td>&gt;4,000 ≤8,000</td>
<td>−2.5</td>
<td>−4.2</td>
<td>−7.1</td>
<td>−3.9</td>
<td>−1.8</td>
</tr>
<tr>
<td>Specialist wine</td>
<td>−2.0</td>
<td>−3.5</td>
<td>6.1</td>
<td>4.4</td>
<td>−0.1</td>
<td>&gt;8,000 ≤15,000</td>
<td>−4.3</td>
<td>−10.6</td>
<td>−6.0</td>
<td>1.8</td>
<td>−1.5</td>
</tr>
<tr>
<td>Specialist orchards—fruits</td>
<td>−2.6</td>
<td>−3.4</td>
<td>−11.2</td>
<td>1.6</td>
<td>−0.3</td>
<td>&gt;15,000 ≤25,000</td>
<td>−5.5</td>
<td>−10.2</td>
<td>−7.3</td>
<td>3.0</td>
<td>−1.6</td>
</tr>
<tr>
<td>Specialist olives</td>
<td>−3.4</td>
<td>−2.9</td>
<td>n.a.</td>
<td>3.4</td>
<td>0.0</td>
<td>&gt;25,000 ≤50,000</td>
<td>−4.7</td>
<td>−6.7</td>
<td>−4.6</td>
<td>6.9</td>
<td>−1.2</td>
</tr>
<tr>
<td>Permanent crops combined</td>
<td>−4.0</td>
<td>−6.3</td>
<td>7.0</td>
<td>3.5</td>
<td>−0.2</td>
<td>&gt;50,000 ≤100,000</td>
<td>−3.7</td>
<td>−5.9</td>
<td>−4.8</td>
<td>18.1</td>
<td>−0.9</td>
</tr>
<tr>
<td>Specialist milk</td>
<td>−3.3</td>
<td>−5.1</td>
<td>−3.6</td>
<td>−3.9</td>
<td>−0.2</td>
<td>&gt;100,000 ≤250,000</td>
<td>−2.6</td>
<td>−5.2</td>
<td>−3.5</td>
<td>19.0</td>
<td>−0.7</td>
</tr>
<tr>
<td>Specialist sheep and goats</td>
<td>−6.9</td>
<td>−12.0</td>
<td>−2.1</td>
<td>−19.1</td>
<td>−0.7</td>
<td>&gt;250,000 ≤500,000</td>
<td>−2.6</td>
<td>−4.7</td>
<td>−2.9</td>
<td>33.9</td>
<td>−0.6</td>
</tr>
<tr>
<td>Specialist cattle</td>
<td>−6.2</td>
<td>−9.2</td>
<td>−12.1</td>
<td>−24.9</td>
<td>−1.1</td>
<td>&gt;500,000 ≤750,000</td>
<td>−2.5</td>
<td>−5.5</td>
<td>−4.2</td>
<td>51.4</td>
<td>−0.8</td>
</tr>
<tr>
<td>Specialist granivores</td>
<td>−3.3</td>
<td>−4.3</td>
<td>−3.9</td>
<td>40.4</td>
<td>−0.7</td>
<td>&gt;750,000 ≤1,000,000</td>
<td>−2.9</td>
<td>−5.9</td>
<td>−5.0</td>
<td>51.7</td>
<td>−0.8</td>
</tr>
<tr>
<td>Mixed crops</td>
<td>−2.6</td>
<td>−7.9</td>
<td>−9.6</td>
<td>18.6</td>
<td>−0.7</td>
<td>&gt;1,000,000 ≤1,500,000</td>
<td>−3.0</td>
<td>−6.9</td>
<td>−3.7</td>
<td>42.9</td>
<td>−1.0</td>
</tr>
<tr>
<td>Mixed livestock</td>
<td>−1.9</td>
<td>−3.4</td>
<td>−3.0</td>
<td>9.1</td>
<td>−0.6</td>
<td>&gt;1,500,000 ≤3,000,000</td>
<td>−1.8</td>
<td>−6.3</td>
<td>−5.0</td>
<td>99.8</td>
<td>−1.2</td>
</tr>
<tr>
<td>Mixed crops and livestock</td>
<td>−3.2</td>
<td>−5.1</td>
<td>−4.1</td>
<td>37.4</td>
<td>−1.0</td>
<td>&gt;3,000,000</td>
<td>−2.3</td>
<td>−4.1</td>
<td>−3.2</td>
<td>92.9</td>
<td>−1.2</td>
</tr>
<tr>
<td>EU-27</td>
<td>−3.1</td>
<td>−6.2</td>
<td>−4.0</td>
<td>20.3</td>
<td>−0.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Model results.

Note: The production change is calculated as the average of production changes over all main sectors (including animal sectors) weighted by production value. Only selected sectors are reported in the table, while the figures for total production reflect the changes over all sectors (including those not reported in the table). Only some marginal sectors are excluded from the total production calculation (e.g. other vegetables, other industrial crops, other crops, nurseries, flowers) because these sectors are not accurately represented in FADN.
relative to the baseline in the EU-27. The impact of CAP greening on animal production (not reported) is small, as the impact on grassland has two opposite effects. The expansion of grassland due to the grassland measure stimulates on-farm feed production, while the corresponding decrease in arable crop area (contributed to by the EFA measure, as set-aside is promoted) has an opposite effect, as it reduces on-farm production of arable-based feed.

The total production changes by farm specialisation and farm size aggregated at EU-27 level reveal more sizeable production effects for certain farm specialisations, but they are still below −3 per cent. For individual crops, the change is greater, in particular for some farm specialisations (e.g. permanent crops, COP, sheep and goats, cattle and mixed farms). Permanent crop and livestock farms tend to be particularly affected by the crop diversification measure because of the less diversified production structure of these farms on arable land and because of the low production levels in the baseline of some of the affected arable crops. In terms of farm size groups, the most affected are the small and large farm economic size classes, whereas middle-sized farms show smaller changes in production (Table 7).

Figure 2 shows the distribution of production change across individual farms in the EU-27 for total production and for selected sectors. The vertical axis is similar to that in Figure 1, although we cut the axis at 35 per cent, to better illustrate the changes for the affected farms. The remaining farms (65 per cent) not shown in the figure have no change in production. As Figure 2 shows, around 29 per cent of farms in the EU-27 (in line with Table 3) register a change in total production. Although some farms report a large total production change, for the vast majority of farms affected by CAP greening (25 per cent of total farms) the rate of change varies between −25 and 10 per cent. The production changes for selected crops vary between −100 and 100 per cent. A 100 per cent production change occurs for an individual crop if farms introduce it as a new crop to comply with the diversification requirements or because it is an EFA-eligible crop. Similarly, a −100 per cent production change occurs when farms replace an arable crop with an EFA-eligible crop or with grassland to comply with the grassland measure.

The proportion of affected farms is around 18 per cent for pulses, 17 per cent for wheat, 15 per cent for barley and 5 per cent for rape (Figure 2). Figure 2 shows that a substantial proportion of farms (8 per cent) increase pulse production by 100 per cent, meaning that it is a new crop on these farms that has been introduced mainly as a result of the EFA measure. There are also some farms (7 per cent) that decrease pulse production. These farms

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22 For comparison, the simulation results of Gocht et al. (2017) show that the CAP greening production effects at sector level for different farm types in the EU vary between +4 per cent and −4 per cent.

23 The large total production changes at farm level (i.e. the extreme negative and positive production changes) are often only a statistical effect caused by a shift in production from higher value outputs to lower value outputs and vice versa. This shift in production structure affects the production value-based weights used to aggregate production changes at farm level by increasing the importance of higher value sectors in total production and thus also their weight used for the aggregation.
include those that already have more than the required EFA in the baseline or are exempt from the EFA measure but not from the diversification and/or grassland measures, which cause pulse cultivation area (and pulse production) to decrease when farms need to reallocate pulse cultivation area to other uses to comply with those measures.

4.4. Income effects

The land reallocation and production effects induced by CAP greening reported above largely explain the income changes.\textsuperscript{24} The results reported in Table 8 show that the decrease in income caused by the implementation of CAP greening measures is rather small when aggregated at EU-27 level, at around 1 per cent compared with the baseline. The standard deviation of the income changes at MS level is about 1.3 per cent.

The results by production specialisation and farm size aggregated at EU level reveal a more significant income effect for certain farm specialisations, but they remain below 2 per cent (Table 8). The exceptions are farms that specialise in granivores and specialist cattle. Farms that specialise in livestock experience the biggest drop in income because they are affected by both the permanent grassland and the crop diversification measures. They tend to have a less diversified production structure on their arable land, given that their

\textsuperscript{24} Income is calculated as the difference between total revenues (production sales and subsidies) and variable costs (e.g. expenditure on fertilisers, pesticides, seeds, feeding).
main activity is not necessarily linked to arable cropping. Livestock farms are more likely to breach the minimum requirement on number of crops in the baseline and thus need to introduce new crops to comply with the diversification measure, which is more costly than the reallocation of land among existing crops (as is more often required in COP-specialised farms).

By farm size, the most affected are farms with a large economic size, followed by small farms. Middle-sized farms are less affected by CAP greening (Table 8). As explained above, this is owing to the relatively minor impact of CAP greening on land use and production for these farms.

Similar magnitudes of income effects to those shown here were found in other studies using individual farm models (e.g. Solazzo et al., 2014; Cortignani and Dono, 2015; Vosough-Ahmadi et al., 2015). For example, the simulations carried out by Solazzo and Pierangeli (2016) showed an average decrease in income of 0.4 per cent for farms in Northern Italy. Cortignani and Dono (2015) reported a more substantial decline in income, of 2.1 per cent, in west-central Sardinia (Italy). One reason for this larger decrease in income reported by Cortignani and Dono (2015) could be the higher EFA rate (7 per cent) in their analysis, compared with the 5 per cent level used here. In addition, Vosough-Ahmadi et al. (2015) reported a more sizeable income reduction (−3 per cent) for beef and sheep farms in Scotland, which appears to be in line with our findings for this farm specialisation. Solazzo et al. (2014) also reported a significant income decrease, varying between 1.9 and 2.3 per cent, for tomato farms in Northern Italy. In contrast to individual farm models,

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Table 8. Income change caused by CAP greening in the EU-27 (per cent change relative to the baseline)

<table>
<thead>
<tr>
<th>Farm specialisation</th>
<th>EU</th>
<th>SD at MS level</th>
<th>Farm size (EUR)</th>
<th>EU</th>
<th>SD at MS level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specialist COP</td>
<td>−1.74</td>
<td>1.75</td>
<td>&lt;2,000</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
<tr>
<td>Specialist other field crops</td>
<td>−1.80</td>
<td>2.91</td>
<td>&gt;2,000 ≤4,000</td>
<td>−3.19</td>
<td>0.84</td>
</tr>
<tr>
<td>Specialist horticulture</td>
<td>−1.72</td>
<td>4.34</td>
<td>&gt;4,000 ≤8,000</td>
<td>−1.82</td>
<td>1.76</td>
</tr>
<tr>
<td>Specialist wine</td>
<td>−0.06</td>
<td>0.24</td>
<td>&gt;8,000 ≤15,000</td>
<td>−1.48</td>
<td>2.27</td>
</tr>
<tr>
<td>Specialist orchards—fruits</td>
<td>−0.30</td>
<td>0.62</td>
<td>&gt;15,000 ≤25,000</td>
<td>−1.51</td>
<td>2.04</td>
</tr>
<tr>
<td>Specialist olives</td>
<td>0.00</td>
<td>0.08</td>
<td>&gt;25,000 ≤50,000</td>
<td>−1.18</td>
<td>1.99</td>
</tr>
<tr>
<td>Permanent crops combined</td>
<td>−0.13</td>
<td>2.66</td>
<td>&gt;50,000 ≤100,000</td>
<td>−1.05</td>
<td>1.59</td>
</tr>
<tr>
<td>Specialist milk</td>
<td>−0.56</td>
<td>1.65</td>
<td>&gt;100,000 ≤250,000</td>
<td>−0.80</td>
<td>1.75</td>
</tr>
<tr>
<td>Specialist sheep and goats</td>
<td>−0.81</td>
<td>4.58</td>
<td>&gt;250,000 ≤500,000</td>
<td>−0.62</td>
<td>1.86</td>
</tr>
<tr>
<td>Specialist cattle</td>
<td>−2.40</td>
<td>18.34</td>
<td>&gt;500,000 ≤750,000</td>
<td>−0.79</td>
<td>2.75</td>
</tr>
<tr>
<td>Specialist granivores</td>
<td>−19.32</td>
<td>5.57</td>
<td>&gt;750,000 ≤1,000,000</td>
<td>−0.87</td>
<td>3.96</td>
</tr>
<tr>
<td>Mixed crops</td>
<td>−0.72</td>
<td>2.16</td>
<td>&gt;1,000,000 ≤1,500,000</td>
<td>−1.08</td>
<td>3.99</td>
</tr>
<tr>
<td>Mixed livestock</td>
<td>−1.13</td>
<td>1.89</td>
<td>&gt;1,500,000 ≤3,000,000</td>
<td>−1.37</td>
<td>6.23</td>
</tr>
<tr>
<td>Mixed crops and livestock</td>
<td>−1.11</td>
<td>2.92</td>
<td>&gt;3,000,000</td>
<td>−2.24</td>
<td>4.55</td>
</tr>
<tr>
<td>EU-27</td>
<td>−1.05</td>
<td>1.27</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Model results.
Note: Farm incomes were calculated as the difference between farm revenues and variable costs (including subsidies).
SD, standard deviation. n.a., not available
regional representative farm models that account for the market effects of CAP greening have reported an increase in income (Van Zeijts et al., 2011; Gocht et al., 2017). This discrepancy in results between the two types of models can be explained by the fact that individual farm models (including IFM-CAP) do not account for the market price feedback effects of CAP greening, which, according to Van Zeijts et al. (2011) and Gocht et al. (2017), tend to offset the productivity reduction caused by greening measures.

Figure 3 shows the distribution of the income change relative to the baseline across the total farm population in the EU-27. The vertical axis is cut at 35 per cent, to better illustrate the changes for the affected farms. The remaining farms (65 per cent) have no change in income. Although the income decrease for some farms is substantial (a drop in income of more than 30 per cent for around 1 per cent of farms), most farms affected by CAP greening (25 per cent of farms) experience an income decrease of less than 30 per cent or even close to zero. In around 2 per cent of the farms, an increase in income is driven by the switch to more risky production activities. These farms experience improved profitability, but this is offset by a loss of utility. This is shown in Figure 3, which shows that all farms report a negative utility change as a result of the introduction of CAP greening.

Figure 4 shows the distribution of compliance costs resulting from CAP greening across the farm population in the EU-27. These costs represent the per hectare loss (or utility decrease) caused by the adoption of greening requirements. Most farms affected by CAP greening (14 per cent of all farms)

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Note that the large income change for some farms shown in Figure 4 is often due to the low income level in the baseline.
have costs between 10 EUR/ha and 100 EUR/ha. Costs greater than 100 EUR/ha are observed in 2 per cent of farms. These farms have high compliance costs often because they own a small agricultural area and specialise in capital- and labour-intensive activities (e.g. vegetable production and granivores) with high per hectare production and profits. CAP greening inflicts sizeable costs on these farms, as they are usually involved in more profitable activities and need to switch to less profitable crops to fulfil the CAP greening requirements, resulting in relatively large per hectare losses. Around 13 per cent of farms have rather insignificant compliance costs (between 0 EUR/ha and 10 EUR/ha). Although these farms are affected by CAP greening, they incur small compliance costs because the land adjustment (and thus the profitability loss) required by CAP greening is rather small.

5. Discussion and conclusions

This paper presents the first EU-wide individual farm-level model (IFM-CAP) aiming to assess the impacts of CAP greening on farm economic and environmental indicators. The rationale for developing a farm-level model is based on the increasing demand for micro-simulation tools able to model farm-specific policies and capture farm heterogeneity across the EU in terms of policy representation and impacts. In this paper, the IFM-CAP is applied to simulate the responses of EU farmers to the CAP greening measures introduced by the 2013 CAP reform.

From a policy perspective, the main finding of the application of this model is that the effect of CAP greening on farm income is rather small at the aggregate level. Although the proportions of farms and UAA subject to CAP greening are sizeable (55 per cent of all farms and 86 per cent of UAA) in the EU-27, the area reallocated as a result of the adoption of CAP greening measures represents only 4.5 per cent of UAA and agricultural income decreases by around 1 per cent. These results are explained by the fact that

![Image](https://example.com/image.png)

**Fig. 4.** The distribution of the compliance costs resulting from CAP greening across the farm population in the EU-27 (EUR/ha).
many farms subject to CAP greening comply with the greening requirements in the baseline (i.e. in the absence of the greening). At the individual farm level, the impact could be more pronounced (e.g. a decrease of production and income of more than 30 per cent), although the number of farms affected by the measures remains relatively small (around 29 per cent of the total farm population). The most constraining measure appears to be the EFA measure, followed by the crop diversification measure.

The relatively small land use effects of CAP greening simulated in our paper indicate that the environmental impacts are rather limited, suggesting that it will not contribute much to improving the CAP’s provision of public goods. This is in line with other studies that found only small changes in environmental indicators in response to CAP greening, such as changes in nutrient surpluses, crop diversity, erosion and greenhouse gas emissions (e.g. Solazzo et al., 2015; Cortignani et al., 2017; Gocht et al., 2017). However, the proponents of CAP greening argue that the inclusion of such measures is a first political step to ‘open the door’ for the future adoption of novel agricultural policy measures promoting a better environmental performance of the EU farming sector. Following this line of reasoning, Galán-Martín et al. (2015) – based on small greening effects seen in Spanish agriculture – suggest that CAP greening needs to be redefined and regionalised to ensure the transition towards a ‘greener’ agriculture.

One needs to be aware when drawing conclusions that our findings obviously reflect the assumptions in the model. First, in our model, we assume a fixed organisational structure, implying that land can be reallocated only within farms in response to the introduction of CAP greening. 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 official or unofficial arrangements with neighbouring farms to rearrange claims for greening payments to ensure compliance and, thus, to avoid a decrease in income related to land reallocation. In such cases, our simulations would overestimate the overall effect. Modelling farmers’ cooperation would require information on personal relationships, farm spatial location, etc., which is beyond the scope of the IFM-CAP model and the available data. In addition, we expect this phenomenon to remain of limited practical relevance.

A second potential caveat to our analysis is that market feedback effects (output price changes) are not taken into account (see, for example, van Zeijts et al., 2011). This is, however, not a major drawback, given the limited EU-wide production effect of CAP greening. Third, certain crops are defined in the model as an aggregation of a set of individual crops (e.g. ‘other cereals’), which may lead to a slight overestimation or underestimation of the simulated impacts, depending on farm production structure and the greening measure in question. Fourth, FADN includes only commercial farms; small non-commercial farms are underrepresented in the database, which may lead to an overestimation of the simulated impacts, as small farms are exempt from the greening measures.
Finally, not all the specificities regarding the ‘greening’ implementation are considered in the model. In particular, we do not consider exemptions from greening obligations for farmers in the ‘small farmers’ scheme’, farmers north of the 62nd parallel and farms with more than 75 per cent of their crops under water. In addition, Member States can opt to define practices that result in a beneficial effect for the climate and the environment equivalent to or greater than that which would result from the three greening obligations. Farms adopting these practices are exempt from the greening measures; this was not considered in this paper either.

Future research should analyse each of these limitations to the current model to test the robustness of the results and to provide a complete picture of the EU-wide impact of CAP greening.

Supplementary data

Supplementary data are available at European Review of Agricultural Economics online.

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