Does the crop diversification measure impact EU farmers' decisions?

An assessment using an Individual Farm Model for CAP Analysis

(IFM-CAP)

Abstract

This paper presents the first EU-wide individual farm level model (IFM-CAP – Individual Farm Model for CAP Analysis) to assess the impacts of the crop diversification measure introduced by the 2013 CAP reform as part of CAP 'greening'. Based on Positive Mathematical Programming, IFM-CAP simulates the behaviour of each individual farmer in the EU-FADN (Farm Accountancy Data Network) database, under the policy constraint of crop diversification and provides distributional impacts over the entire EU farm population. Simulation results show that the effects of the crop diversification measure on the EU farming sector are rather small. At the aggregate EU level, the proportion of the reallocated area due to the diversification measure represents less than 1 % of the total agricultural area and the crop production and income decline by less than 0.5 %. At the individual farm level, the impacts could be more pronounced (more than –25 %), although the number of affected farms by the measure remains small (around 5 % of the total farm population). The most constraining component of the diversification measure appears to be the 75 % threshold imposed for the main cultivated crop.

Keywords: *Common Agricultural Policy; Crop Diversification; Farm Level Model; Positive Mathematical Programming; Land Use; EU*

1. Introduction

The Common Agricultural Policy (CAP) was reformed in 2013 with the aim to enhance the environmental performance of the EU agricultural sector. The key change introduced by the reform was to create a stronger linkage of the direct payments to “agricultural practices beneficial to the climate and environment” (so called 'CAP greening'). 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 respect of ecological focus areas (EU, 2013).

In this paper we attempt to quantify the impact of the crop diversification measure on land use, production and income of EU farm sector. The crop diversification measure targets

land allocation at farm level with the aim to generate environmental public goods to the society. The eligibility and uptake of the crop diversification measure largely depends on farm-specific characteristics (size, cropping pattern, etc.), posing challenges for policy evaluation and raising the need for the application of farm level modelling tools. In fact, most of the currently applied models at EU-wide scale are aggregate models (representative farm, regions, countries, groups of countries) and are not fully able to model policies targeted at farm level without imposing strong *ad hoc* assumptions (Lansink and Peerlings, 1996; Gocht and Britz, 2011; Cantelaube *et al.*, 2012; Louhichi *et al.*, 2013). Farm-specific policies can be better assessed using models that operate at the level of individual farms and that are able to account for farm heterogeneity in terms of policy representation and impacts. The more local and farm-specific the interventions are, the more the modelling at the individual farm-level becomes important (Buysse *et al.*, 2007).

Although several modelling approaches have been used in the literature¹, mathematical programming is the most frequently used method for modelling policies at the farm level in *ex-ante* evaluations. Most of these farm-level models are based either on individual (real) farms (e.g. Buysse *et al.*, 2007; Solazzo and Pierangeli, 2016) or on representative (average) farms (e.g. Gocht and Britz, 2011; Louhichi *et al.*, 2010). Although representative farm models can assess to some extent the farm-specific policies (such as CAP greening), they are subject to some limitations. They cannot model policies for which eligibility depends on individual farm characteristics and location (as is the case for the crop diversification policy) as they are subject to significant aggregation bias. In the case of the crop diversification measure, certain farms have to produce a minimum of two crops, with the main crop representing maximum 75% of 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 requirements will usually be respected (not binding) at the level of the representative farm, although the restriction may be binding at the level of individual farms. In contrast, the other two greening measures – maintenance of permanent pasture and the ecological focus area – can be modelled with representative (average) farms models by imposing less restrictive assumptions even though aggregation bias cannot be fully eliminated. Similar types of policies available within the past CAP (e.g. set-aside, grassland regulation within cross-

¹ Five categories of models are often used in empirical applications: accounting, simulation, agent-based, econometric and mathematical programming (For a review, see Weersink *et al.* 2002; Janssen and Van Ittersum 2007; Louhichi *et al.* 2013).

compliance requirements) were extensively modelled with aggregated models at regional or representative farm level (e.g. Kupker *et al.*, 2006; Philippidis *et al.*, 2006; Schuler and Sattler, 2010).

Another drawback of existing farm models is that most of them are developed for a specific purpose and/or location and, consequently, cannot easily be 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: CAPRI-FT (Gocht and Britz, 2011) and AROPAj (De Cara and Jayet, 2011). The other models cover either a specific Member State (MS) (e.g. FAMOS, Schmid, 2004) or a selected set of MSs/regions (e.g. FARMIS by Offermann *et al.*, 2005, Depperman *et al.*, 2013 and 2016; FSSIM by Louhichi *et al.*, 2010; AGRIPOLIS by Kellermann *et al.*, 2008) or a specific policy issue (e.g. farm-level investment behaviour under different policy settings in Viaggi *et al.* 2010; Raggi *et al.* 2015). To our knowledge there are no individual (real) farm-level models with a full EU coverage available in the literature. Probably the main reasons for this gap relate to the computational difficulty in solving an individual farm-level model with a large spatial coverage such as EU as well as these types of models being very demanding in data (which might not be available or easily accessible), parameterisation and calibration compared to farm-representative models.

With respect to modelling the impact of CAP greening measures, there is a growing literature investigating their socio-economic impacts (e.g. Heinrich 2012; Czekaj *et al.*, 2013; Mahy *et al.*, 2015; Ahmadi *et al.*, 2015). While a number of studies have opened the debate on the effectiveness of greening measures (Matthews, 2012; Westhoek *et al.*, 2013; Singh *et al.*, 2014), the few available farm-level studies contribute only partially to the ongoing debate because they are applied only for specific agricultural sectors and/or selected countries or regions (Heinrich, 2012; Brown and Jones, 2013; Vanni and Cardillo, 2013; Solazzo *et al.*, 2014; Was *et al.*, 2014; Cimino *et al.*, 2015; Mahy *et al.*, 2015; Cortignani and Dono, 2015;;Galán-Martín *et al.*, 2015). Other farm level studies deal with other CAP measures such as decoupled payments (Fragoso *et al.*, 2011; Moro and Sckokai, 2013; Karlsson and Nilson, 2014), the young farmers scheme (Bournaris *et al.*, 2014) or the impact of CAP on natural resource management (Gibbons *et al.*, 2005; Cortignani and Severini, 2009). None of these models allows for a comprehensive EU-wide analysis of CAP greening measures at farm level.

This paper attempts to contribute to the literature by providing the assessment of farm level impacts of crop diversification measure using an EU-wide individual farm-level model,

IFM-CAP (Individual Farm Model for Common Agricultural Policy Analysis). The main advantage of IFM-CAP is that it provides a comprehensive assessment of farm-specific policies such as crop diversification measure by accounting for the full heterogeneity and behaviour of EU commercial farms² in terms of policy representation and impacts and by estimating the distributional impacts of policies across the farm population. The model is developed based on the Farm Accountancy Data Network (FADN) and complemented by external statistical sources.

The paper is structured as follows: Section 2 describes the IFM-CAP model structure, calibration process and data processing. Section 3 presents the baseline and the crop diversification scenarios simulated in this paper. Section 4 describes the results of the model application for the crop diversification measure. Section 5 provides a short discussion of the results and explains the limitations of the model. Finally, Section 6 draws the main conclusions and policy implications.

2. The IFM-CAP model

2.1. Model specification and mathematical structure

The IFM-CAP model is a static Positive Mathematical Programming (PMP) model, which builds on the FADN data, and is complemented by other relevant EU-wide data sources such as the Farm Structure Survey (FSS), Eurostat, CAPRI (Common Agricultural Policy Regional Impact Analysis) database (Britz and Witzke, 2014) and other sources. 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.

IFM-CAP relies on profit maximizing behaviour and attempts to find the optimal land allocation among production activities, taking into account resource (arable and grass land and animal feeding) 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 use by the different agricultural activities. Constraints related to feed availability and feed requirements of animal activities are used to ensure that the total energy, protein and fibre requirements are met by farm-grown or/and purchased feed.

² The Farm Accountancy Data Network (FADN) survey (therefore the IFM-CAP model) does not cover all the farms in the EU but only those that, because of their size, could be considered commercial (the specific threshold varies by each MS) (FADN, 2015).

Farm profit is defined as the sum of gross margins minus a non-linear (quadratic) activity-specific function. The gross margin equals to the total revenue including sales from agricultural products and compensation payments (coupled and decoupled payments) minus the accounting variable costs of production activities. The accounting costs include costs of seeds, fertilisers, crop protection, feeding and other specific costs (Figure 1). The quadratic activity-specific function is a behavioural function introduced to calibrate the farm model to an observed base year situation³, as is usually done in positive programming models. This function intends to capture any type of model misspecification such as aggregation bias, price expectation and lacking representation of risk behaviour, capital and labour perceived costs, and other non-observed non-linear constraints (Heckeley, 2002; de Frahan *et al.*, 2007).

An identical model structure was applied for all modelled FADN farms in order to ensure a uniform handling of all the individual farm models and their results (i.e. farm models have the same equations and variables, but the model parameters are farm specific). There are no cross-farm constraints or relationships assumed in the current version of the model.

The general mathematical formulation of the profit maximization problem of farm f ($= 1, 2, \dots, F$) is as follows:

$$\begin{aligned} \underset{x_{f,i} \geq 0}{\text{Max}} \pi_f = & \sum_i (p_{f,i} y_{f,i} + s_{f,i}) x_{f,i} + e_f t_f - \sum_{i,k} C_{f,i,k} x_{f,i} - \sum_i d_{f,i} x_f \\ & - 0.5 \sum_{i,i'} x_{f,i} Q_{f,i,i'} x_{f,i'} \end{aligned} \quad (1)$$

subject to

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

where indices $i, i' = 1, 2, \dots, I$ denote the crop and livestock activities and products;⁴ $k = 1, 2, \dots, K$ the intermediate inputs (i.e. fertiliser, seeds, crop protection, etc.) and $m = 1, 2, \dots, M$ the resource and policy constraints (e.g. agricultural land, quotas, set-aside, animal feeding). π_f is the objective function value of farm f , $x_{f,i}$ is the non-negative level (i.e.

³ In principle, any non-linear convex function with the required properties can be used to represent the behavioural function. For simplicity, and in the absence of any strong arguments for other types of functions, a quadratic function is often employed. Some exceptions can be found in Paris and Howitt (1998 and 2000), Mérel and Bucaram (2010) and Mérel *et al.* (2011).

⁴ To simplify mathematical notations we assume one product per activity, so that indices for activity and product are identical.

hectares, heads) of activity i , $p_{f,i}$ denotes product prices (including for feed and young animals), $y_{f,i}$ are yields, $s_{f,i}$ are coupled payments, e_f are decoupled payments, t_f is eligible area for decoupled payments,⁵ $C_{f,i,k}$ are accounting variable costs for intermediate input k and activity i , $d_{f,i}$ is the linear term of the behavioural activity function and $Q_{f,i,i'}$ is the quadratic term of the behavioural activity function. $A_{f,i,m}$ are coefficients for resource and policy constraints (i.e. land, set-aside obligations, quotas 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.⁶

It is important to note that the removal of the accounting variable costs from the quadratic behavioural function by introducing a Leontief production function for variable input costs presents some advantages: (i) it provides an explicit link between production activities and the total physical input use; (ii) it eases the linkage to environmental indicator calculation; and (iii) it allows the simulation of policy measures linked to specific farm management. Its main limitation, according to Heckeley and Wolff (2003), is the lack of rationalization, as intermediate input uses are assumed to be independent of the unknown marginal costs captured by the quadratic behavioural function.

2.2. Model calibration

Over the last decade, several PMP approaches have been developed to derive the parameters of the behavioural functions ($d_{f,i}$ and $Q_{f,i,i'}$) and to accurately calibrate programming models⁷. However, as the number of observations is usually not sufficient 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 $Q_{f,i,i'}$ 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

⁵ The eligible area in MS implementing the Single Payment System (SPS) is equal to the amount of farm's entitlements, whereas in MS which implement the Single Area Payment System (SAPS) it is equal to the total agricultural area. This implies that a given farm receives decoupled payment corresponding to the amount of entitlements (s)he owns in MS implementing SPS and corresponding to the total agricultural area in MS implementing SAPS. Each farm receives a uniform unit payment for all eligible area as available in FADN data. However, the unit payments may vary across farms in a MS or region depending on the implemented decoupled payment model in a particular MS. Note that since we do not model the land market we also do not consider the market for entitlements. This modelling of decoupled payments implies that they are fully decoupled from production.

⁶ A detailed mathematical description of the first version of IFM-CAP can be found in Louhichi *et al.* (2015).

⁷ For a review on PMP models see de Frahan *et al.* (2007), Mérel and Bucaram (2010), Paris (2011), Mérel *et al.* (2011) and Heckeley *et al.* (2012).

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

In this paper, we use both multiple observations (cross-sectional data) and prior information on supply elasticities ($\bar{\epsilon}_{r,i,i'}$) and on dual values of constraints ($\bar{\rho}_{r,m}$) at NUTS 2 regional level r ($= 1, 2, \dots, R$) to calibrate the model. Supply elasticities are taken from Jansson and Heckelei (2011) who econometrically estimated them at NUTS 2 level. Prior information on dual values is derived from FADN. The use of multiple observations (i.e. cross-sectional data) allows to estimate the full set of $Q_{f,i,i'}$ coefficients for crop activities and to base the model specification on observed differences in behaviour. The use of exogenous information allows to avoid arbitrary behaviour of the model in the simulation phase. More exactly, with the proposed calibration method we aim not only to exactly reproduce the observed activities in the base-year (2007-2009), $x_{f,i}^0$, - as most of the PMP methods do - but also to ensure that the estimated NUTS2 supply responses (NUTS2 averages of $\epsilon_{f,i,i'}$) and the estimated dual values of resources ($\rho_{f,m}$) are as closely as possible to the given ones ($\bar{\epsilon}_{r,i,i'}$; $\bar{\rho}_{r,m}$).

To perform the estimation we derive the first-order conditions (FOCs) of the optimization model (1) and (2) (Heckelei, 2002) and, then, we apply the Highest Posterior Density (HPD) method (Heckelei *et al.*, 2005)⁸ to estimate the unknown parameters ($d_{f,i}$, $Q_{f,i,i'}$ and $\rho_{f,m}$).

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

- The HPD model minimizes, in each NUTS 2 region, the weighted sum of normalized 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 normalized squared deviations of farm dual values are weighted with the proportion of the farm in the NUTS 2 region, $\omega_f^\rho = w_f / \sum_f w_f$, to obtain a weighted average

⁸ 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 (Heckelei *et al.*, 2005 and 2008).

normalized squared deviation at the NUTS 2 level, where w_f is the farm weighting factor reflecting the number of farms in the population that is represented by farm f .

- The normalized squared deviations of regional supply elasticities are weighted with the proportion of observed activity level in the total regional land, $\omega_r^\varepsilon = N_r x_{i,r}^0 / \sum_i x_{i,r}^0$, to allow activities with a high proportion of the area to dominate, where N_r is the number of observed crop activities (for $x_{r,i}^0 > 0$) in NUTS 2 region r .

- Prior information on dual values, $\bar{\rho}_{r,m}$, are set to the average land rental price at regional (NUTS2) level for (arable and grassland) land, 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 (i.e. knowing that the only constraints in the base year for crops are land, sugar beet quota and obligatory set-aside) for the set-aside obligations. Large standard deviations for prior information are assumed in order to allow for sufficient flexibility around the prior values. As such, the individual farm data can still dominate the parameter estimation. 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. The livestock and feeding activities are calibrated following the approach of Helming et al. (2001) (with all off-diagonal elements of Q being set to zero)⁹.

- In order 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). Moreover, the non-negativity condition was omitted due to the heavy computational requirement. That is, all optimal activity levels are assumed to be positive. This implies that we may over-estimate the profitability of non-observed activities.

- The exchange of production factors and production rights between farms is not allowed (i.e. there are neither land nor quota markets).

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

⁹ The proposed approach by Helming et al. (2001) 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 behavioural functions (for more details see Louhichi *et al.*, 2015).

$$Min H_r = \left[\sum_{f,m} \omega_f^\rho \frac{(\rho_{f,m} - \bar{\rho}_{r,m})^2}{(\sigma_{r,m}^\rho)^2} + \sum_i \omega_r^\varepsilon \frac{(\varepsilon_{r,i,i} - \bar{\varepsilon}_{r,i,i})^2}{(\sigma_{r,i,i}^\varepsilon)^2} \right] \quad (3)$$

Subject to:

$$y_{f,i} p_{f,i} + s_{f,i} - \sum_k C_{f,i,k} - d_{f,i} - \sum_{i'} Q_{f,i,i'} x_{f,i'}^0 - \sum_m A_{f,i,m} \rho_{f,m} = 0 \quad (4)$$

$$y_{f,i} p_{f,i}^q + s_{f,i} - \sum_k C_{f,i,k} - d_{f,i} - \sum_{i'} Q_{f,i,i'} x_{f,i'}^0 - \sum_m A_{f,i,m} \rho_{f,m} = 0 \quad (5)$$

$$b_{f,m} - \sum_i A_{f,i,m} x_{f,i}^0 = 0 \quad (6)$$

$$b_{f,m} - \sum_i A_{f,i,m} q_{f,i}^p = 0 \quad (7)$$

$$\varepsilon_{f,i,i'} = \left[Q_{f,i,i'}^{-1} - \sum_m \left(\sum_j A_{f,j,m} Q_{f,i,j}^{-1} \left(\sum_{j,j'} A_{f,j,m} Q_{f,j,j'}^{-1} A_{f,j',m} \right)^{-1} \sum_j A_{f,j,m} Q_{f,j,i'}^{-1} \right) \right] \frac{gm_{f,i'}}{x_{f,i}^0} \quad (8)$$

$$\varepsilon_{r,i,i'} = \frac{\sum_f w_f x_{f,i}^0 \varepsilon_{f,i,i'}}{\sum_f w_f x_{f,i}^0} \quad (9)$$

$$\begin{aligned} \sum_j Q_{f,i,j} Q_{f,j,i'}^{-1} &= 1 \quad \forall i = i' \\ \sum_j Q_{f,i,j} Q_{f,j,i'}^{-1} &= 0 \quad \forall i \neq i' \end{aligned} \quad (10)$$

$$B_{ft,i,i'} = \sum_j L_{ft,i,j} L_{ft,i',j} \quad L_{ft,i,i'} = 0 \quad \text{for } i' > i \quad (11)$$

$$Q_{f,i,i'} = \sum_{ft} \delta_{f,i} B_{ft,i,i'} \delta_{f,i'} \quad (12)$$

1

2 where indices $j, j' = 1, 2, \dots, I$ (similar to i, i') denote the agricultural activities and products;

3 $p_{f,i}^q$ is farm in-quota price (Euros/Ton); $p_{f,i}^q$ is the farm in-quota price (Euros/Ton); $q_{f,i}^q$ is the

4 farm in-quota production (Ton); $gm_{f,i}$ is gross margin for activity i (EUR/ha) with $gm_{f,i} =$

5 $p_{f,i} y_{f,i} + s_{f,i} x_{f,i} - \sum_k C_{f,i,k} x_{f,i}$; $\bar{\rho}_{r,m}$ and $\sigma_{r,m}^\rho$ are mean and standard deviation of the

6 regional dual values of resource and policy constraints (land rental prices, in-quota prices)

7 used as prior; $\bar{\varepsilon}_{r,i,i}$ and $\sigma_{r,i,i}^\varepsilon$ are mean and standard deviation (assumed to be 50% of the

mean) of regional own price elasticities of supply used as prior (Jansson and Heckelei 2011);

and $\delta_{f,i}$ is scaling factor with $\delta_{f,i} = \sqrt{1/x_{f,i}^0}$.

The endogenous variables of the HPD problem defined in equations (3)-(11) are: (i) the dual values of resource and policy constraints, $\rho_{r,m}$, (ii) the farm own- and cross- price elasticities of supply, $\varepsilon_{f,i,i'}$, (iii) the regional own- and cross- price elasticities of supply, $\varepsilon_{r,i,i'}$, (iv) the elements of the lower triangular Cholesky decomposition related to $B_{ft,i,i'}$ parameters, $L_{ft,i,i'}$, and (v) the behavioural parameters $d_{f,i}$ and $Q_{f,i,i'}$ (including the inverse matrix $Q_{f,i,i'}^{-1}$).

The estimated $B_{ft,i,i'}$ parameters related to $Q_{f,i,i'}$ (see further) are common across farms belonging to the same region and the same farm type (group) ft . Farms are grouped based on 14 production specializations¹⁰ ($ft = 1, 2, \dots, 14$). However, the $Q_{f,i,i'}$ parameters are 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.

The estimation of $B_{ft,i,i'}$ (and thus $Q_{f,i,i'}$) parameters 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.¹¹

The constraints (4) and (5) represent the FOCs of the optimization model, (1) and (2), for crop activities and in-quota sugar beet production, respectively. Equations (6) and (7) represent the FOC for land and quota constraints. Equations (8) and (9) compute supply elasticities at farm and NUTS2 levels, respectively¹². Equation (10) calculates the farm-specific $Q_{f,i,i'}$ parameters. Equation (11) is the Cholesky decomposition which ensures appropriate curvature properties of the estimated quadratic cost function (i.e. convex in

¹⁰ We consider 14 production specializations defined by the TF14 grouping in FADN (FADN, 2015).

¹¹ This approach does not allow farms to choose activities not observed in the same region and farm type. However, given that we do not account for full farm structural change (e.g. farm re-specialization) in our model, this assumption seems plausible. This consideration is based on the assumption that if activities are not observed in other similar farms, it indicates that they likely were not economically feasible because of various unobserved factors (e.g. experience, skills, fixed costs, environmental conditions) that are not accounted for in our model.

¹² Given the fact that yields and gross margins are constant per unit of crop production activity, the employed 'supply elasticities' can be defined as land allocation elasticities with respect to changes in gross margins (see Heckelei, 2002 and Heckelei and Wolf, 2003).

activity levels). Finally, equation (12) calculates farm-specific quadratic parameters of the cost behavioural function.

The estimated parameters ($d_{f,i}$, $Q_{f,i,i'}$ and ρ_m) guarantee the reproduction of the observed production structure when the model (1) and (2) is run for the base year.

2.3. Data

As mentioned above, the primary data source used to parameterize IFM-CAP are individual farm-level data from the FADN database (FADN, 2015) for the three-year average around 2008 (2007, 2008 and 2009). The FADN data is complemented by other external EU-wide data sources such as the Eurostat, FSS and CAPRI databases for variables not available in FADN (Figure 1). However, most of these external data are not directly used in the model but only serve as input in the estimations.¹³

In total 37 crop activities and 16 animal activities are represented in IFM-CAP. Some minor activities are grouped in mixed categories (e.g. other cereals, other vegetables) in order to speed up the computational time and to reduce the parametrization complexity of the model.

For each farm the following variables are derived from FADN: levels (hectares or number of animal heads), yields, product prices for all crop and animal activities, available farmland (utilized agricultural area, arable land and grassland), rental prices, coupled and decoupled subsidies and set-aside rate¹⁴. Data on labour and capital costs are not included; as explained before, they are not explicitly modelled but captured by the quadratic terms of the behavioural activity function.

Before being used, the FADN data are screened and adjusted to the IFM-CAP modelling framework. This includes the identification and correction of outliers and handling the missing values. The outlier correction is applied to the price data using the interquartile range rule ($\pm 1.5 \times \text{IQR}$). The reason for correcting the price data is because they are indirectly derived from the original FADN data and for some farms they may deviate significantly from the rest of the sample¹⁵. The outliers were replaced with the regional and farm-type average prices calculated from FADN.

¹³ A detailed data description of the data handling in IFM-CAP model can be found in Louhichi *et al.* (2015).

¹⁴ Note that the set-aside rate in IFM-CAP is set to the observed rate and not to the policy rate as established in the CAP because for many farms the observed rate is found to be lower than the policy rate. This consideration is made for the purpose to avoid data distortions for activity levels and/or infeasibilities in model calibration.

¹⁵ Prices are derived by dividing production value and production quantity. The production value, in turn, is calculated as the sum of monetary value of sales, own consumption and change of stocks, which may result in

The handling of missing data concerns production value (and price) and/or output quantity (and yield) for crop activities for which a (positive) cultivated area is reported¹⁶. By setting crop prices or yields equal to the average at regional level (NUTS 2), we derive the missing data on production value and/or output quantity. Fodder crops (i.e. fodder maize, fodder root crops, pasture, straw and other fodder on arable land) represent a special case since only data on cultivated fodder area is available in FADN, while the quantity and value of fodder production is often not reported in FADN because it is usually consumed on farm. In this case we use external sources to obtain price and yield data (see further) which then allow us to calculate production value and quantity.

Data on unit input costs of crops, animal feeding and sugar beet quota are not directly available in the FADN database, but are estimated based on FADN data combined with external data sources. We employ the HPD estimation approach to estimate these missing data in FADN. The advantage of the HPD in this context is that it allows using prior information directly from FADN and/or from other sources as well as it allows taking into account data-consistency constraints (Heckeley et al. 2005, 2008). More details are provided in Appendix A.

3. Baseline and the crop diversification scenario

3.1. Baseline

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 an external baseline¹⁷. More precisely, we use CAPRI projections¹⁸ to construct the IFM-CAP baseline for the year 2020, taken as the time horizon for running policy 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

negative, very small or very large positive (i.e. out-of-range) values for the derived prices for some products and farms. For example, a farm with high carry-over stock and experiencing high drop in sale prices may report a negative total production value, which will generate a negative product price.

¹⁶ Since FADN assigns zero values to variables for which data is not collected, we decided to also consider all zero values for existing (non-zero) crop activity levels as ‘missing values’.

¹⁷ The advantage of this approach is that we can indirectly benefit from specialized expert knowledge on market projections/outlooks employed for the construction of the external baseline. The second advantage is that IFM-CAP is used for policy impact assessment which ensures the consistency and comparability with other models for which the same baseline is used. The drawback of this choice is that consistency may not be fully achievable between IFM-CAP and the model assumptions used for baseline construction as each model may rely on specific methodology, data sources, commodity and geographic aggregates and policy and economic assumptions (Blanco-Fonseca, 2010).

¹⁸ For more information, refer to Blanco-Fonseca (2010), Britz and Witzke (2014) and Himics *et al.* (2013).

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 (Nii-Naate, 2011; Himics, et al., 2013; Britz and Witzke, 2014).

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 for input costs and behavioural function parameters; 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 NUTS2 level, we impose 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 2020. Structural change is not taken into account, i.e. total farm area is assumed constant and no farm exit/entry neither substitution between arable and grassland are considered.

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

3.2. *Crop diversification scenario*

The 2013 CAP reform introduces specific measures to enhance the provision of public goods by farmers, the so called "greening payment" (EU, 2013). Under the CAP greening measures, 30% 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 5% of land to "Ecological Focus Areas" (EFAs).

In this paper we focus on modelling the crop diversification measure. The crop diversification requirements apply only to farms with an arable area greater than 10 hectares. Farms with more than 75 % of their total eligible land covered by grassland, farms with 75% of their arable area cultivated with forage and organic farms are not subject to the crop diversification measure.¹⁹ Furthermore, there are additional 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 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

¹⁹ MS could also opt to exempt farms that apply 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 the scenario due to data limitations.

land and the two main crops together should not cover more than 95 % of the arable land. The simulated policy scenario considers that all the farmers would fully comply with the requirements imposed by the regulation. Table 1 shows how crop diversification measure was modelled in this study.

4. Results

In this section we report the simulation results for the EU-27.²⁰ We first discuss the number of farms that are concerned and affected by the measure. Then we analyse how the crop diversification scenario affects land use, production and income effects and provide results at MS and EU-27 aggregate level, by farm specialization and farm size and for the full distribution across farm population.

4.1. *Share of farms concerned and affected by the crop diversification policy*

Table 2 (column A) provides statistics on the simulated number of concerned farms, i.e. those farms that are subject to the crop diversification measure under the baseline scenario. Out of the five million commercial farms represented in IFM-CAP for the EU-27, only 31 % are concerned, the rest (69 %) are exempted from the measure in the baseline. The latter include non-arable farms, farms with a small arable area (less than 10 ha), farms with a large proportion of land planted with fodder crops or grassland or organic farms. The MSs with the largest proportion of concerned farms include Denmark (91 %), Slovakia (90 %), Finland (78 %), Sweden (75 %), Germany (74 %), Lithuania (69 %), the Czech Republic (67 %), Belgium-Luxembourg (64 %) and France (60 %). These MSs have a farm structure dominated by large farms and/or by specialized 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 (12 %) and Greece (14 %). Many of these MSs have a high proportion of small 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 2, column A).

²⁰ The IFM-CAP model is programmed in GAMS (General Algebraic Modelling System) and solved using CONOPT and SBB (Standard Branch and Bound algorithm)²⁰ solvers. CONOPT is applied to solve the non-linear program (NLP) in calibration and baseline, while SBB is used to solve the mixed integer non-linear program (MINLP) induced by the modelling of the crop diversification scenario because the restriction on the number of crops implies a discrete choice decision.

Of these concerned farms, about 84% is already in line with the diversification measure in the baseline scenario. This means that they do not have to make any changes in their land allocation in response to the crop diversification requirements, since they already comply anyways. As such they are not affected by the policy. The remaining 16% of concerned farms (corresponding to 5% of the total commercial farms in the EU-27) are not complying with the diversification measure in the baseline scenario. These non-compliant farms in the baseline scenario represent a hypothetical situation in breach of the diversification requirements before the implementation of the measure. These are the farms that will be affected by the policy, as they will need to adjust their behaviour in order to comply with the diversification measure if they do not want to face a reduction in subsidy (i.e. lower greening payments). The proportion of concerned farms that are non-compliant in the baseline and thus affected by the policy varies between 0 % in Malta and 57 % in Cyprus (Table 2, column A).

4.2. *Land use effects*

Table 2, column B, and Table 3 report the relocated area induced by the crop diversification measure. The figures are calculated by summing-up the area that changed its use over all farms at MS and EU levels (Table 2, column B), by farm specialization (Table 3, panel a) and by farm size (Table 3, panel b). The reallocated area due to the diversification measure represents 0.8 % of the total arable area and 0.6 % of the UAA in the EU-27. It ranges from 0 % to 5.6 % of both arable area and UAA across different MSs (Table 2, column B). The reallocated area is mostly induced by the 75 % threshold imposed for the main crop cultivated on the farm. To illustrate this, Figure 2 shows the contribution of the 75 % and 95 % thresholds to the total non-compliant area in baseline. At EU-27 level the share of non-compliant area due the 75 % threshold represents 78 % of the total non-compliant area, while across MS this share varies from 48 % in the Czech Republic to 91 % in Austria, Belgium, Poland and Slovenia. The 95 % threshold is significantly less important in causing land use changes. It represents less than 22 % of the total non-compliant area in the EU-27 and ranges between 9 % and 52 % at MS level (Figure 2). This result can be partly explained by the fact that the 75 % threshold concerns all farms with an arable area greater than 10 hectares, whereas the 95 % threshold concerns only those farms with an arable area greater than 30 hectares.

As reported in Table 3, panel a, farms with a significant relocated area share in the arable area or UAA due to the diversification measure are specialized in cereals, oilseed and protein crops. This is in line with expectations given that these are the farm groups which are targeted by the crop diversification measure. Yet, some farm groups not necessarily targeted by the measure are also significantly affected in relative terms, such as farms specialised in permanent crops, horticulture, pigs and poultry, dairy and mixed crops. These farms types typically have a less diversified production structure on their arable land, given that their main activity is not necessarily linked to arable cropping. As a result, they are more likely to breach the diversity requirements and thus need to introduce new crops and/or expand the smaller crops when the diversification measure is introduced. For farm size, the most affected are middle-sized farms between 6 and 40 ESU²¹ followed by large farms (greater than 40 ESU) and small farms (smaller than 6 ESU) (Table 3, panel b). In line with expectations, small farms are affected to a lesser extent because they are either exempted (farms with arable area smaller than 10 hectares) or are subject to less strict diversification requirements (farms with arable area between 10 and 30 hectares). Large farms are affected less by the crop diversification measure because they usually have a more diversified production structure even in the absence of crop diversification measure, while when the measure is introduced they need to undergo relatively small area adjustment to be fully compliant.

The aggregated impacts reported in Table 3 may hide sizeable effects for individual farms. To gain further insight, Figure 3 shows the distribution of the relocated area over all EU-27 farms (i.e. the total number of farms in the EU-27 is equal to 100) compared to the baseline. This figure is constructed by sorting, in descending order, all the farms according to the size of the relocated area until all farms (100 %) are reported. The vertical axis of Figure 3 starts at 92.5 %, in order to better illustrate the changes for the affected farms. Although the reallocated area is substantial for some farms (more than a 20 %), 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 because they are exempted from the crop diversification measure.

²¹ ESU stands for European Size Unit representing 1200 EUR.

4.3. *Production effects*

It is not straightforward to quantify the impact of the crop diversification measure on production. The production effects depend on production structure of each farm and to which extent it is diversified. The production of crops that have large land share in baseline (i.e. those that do not comply with the diversification requirements) will tend to decrease, whereas the production of crops with low land shares will tend to increase as a result of the diversification measure. At aggregate EU, MS or farm type levels, the impact will depend on which farm specialization pattern dominates and this will determine the net production effects across individual crops.

Table 4 reports the production quantity effects of the crop diversification at MS/EU level (panel a), by farm specialization (panel b) and by farm size (panel c). The results show that the potential production change caused by the crop diversification measure is rather small. The overall crop production change at EU-27 level represents a decline of around 0.4 % compared to the baseline. The production declines because farms are required to adjust land allocation in line with the crop diversity requirements which they would not do in the absence of this measure. The largest overall change in crop production is observed in Spain, but its magnitude is still small (about -1.4 %).

The variation in production changes across the reported crops is between -1.5 % and +0.11 % at EU-27 level (Table 4, panel a). At MS level there are some more sizable production changes reported for maize in the Netherlands (+11 %), for sunflower in Italy (+11 %) and potatoes in Finland (-12 %). This is because these crops are relatively minor sectors relative to the overall size of the arable sector. However, most of the production changes across crops and MS are between -5 % and +5%.

The results by farm specialization and farm size aggregated at EU-27 level reveal more sizable production effects for certain farm specializations, but they are still below 2 % for total crop production. For individual crops, the change is larger, in particular for specialized farms (e.g. permanent crops, horticulture and sheep and goats) due to the less diversified production structure of these farms on arable land and because of low production level in the baseline of some of these crops. For farm size groups, as expected, the most affected are middle size farm classes, whereas large and small farms show smaller changes in production (Table 4, panels b and c).

Figure 4 and Figure 5 display the distribution of production change across individual farms in the EU-27 for total crop production and for selected crops, respectively. The vertical

axis is similar to that in Figure 3, with the exception that the axis is cut at 6 % and 3 % in Figure 4 and 5 respectively, in order to better illustrate the changes for the affected farms. The remaining (84 % and 87 % of) farms that are not shown in the figures have zero production change. Figure 4 shows that only a small share of farms, around 5 %, register a change in total crop production in EU-27, which is in line with Figure 3. For most of these, the change in total production is limited (less than 10%). Only a small number of farms experiences larger changes in total production, reaching up to -50 % or +100 %²². The share of farms experience a change in production is around 2.95 % for barley, 2.04 % for wheat, 1.37 % for sunflower, 1.30 % for maize, 0.86 % for pulses, 0.84 % for potatoes, 0.76 % for rape, and 0.21 % for sugar beet.

4.4. *Income effects*

The income effects of the crop diversification measure can be explained by the land reallocation and the production effects reported above. Table 2 (column C) and Table 5 report the income effects at MS/EU level (Table 2, column C), by farm specialization (Table 5, panel a) and farm size (Table 5, panel b). The results show that the potential decrease in income caused by the implementation of the crop diversification measure is very small. The overall income loss represents less than 0.5 % compared with the baseline at MS and EU levels (Table 2, column C). The largest decrease in income is observed in Finland, but its magnitude is still small (about -0.35 %). The results by farm production specialization and farm size aggregated at EU level reveal more sizable income effects for certain farm specializations, but they are still below 2 %. However, at MS level, the income may change up to 12 % for certain farm specializations and up to around 1.5 % for certain farm sizes (Table 5, panel a and b).

The most affected are farms specializing in cereals, oilseeds and protein crops and general field cropping. The income decrease in these farm types varies considerably across MSs; it reaches up to 12 % compared to baseline for certain MSs (Table 5, panel a). This is in line with expectations, given that the crop diversification measure targets arable farming. These farm types are followed by farms specialized in horticulture, cattle rearing, dairy and mixed farms. As explained above these farm types often have a less diversified production

²² For individual crops, a 100 % production change means that farms introduce it as a new crop. For total crop production, the 100 % change means that farms are not cultivating any marketable crops on arable land in the baseline (hence cultivating only intermediate crops as fodder crops) and diversify into marketable crops in the diversification scenario. Note that we aggregate production across marketable crop outputs as a result of which intermediate outputs (e.g. fodder) are not included in the total crop production.

1 structure on their arable land, given that they specialise in non-arable cropping related
2 activities. They are more likely to breach the minimum requirement on the number of crops
3 in the baseline and thus need to introduce new crops in the diversification scenario which is
4 more costly than the relocation of land among existing crops to fulfil the 75% and/or 95
5 thresholds. For the remaining farm specializations the maximum decrease in income across
6 the MSs is very small: less than –1 % compared to the baseline (Table 5, panel a).

7 By economic size, the most affected are farms in the middle class (between 8 and 16
8 ESUs) followed by large ones. Small farms are only marginally affected by the crop
9 diversification measure (Table 5, panel a) because they are exempted from the crop
10 diversification measure or are subject to less strict diversification requirements.

11 Figure 6 shows the distribution of the income change relative to the baseline across
12 the whole farm population in EU-27. The vertical axis is cut at 6 %, in order to better
13 illustrate the changes for the affected farms. The remaining farms (84 %) have zero income
14 change. As shown in this figure, only a small proportion of farms is affected by the
15 diversification measure. Although the income decrease of some farms is substantial (more
16 than a 25 % decline for 0.12 % of farms), the total proportion of farms affected by the
17 measure represents only around 5 % of the total farm population in the EU-27. For most of
18 these (i.e. 4.1 %) income reduces by less than 5 %, while only 0.9 % of experience an income
19 decrease of more than 5 %. Note that the few farms with a large income decrease (more than
20 25%) shown in Figure 6 usually correspond to farms with a very low income level attained in
21 baseline.

22 Figure 7 shows the distribution of compliance costs with CAP crop diversification
23 across the farm population in EU-27. These costs represent the per hectare income loss due to
24 the adoption of crop diversification requirements. Out of 5% affected farms by the crop
25 diversification measure, 1.4 % of farms have compliance costs greater than 50 EUR per
26 arable area. The rest of farms (3.6 %) have costs lower than 50 EUR per ha. A small share of
27 farms (0.2% of all farms in EU-27) with high compliance costs (reaching 400 EUR per ha or
28 more) often own small arable area and/or are specialised in capital and labour intensive
29 activities (e.g. vegetable production, granivores) with high per hectare production and
30 income.

5. Discussion

5.1. *Comparison with the literature*

The available studies in the literature which estimate the CAP greening impacts at farm level vary considerable in terms of the regional coverage, methodology, data source, farm coverage and CAP greening measures covered. Hence, it is not straightforward to compare our analysed with the results obtained in the literature. Despite this limitation, in the following, we aim to conduct a comparative analysis to benchmark our estimates.

The share of affected farms reported in our paper is close in magnitude to the findings in the literature. For example, based on the 2007 Italian Agricultural Census, Vanni and Cardillo (2013) estimate that the crop diversification measure would affect 3.8 % of Italian farms, which is slightly lower than our estimate of 4.5 %. This is expected as we model only commercial farms, whereas census data also include small non-commercial farms which are exempted from the greening policy. In contrast, Solazzo and Pierangeli (2016) report a significantly greater share of affected farms (12.3 %) by the crop diversification measure for Northern Italy using a combination of FADN data and the Integrated Administration and Control System database (IACS) micro data for 2012. The reason for this difference with our results is related to their focus on selected regions of Italy only as well as their use of single year data for model calibration compared to our three year average data. Based on survey data from 2010, DEFRA (2013) estimates for England that about 7.0 % of farms will be affected by the crop diversification measure, which is slightly lower than our estimate of 7.8 % for UK.

In terms of income effects, consistently with our findings, other studies also report a small and negative income change due to the introduction of crop diversification at MS or regional level such as Was et al. (2014) for Poland, Mahy et al. (2015) for Belgium, Solazzo and Pierangeli (2016) and Cortignani et al. (2017) for Italian regions. Our results also show that the income effects are not homogenously distributed among farms, but specialized farms may suffer heavy losses. This is supported by Cimino et al. (2015), whose estimates show substantial negative income effects of crop diversification on specialised farms in Italy. Also Solazzo *et al.* (2015) found that, in the Emilia-Romagna (Italy), the economic losses are bigger for farms specialized in field crops and livestock farms, with predominant monoculture, or low number of production processes, and large arable crop areas.

Our simulation results expect a relatively small change in land use caused by the crop diversification measure. The comparison of our results with the findings in the literature is not readily possible given that studies often report area of concerned farms (e.g. Vanni and Cardillo, 2013) or net land use changes caused by specific greening measures (e.g. Gocht et al., 2016) or all greening measures combined (e.g. Solazzo and Pierangeli, 2016; Solazzo *et al.*, 2015) instead of reporting the actually relocated area between different crops. However, in line with our simulations, the literature confirms that the impact of crop diversification measure on land use is rather limited, either because of the existence of various exemption rules or because many farms have sufficiently diversified production structure even in the absence of the crop diversification measure.

Although the current version of the IFM-CAP model does not simulate the environmental effects of the crop diversification measure directly, the limited changes in land allocation reported in our paper (and other studies) allow us to infer that the environmental benefits are expected to be rather low. This is confirmed by Gocht *et al.*, (2016) who simulate environmental impacts of crop diversification measure in EU using a representative farm model (CAPRI). Although their results are subject to some aggregation bias because they use a representative farm model, their simulations reveal very small environmental impacts of crop diversification measure. According to Gocht et al. (2016), the crop diversification measure has almost zero impact on the greenhouse gas emissions and soil erosion and hardly any effect on ammonia emissions. Some positive environmental improvement is observed only for biodiversity-friendly farming practices and nitrogen surplus.

5.2. *Limitations and further developments*

One needs to be aware when drawing conclusions, that our findings obviously reflect the model 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 specialized 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 somewhat less binding in our model than it is in reality. Therefore, our results will underestimate the non-compliant area in the baseline scenario, although we believe that the bias introduced in this way is limited. On the other hand, using a three-year average has the advantage of making our model less sensitive

1 to year-specific fluctuations in price ,yield and crop allocation data, which can be expected to
2 be especially high when using individual farm-level data.

3 A second potential caveat in our analysis is that we assume a fixed organizational
4 structure, implying that land can be reallocated only within farms in response to the
5 introduction of the crop diversification measure. In reality, farmers can reallocate land
6 between farms or may decide to adjust other elements of farm organization that are not
7 necessarily linked to land allocation. For example, farms may enter into (un)official
8 arrangements with neighbouring farms to rearrange claims for the greening payments in order
9 to ensure compliance and, thus, to avoid the decrease in income related to potential land
10 relocation. If this is the case, our results overestimate the overall effect. Modelling farmers'
11 cooperation would require information on personal relationships, farm locations etc, which is
12 lacking and beyond the scope of this paper.

13 Third, we do not take market feedbacks (output price changes) into account in the
14 model (e.g. see van Zeijts *et al.*, 2011; Gocht *et al.*, 2016). IFM-CAP provides only first-
15 round effects, without taking into account market adjustments. Thus, not only are the first-
16 round income effects projected to be small, but the market responses to the reduction in
17 production may reduce them even further. Fourth, certain crops are defined in the model as
18 an aggregation of a set of individual crops (e.g. other cereals), which may also lead to an
19 overestimation of the simulated impacts. Fifth, the FADN includes only commercial farms,
20 whereas small non-commercial farms are underrepresented in the database which may lead to
21 an overestimation of the simulated impacts as small farms are exempted from the greening.
22 Sixth, the direct payments considered in the simulation are based on the system in place prior
23 to the 2013 CAP reform as available in FADN data.

24 Seventh, the model specification assumes that farmers' decisions are uniquely driven
25 by profit-maximising behaviour. We do not explicitly take into account farm behaviour under
26 risk and uncertainty, which could be unrealistic as the presence of risk aversion often leads to
27 production decisions that conflict with the profit-maximising behaviour and utility
28 maximisation may be a more appropriate approach (Gómez-Limón et al, 2003). However, the
29 modelling of risk in PMP models is not straightforward and only very few examples have
30 been proposed and tested at farm level using small samples (Petsakos and Rozakis, 2015;
31 Arribas et al., 2017).

1 Finally, regarding the policy scenario assumptions, not all the specificities regarding
2 the ‘greening’ implementation are considered in the model. In particular, it is not considered
3 that farmers in the ‘small farmers’ scheme’, farmers north of 62nd parallel, and farms with
4 more than 75% of the crops under water are exempted from the greening obligations. In
5 addition, MSs can opt to define practices that yield an equivalent or higher beneficial effect
6 for the climate and the environment as the ‘greening’ obligations. Farms adopting these
7 practices are exempted from the greening which was also not considered in the current paper.

8 A careful analysis of each of these limitations to the current model is needed to test
9 the robustness of these results and to provide a complete picture of the EU-wide impact of the
10 crop diversification measure.

11 **6. Conclusions and policy implications**

12 This paper presents the EU-wide impacts of crop diversification measure on the European
13 farming sector. The crop diversification measure was adopted as part of the CAP greening
14 within the 2013 CAP reform. To quantify the impacts of the crop diversification measure we
15 have employed a novel individual farm-level model, IFM-CAP. Based on positive
16 mathematical programming, IFM-CAP seeks to improve the quality of policy assessment
17 upon existing regional and aggregated farm-type models and to assess distributional effects
18 over the EU farm population. To guarantee the highest representativeness of the EU
19 agricultural sector, the model is applied to every FADN individual farm (around 60 500
20 farms).

21 From a policy perspective, the main findings of this paper suggest that the effect of
22 crop diversification on farm income is rather limited at the aggregate level. Agricultural
23 income at MS level decreases by less than 0.5 %. At the individual farm level, the impact
24 could be more pronounced (more than –25 %), although the number of affected farms by the
25 measure remains small (around 5 % of the total farm population). The proportion of the
26 reallocated area due to the diversification measure represents less than 1 % of the total
27 agricultural area, while the crop production declines by less 0.5 % in EU-27. The most
28 constraining component of the diversification measure appears to be the 75 % threshold
29 imposed for the main cultivated crop for farms with an arable area greater than 10 hectares.

30 The small land use impacts of the crop diversification measure simulated in our paper
31 indicate that the expected environmental impacts may be limited and that its contribution to

enhancing the CAP efficiency in provision of public goods to the society might be small. Other studies also pointed to the potentially limited environmental effects of the greening measures (e.g. Solazzo et al., 2015; Erjavec and Erjavec, 2015; Gocht *et al.*, 2016). In addition, when adding the costs of monitoring and implementation of the crop diversification measure, the overall societal benefit might be insignificant (Cortignani et al., 2017). However, the proponents of CAP greening in general and the crop diversification policy in particular argue that their inclusion in CAP can be considered as a first political step necessary to be undertaken in order to 'open the door' for the future adoption of novel agricultural policy measures that promote better environmental performance of EU farming sector.

The most commonly advocated proposal in the scientific and political debates to improve the efficiency of crop diversification measure considers a better targeting of the environmental requirements across different farm typologies (e.g. specializations) and farm locations (European Parliament, 2016). This is confirmed in our results which show that the effects of crop diversification measure across different farm types and EU regions are highly heterogeneous. Although the aggregate impacts are rather low, farms specialised in permanent crops and some livestock or mixed farms are often more affected in relative terms than arable farms, which were the primary target of the measure. The main explanation is that the former farm types usually have less diversified production on arable land and have fewer (or more costly) options to diversify into new arable crops given that their main specialization is not arable farming. Our results also suggest heterogeneous impacts of the crop diversification measure across farm sizes. The middle sized farms tend to bear the greatest impact of the crop diversification measure, in comparison to small and large farms. In line with policy objectives, small farms are only slightly impacted because they are exempted from the measure. Large farms are less affected because they usually have sufficiently diversified production structures also in the absence of crop diversification measure. Further, our results suggest that the impacts are heterogeneous across MS, which is mainly driven by variation in farm structure. Overall, these results suggest that the crop diversification measure needs to be tailored to better reflect the farm heterogeneity across EU in order to make a more homogenous dispersion of the impacts across farms and regions and to avoid unintended impacts on certain farm specializations (e.g. permanent crop farms).

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8. Tables

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

	Exempted farms	Farms group 1	Farms group 2
Arable land (AL)	< 10 ha*	10 ha - 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%

*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, (iv) AL – other herbaceous crops < 30 ha or (v) organic farmers.

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

Table 2. EU wide simulation results: (A) Farms concerned and affected by the crop diversification measure (% of farms) in baseline and (B) Relocated area under crop diversification scenario (% change relative to baseline) and (C) Income change relative to baseline

	A					B		C
	Farms concerned by and complying with crop diversification measure					Relocated area due to diversification measure (% change relative to baseline)		Income change (% change relative to baseline)
	Exempted farms (% of total farms)	Concerned farms (% of total farms)	Compliant farms (% of concerned farms)	Non-compliant farms		Relocated area (% of arable area)	Relocated area (% of UAA)	Income change
				(% of concerned farms)	(% of total farms)			
BL	35.2	64.8	88.3	11.7	7.6	0.80	0.49	-0.010
DK	8.7	91.3	85.9	14.1	12.9	0.71	0.68	-0.195
DE	26.0	74.0	92.7	7.3	5.4	0.40	0.30	-0.022
EL	86.0	14.0	75.0	25.0	3.5	1.54	1.47	-0.101
ES	71.8	28.2	63.9	36.1	10.2	1.80	1.38	-0.077
FR	39.5	60.5	92.8	7.2	4.4	0.28	0.21	-0.009
IR	93.2	6.8	51.8	48.2	3.3	2.19	0.27	-0.001
IT	79.1	20.9	78.4	21.6	4.5	1.11	0.98	-0.010
NL	69.3	30.7	55.7	44.3	13.6	4.07	1.94	-0.225
AT	51.5	48.5	97.0	3.0	1.5	0.21	0.12	-0.006
PT	87.6	12.4	73.1	26.9	3.3	1.70	1.31	-0.019
SE	24.2	75.8	92.1	7.9	6.0	0.45	0.40	-0.104
FI	21.9	78.1	77.9	22.1	17.3	1.35	1.33	-0.347
UK	55.4	44.6	82.5	17.5	7.8	0.56	0.24	-0.064
CY	86.9	13.1	42.6	57.4	7.5	5.58	5.58	-0.090
CZ	33.0	67.0	94.6	5.4	3.6	0.06	0.04	-0.007
EE	46.0	54.0	91.9	8.1	4.4	0.49	0.38	-0.077
HU	49.7	50.3	90.2	9.8	4.9	0.31	0.27	-0.078
LT	31.1	68.9	89.5	10.5	7.2	0.48	0.42	-0.103
LV	59.9	40.1	93.1	6.9	2.8	0.34	0.24	-0.020
MT	98.9	1.1	100.0	0.0	0.0	0.00	0.00	0.000
PL	60.1	39.9	86.1	13.9	5.5	0.88	0.73	-0.085
SI	90.2	9.8	93.1	6.9	0.7	0.41	0.15	0.030
SK	9.8	90.2	96.3	3.7	3.3	0.11	0.07	-0.006
BG	87.4	12.6	75.2	24.8	3.1	0.58	0.52	-0.015
RO	87.7	12.3	95.2	4.8	0.6	0.21	0.18	-0.021
EU	68.7	31.3	83.9	16.1	5.0	0.78	0.55	-0.038

Source: model results

Table 3. Relocated area due to diversification measure by farm specialization (a) and farm size (b) (relative change to baseline)

a) By farm specialization in EU-27 (%)

	EU		MS variation					
			Min		Max		Standard deviation	
	% of arable area	% of UAA	% of arable area	% of UAA	% of arable area	% of UAA	% of arable area	% of UAA
Cereals, oilseed and protein crops	0.80	0.76	0.00	0.00	16.89	16.89	3.54	3.49
General field cropping	0.55	0.52	0.00	0.00	3.09	3.09	0.93	0.89
Horticulture	3.41	3.21	0.00	0.00	8.28	8.01	2.57	2.45
Vineyards	0.37	0.37	0.00	0.00	1.43	1.43	0.40	0.40
Fruit	0.24	0.22	0.00	0.00	3.48	3.29	0.72	0.69
Olive	0.27	0.26	0.00	0.00	0.75	0.73	0.24	0.24
Permanent crops	0.70	0.67	0.00	0.00	4.85	4.85	1.43	1.31
Dairy farms	0.92	0.47	0.00	0.00	6.82	2.61	1.64	0.60
Sheep and goats	1.41	0.28	0.00	0.00	10.21	3.01	2.17	0.83
Cattle-rearing and fattening	0.62	0.23	0.00	0.00	8.24	6.40	1.79	1.43
Pigs and poultry	2.01	1.77	0.00	0.00	18.30	7.29	4.29	2.01
Mixed crops	1.27	1.14	0.00	0.00	5.56	5.40	1.34	1.25
Mixed livestock	0.90	0.65	0.00	0.00	6.77	3.00	1.59	0.89
Mixed crops and livestock	0.50	0.38	0.00	0.00	8.19	8.19	1.70	1.61

b) By farm size in EU-27 (%)

	EU		MS variation					
			Min		Max		Standard deviation	
	% of arable area	% of UAA	% of arable area	% of UAA	% of arable area	% of UAA	% of arable area	% of UAA
< 2 ESU	0.07	0.06	0.00	0.00	1.15	0.89	0.58	0.44
2 - <4 ESU	0.31	0.24	0.00	0.00	3.26	2.49	1.00	0.81
4 - <6 ESU	0.54	0.40	0.00	0.00	3.99	3.99	1.23	1.05
6 - <8 ESU	1.40	1.08	0.00	0.00	7.89	7.89	1.99	1.94
8 - <12 ESU	1.12	0.79	0.00	0.00	3.94	3.46	1.15	0.99
12 - <16 ESU	1.23	0.89	0.00	0.00	6.56	6.53	1.78	1.37
16 - <40 ESU	1.12	0.65	0.00	0.00	6.25	6.25	1.36	1.18
40 - <100 ESU	0.75	0.49	0.00	0.00	3.34	3.15	0.98	0.81
100 - <250 ESU	0.71	0.53	0.00	0.00	9.88	9.88	2.37	2.15
>= 250 ESU	0.43	0.38	0.00	0.00	5.37	3.56	1.14	0.80

Source: model results

Table 4. Production quantity change due to diversification measure (relative change to baseline)**a) At MS and EU level (relative change to baseline)**

	Soft wheat	Barley	Maize	Rape	Sunflower	Potatoes	Sugar beet	Pulses	Total crop production*
BL	0.12	0.50	2.66	0.31		0.01	-0.01		-0.05
DK	-0.56	-0.38		0.18		-3.88	0.01		0.03
DE	-0.04	0.17	-2.74	0.16		-1.35	-1.30	0.57	-0.28
EL	-1.34	0.13	-0.72		2.90	-3.77	3.39	4.17	-0.54
ES	-1.12	-4.01	-2.83		3.45	-0.48	1.03	-1.08	-1.40
FR	0.07	0.13	-1.68	0.03	0.04	-0.18	0.01	0.10	-0.21
IR	-0.34	-3.81				-3.13			0.72
IT	-0.17	0.74	-2.48		10.96	-5.04	0.02	2.46	-0.29
NL	0.26	4.47	10.57			-3.13	2.51		0.45
AT	0.04	0.12	-1.91	0.38	0.60	0.00	0.00	0.24	-0.21
PT	3.67	5.73	0.96		2.60	-0.93		0.68	0.61
SE	0.12	-0.08	0.22	0.19		-2.33	0.02	0.77	-0.09
FI	0.22	-1.30		0.54		-12.21	0.05	1.18	-0.80
UK	-0.37	-0.17		0.05		-0.41	0.42	0.42	-0.07
CY		-9.23				-1.96		0.00	0.11
CZ	-0.03	-0.03	-0.02	-0.01	0.13	-0.08	0.00	0.86	-0.01
EE	0.06	-0.45		0.25		-1.43		1.05	0.14
HU	-0.26	0.12	-0.69	0.02	0.02	0.00	0.00	2.41	-0.09
LT	0.23	-1.20		0.26		-0.29	0.02	0.83	-0.24
LV	-0.48	-0.23		-0.07		-1.42		2.52	-0.27
MT						0.00			-0.28
PL	0.13	0.79	-2.04	-0.03		-0.06	0.19	2.60	-0.57
SI	0.70	0.57	0.47	0.48		-1.00			0.41
SK	0.02	-0.03	-0.16	0.00	0.00	-0.39	0.00	0.22	0.03
BG	-0.35	-0.34	0.25	0.47	-1.78	-4.98		1.64	-0.39
RO	-0.22	0.01	0.01	1.31	0.07	-1.28	-0.87	11.16	-0.03
EU-27	-0.16	-0.81	-1.36	0.11	0.75	-1.46	-0.14	0.68	-0.37

*Note: * The total crop production change is calculated as the average of production changes over all crop sectors weighted by area. Only the main crops are reported in the Table, while the total crop production column reflects the changes over all the crops (also those not reported in the table).*

b) By farm specialization in EU-27 (relative change to baseline)

Farm specialization	Soft wheat	Barley	Maize	Rape	Sunflower	Potatoes	Sugar beet	Pulses	Total crop production*
Cereals, oilseed and protein crops	-0.36	-0.83	-2.21	0.04	0.39	-1.77	0.43	0.39	-0.32
General field cropping	0.03	-0.42	-0.78	0.14	2.13	-1.42	0.02	0.44	-0.32
Horticulture	2.81	-8.67	2.04			-8.15			-1.93
Vineyards	0.09	-3.87	-0.96	0.18	0.36	0.24	1.66		-0.23
Fruit	-0.54	-0.88	-0.55			-0.01	-0.27	0.86	-0.13
Olive	0.46	0.03	0.00		5.45	0.00		0.38	0.04
Permanent crops	-0.12	-6.77	-3.41		4.21	0.00	0.00		-0.36
Dairy farms	0.45	0.09	1.04	0.31		-0.53	-2.86		0.11
Sheep and goats	2.27	-2.70	0.30			-0.03	-1.02	3.84	-1.62
Cattle-rearing and fattening	0.39	0.11	0.92	0.33		-1.56	-5.71	-0.70	-0.36
Pigs and poultry	0.39	-0.98	-3.64	2.03	9.74	-2.41	0.40	2.39	-0.86
Mixed crops	0.21	-3.30	-0.34	0.37	2.42	-2.41	0.91	-2.76	-0.81
Mixed livestock	0.41	0.16	-0.18	0.40	0.52	1.89	-6.61	30.36	-0.37
Mixed crops and livestock	-0.35	-0.32	-0.41	0.05	0.58	-1.35	0.13	0.49	-0.27

Note: * The total crop production change is calculated as the average of production changes over crop sectors weighted by area

c) By farm size in EU-27 (relative change to baseline)

Farm size		Soft wheat	Barley	Maize	Rape	Sunflower	Potatoes	Sugar beet	Pulses	Total crop production*
< 2 ESU	1	-0.03	0.00	0.00		-2.44	0.00	0.00	0.00	-0.12
2 - <4 ESU	2	-0.27	-0.07	0.01	0.01	-4.39	0.03	0.00	0.79	-0.26
4 - <6 ESU	3	-0.32	-1.07	-0.73	-0.09	0.14	0.06	0.00	0.93	-0.46
6 - <8 ESU	4	-1.55	-3.29	0.46	0.26	4.12	0.18	0.41	4.33	-0.91
8 - <12 ESU	5	-0.83	-2.99	-1.27	0.44	3.12	-0.61	0.59	-1.26	-0.85
12 - <16 ESU	6	-0.79	-2.64	-2.37	0.32	2.12	0.37	0.37	-0.86	-0.88
16 - <40 ESU	7	-0.49	-1.78	-1.42	0.11	2.45	-1.95	0.63	0.78	-0.63
40 - <100 ESU	8	-0.23	-0.60	-1.64	0.15	0.72	-1.45	0.28	0.14	-0.32
100 - <250 ESU	9	0.03	-0.39	-1.84	0.03	0.89	-1.90	0.13	1.44	-0.17
>= 250 ESU	10	-0.05	0.18	-1.41	0.15	0.11	-1.53	-1.23	0.35	-0.16

Note: * The total crop production change is calculated as the average of production changes over crop sectors weighted by area

Source: model results

Table 5. Income change due to diversification measure farm specialization (a) and farm size (b) (relative change to baseline)

a) By farm specialization in EU-27 (relative change to baseline)

Farm specialization	EU	MS variation		
		Min	Max	Standard deviation
Cereals, oilseed and protein crops	-0.03	-11.879	0.000	2.341
General field cropping	-0.06	-2.910	0.000	0.561
Horticulture	-1.54	-7.117	0.000	1.548
Vineyards	0.00	-0.055	0.000	0.013
Fruit	0.00	-0.355	0.000	0.071
Olive	-0.01	-0.020	0.000	0.008
Permanent crops	0.00	-0.127	0.000	0.030
Dairy farms	-0.01	-1.652	0.000	0.315
Sheep and goats	0.00	-0.236	0.000	0.059
Cattle-rearing and fattening	0.00	-1.228	0.000	0.310
Pigs and poultry	-0.11	-0.795	0.000	0.227
Mixed crops	-0.04	-6.965	0.000	1.359
Mixed livestock	-0.02	-0.724	0.000	0.155
Mixed crops and livestock	-0.02	-1.296	0.000	0.265

b) By farm size in EU-27 (relative change to baseline)

Farm size	EU	MS variation		
		Min	Max	Standard deviation
< 2 ESU	-0.002	-0.007	0.000	0.003
2 - <4 ESU	-0.002	-0.046	0.000	0.013
4 - <6 ESU	-0.003	-0.248	0.000	0.075
6 - <8 ESU	-0.012	-0.337	0.000	0.091
8 - <12 ESU	-0.009	-1.468	0.000	0.338
12 - <16 ESU	-0.011	-0.476	0.000	0.102
16 - <40 ESU	-0.027	-0.477	0.000	0.126
40 - <100 ESU	-0.022	-0.367	0.000	0.094
100 - <250 ESU	-0.033	-1.218	0.000	0.319
>= 250 ESU	-0.221	-1.456	0.000	0.303

Source: model results

9. Figures

Figure 1. IFM-CAP model description

Figure 2. The distribution of non-complying area with the diversification measure in baseline for the area threshold requirements (% of total non-compliant area in baseline)

Figure 3. The distribution of relocated area due to diversification measure across farm population in EU-27 (all farms, relative change to baseline)

Figure 4. The distribution of total crop production change due to diversification measure across farm population in EU-27 in EU-27 (all farms, % change)

Notes: To avoid division by zero and extreme values, the production change of individual crops between the diversification and baseline scenario was divided by the maximum quantity of baseline production and diversification scenario production. The total crop production change is calculated as the average of production changes over crop sectors weighted by area

Figure 5. The distribution of production change for selected crop sectors due to diversification measure across farm population in EU-27 (all farms, % change)

Notes: To avoid division by zero and extreme values, the production change of individual crops between the diversification and baseline scenario was divided by the maximum quantity of baseline production and diversification scenario production. The total crop production change is calculated as the average of production changes over crop sectors weighted by area

Figure 6. The distribution of income change due to diversification measure across farm population in EU-27 (all farms, relative change to baseline)

Figure 7. The distribution of compliance costs due to diversification measure across farm population in EU-27 (all farms, EUR per arable area)

Appendix A. Estimation of additional data using HPD approach.

Data on (i) unit input costs of crops, (ii) animal feeding and (iii) sugar beet quota are not directly available in the FADN database, but are estimated based on FADN data combined with external data sources.

(i) Unit input costs of crops

The FADN database does not provide the unit input costs $C_{f,i,k}$ disaggregated by crop activity that are needed to capture policy impacts and to represent technologies in an explicit way in IFM-CAP model given by equations (1) and (2). FADN provides only the total value of variable costs spent for all crop activities by input category (i.e. seeds and seedlings, fertilisers, plant protection and other crop specific costs). To overcome this lack of information, we opt for the HPD approach to estimate the unit input costs based on the total farm-level input costs per category reported in FADN. In line with the literature in the field (Léon *et al.*, 1999; Kleinhanss, 2011), we assume a Leontief production function with a common input-output coefficient (i.e. common technology) for farms within the same farm-type and region. The proportion of activity output value in the total farm output value is used as prior information. The HPD approach then minimises the normalised least square deviation between the estimated input–output coefficients and the prior information subject to data consistency constraints to estimate the unit variable costs (Louhichi *et al.* 2015).

(ii) Animal feeding

Following the applied mathematical programming models in the literature, we represent the interaction between crop and animal activities through feed supply and demand balances implemented at farm level (e.g. Arata *et al.*, 2013; Britz and Witzke, 2012; Crosson *et al.*, 2006; De Cara and Jayet, 2000; De Cara *et al.*, 2005; Heckeley *et al.*, 2012). The feed balances guarantee that animal-specific nutrient demands (requirements) are met from farm-grown or purchased feed (e.g. forage, grains, concentrates) where the balancing between feed requirements and supply (availability) is done through nutrient values (i.e. energy, dry matter, protein, fibre and lysine) (Louhichi *et al.* 2015). 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. Following the FADN based models applied in the literature (e.g. Arata *et al.* 2013; De Cara *et al.* 2005; De Cara and Jayet 2000), various external sources are used. Prior information on animal feed (nutrient) requirements is

obtained by adjusting the CAPRI methodology to the farm-level data (based on Britz and Witzke, 2014; IPCC, 2006; Nasuelli *et al.*, 1997). Although nutrient requirements based formulas are obtained from these external sources, their actual values are calculated using animal productivity parameters some of which were retrieved from FADN (e.g. milk yield, age of animals), while others are taken from external sources (e.g. CAPRI). The nutrient content of feed, and price data for the calculation of fodder and concentrate feed costs are not recorded in FADN and are instead extracted from CAPRI database. Fodder yields are extracted from Eurostat. However, most of this external information is only used as prior values in HPD estimation. The HPD approach combines these external data with FADN data (e.g. feed costs, feed availability) to obtain farm level feed use and nutrient requirements. That is, HPD estimation minimizes the square deviation between prior values and the estimated values subject to feed balancing constraints (i.e. by balancing farm level nutrient supply and nutrient demands) and FADN based data restrictions (e.g. balancing farm level supply and demand of feed, ensuring that the sum of feeding costs across activities correspond to the total feeding costs reported in FADN) with the aim to generate farm level feed data (Louhichi *et al.* 2015).

(iii) Sugar beet quota

The market organisation for sugar in EU is subject to production controls implemented by a system of supply quotas for the period covered in this paper. The overall quotas are defined for each MS, which allocates the quota to sugar refineries, which in turn allocate ‘delivery rights’ to individual farms. To parametrize the IFM-CAP correctly, the sugar beet quota system needs to be accounted for at farm level. However, the sugar beet quota related data (quota and prices) cannot be fully recovered from FADN and need to be estimated based on external data sources²³. Following Adenäuer (2005), the sugar beet quotas are estimated based on FADN data using the HPD approach. Prior information on (in- and out-of-quota) prices and quota production at MS level is derived from Agrosynergie (2011) and DG-AGRI (2014), respectively. Prior information on farm quota production is obtained by multiplying sugar beet production at each farm with the ratio between the official MS sugar beet quota (DG-AGRI 2014) and the FADN aggregate MS sugar beet production quantity. The HPD approach minimises the sum of the farm-level relative squared difference between the

²³ Although there are reported data in FADN on sugar beet quota for ten MSs, their quality is highly questionable. Sugar quota data are available in FADN for Belgium-Luxembourg, Germany, Lithuania, Poland, Austria, the Netherlands, Spain, Sweden, Greece and the United Kingdom, but only for the first four of these MS do the aggregated quota across FADN farms correspond broadly to (i.e. being within the range of 50 to 150% of) the officially reported quota (DG-AGRI, 2014).

estimated data and the prior information for the sugar quota production, and in-quota and out-of-quota prices subject to data consistency constraints. The estimation approach allows for the under-delivery of the quota because in reality the sugar beet production might be lower than the quota in some farms (Louhichi et al. 2015).

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