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D5.3 AGRICORE Market Module

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Executive Summary

AGRICORE is a research project funded by the European Commission under the RUR-04-2018 call, part of the H2020 programme, which proposes an innovative way to apply agent-based modelling to improve the capacity of policymakers to evaluate the impact of agricultural-related measurements under and outside the framework of the Common Agricultural Policy (CAP).

This deliverable presents the results of Task 5.3 - Market Module, led by AKD. The objective of Task 5.3 is to design a module which considers the interaction between agents regarding external markets different than Land Market, which is specifically addressed in D5.2. These markets are the production market, on which the price of the outputs of the agricultural holdings is set, but also the markets for other production factors, such as the labour market.

The agents, i.e., the agricultural holdings being simulated, interact within the aforementioned markets, so that their aggregated taken actions have an effect on the output of the market themselves.

Abbreviations

Abbreviation	Full name
ABM	Agent-based model
CGE	Computable general equilibrium (model)
DG-AGRI	General Directorate for Agriculture and Rural Development
FADN	Farm Accountancy Data Network
ICT	Information and communication technology
LP	Linear programming
KKT	Karush-Kuhn-Tucker conditions
MP	Mathematical programming
PE	Partial equilibrium (model)
PMP	Positive mathematical programming

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1 Introduction

AGRICORE proposes to build a novel modelling suite which will be used to carry out impact analyses regarding agricultural structural and policy changes. The proposed solution follows a farm-level agent-based approach rather than activity-related, and regional-level analyses. This is featured by taking advantage of the latest progress in modelling approaches and ICT. Within this approach, each farm is considered as an autonomous decision-making entity behaving according to the markets' developments and based on its economic situation and expectations. Modelling the heterogeneous structure of farms, and their interactions with each other, while computing the impact on the environment, rural economy and ecosystem services is the other distinguishing feature of the AGRICORE platform. This platform will provide an open-source modular suite for institutions to carry out relevant research in the future.

Within AGRICORE, WP3 aims at developing a module that allows mimicking how agricultural holdings (the agents) take short- and long-run production decisions, given their resources, constraints, inputs and market prices. Financial and tangible assets constitute the main resources of the farms. Physical capital including machinery and land, represent the fixed costs of the farms, and, at the same time, the binding factors. Other production factors such as labour, water, feed, seeds, all fertilizers and other chemicals represent the variable costs. Given these constraints and variable costs, farms respond to changes in market prices allocating their resources accordingly, to certain products and activities.

As mentioned, some price values need to be available during the AGRICORE execution flow:

- First, during financial optimization, it is necessary to know the average price of structural or fixed production factors (primarily land, although machinery labour unit cost could also be incorporated). Average land prices for sale or rent are computed in the Land Market Module (D7).
- Second, during agroeconomic optimization, it is necessary to have estimates of the average price of the products produced at the farm gate. Additionally, estimates for the price of variable production factors (water, fertilizers, etc.) may also be needed.
- Finally, in order to be able to update the economic-financial statements of each agent, it is necessary to use a price for each of the products, representing the *actual* price the farmer managed to sell its production. This *actual* price may coincide with the estimate made during optimization or deviate from it, representing the inevitable divergences that occur in real life between both values.

In AGRICORE, the Product Market Module oversees providing the necessary prices to implement the last two points above. On the one hand, it should allow to obtain estimates on the short and medium-term price of a series of final products and/or production factors. On the other hand, it should make it possible to simulate what the "real" average price of these products would be (and how future price projections would be modified) as a result of the aggregation of the actions taken individually by each agent in each simulation step (i.e. in each agricultural season).

This document consists of five sections. Following the introduction, the second section provides an overview of the AGRICORE modelling platform. The third section explains the supply-side interactions by focusing on production costs, binding resources and outputs. The fourth section is about market prices formation and the fifth one presents the conclusions of the document.

2 An Overview of the AGRICORE modelling approach

Figure 1 depicts the main components and relations in the AGRICORE modelling approach. The temporal dimension in the AGRICORE model is structured as a yearly recursive cycle with a 7 years horizon. This approach allows to carry out short- to long-period analyses. The long-term period (7 years), based on the CAP duration and the average life cycle of the agricultural machinery, is modelled in the so-called "Structural" module and it is solved as a model predictive controller (MPC) that represents the efforts of the farm manager to steer the financial status of the Agricultural Holding within safe and efficient limits. The yearly farm's agricultural optimization takes place in the so-called "Agroeconomic" module, based on the positive mathematical programming approach (PMP).

In the short-period (the agroeconomic module), conditions in the variable input markets, other constraining factors (land and machinery), biophysical conditions and farmers' risk aversion affect farm behaviour. By applying the positive mathematical programming (PMP) approach, in a recursive manner, the variable costs of production are estimated and resources are distributed accordingly, so that output allocation is derived. In the long-term (the structural module), structural, technological and environmental policies together with fixed costs and farmers' demographic conditions affect farm behaviour. In the financial module, risk aversion, investment decision and financial capacity determine the acquisition or alienation of agricultural land, which in turn affects the agroeconomic module as well.

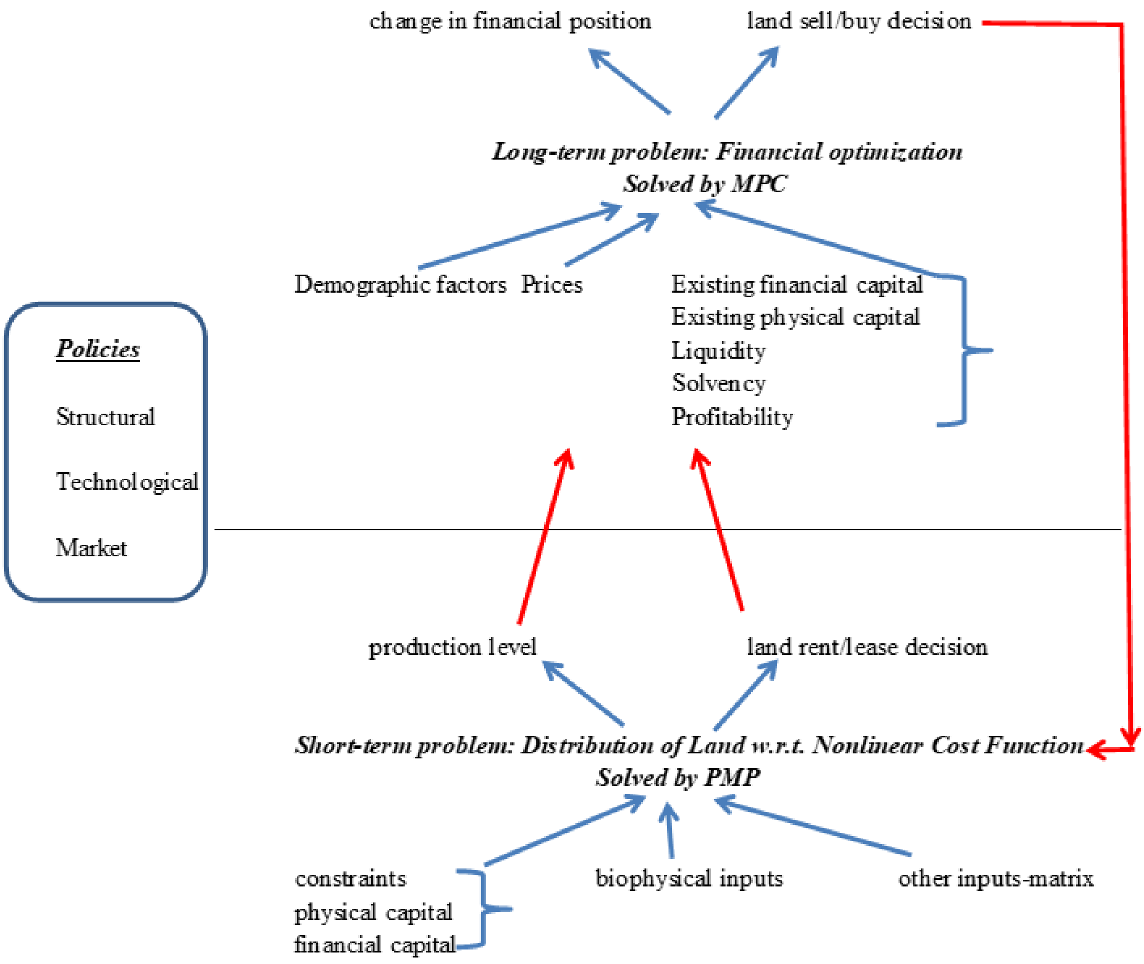

Figure 1 AGRICORE Modelling Platform: Main Components and Relationships

3 Methodology of Modelling Output and Input Markets in AGRICORE

3.1 Main Problem

One of the main problems when using agent-based approaches for policy impact analysis or modelling structural changes is estimating the farm-level variable cost per activity. Agricultural databases in general provide data on farm location, economic and physical structure of the farm, production specialization and yield per activity. In addition to these, sometimes, total cost differentiated with respect to input category can also be found (e.g., the Italian FADN, RICA). However, obtaining variable costs per activity type is generally very difficult. The difficulty aggravates when farms belong to different typologies, when farmers' attitudes are not explicitly characterized, and when models are built at a regional or sectoral level rather than at the farm level.

In general, two types of problems are encountered when dealing with the variable costs of production in agricultural modelling platforms. The first one is the technology matrix (input-output matrix) which shows input use per production of output by type; the second one is the changing unit cost of production. Equilibrium-type (CGE and PE) models, that solve prices by basing on supply and demand functions of inputs, consider input markets at aggregate levels and therefore this approach does not deliver information about technology matrix and respective individual prices. Programming models seem more appropriate for modelling the interactions between output and inputs and in most cases, the technology matrix for the EU countries are obtained from data published by DG-AGRI. The problem of unit costs (specific costs regarding feed, seed, all chemicals etc.) can be solved either by estimating the Bayesian approach [1] (using info on input-output matrix) or using positive mathematical programming by deriving the total variable cost of production. The technology matrix reflects the Leontief production function (linear input demand function) that links production activities and total physical input use. As the production increases, the respective input use also increases linearly, showing a rigid production technology (constant soil quality, weather conditions etc.). This technology's rigidness can be overcome by the integration of biophysical conditions or by discrete representations of the technology.

Without knowing the variable costs per activity, it is not possible to model farmers' behaviour towards profit maximization, which is engaged with a mix of activities and tends to change the farm's land cover according to changing costs, policies and yields.

Therefore, in AGRICORE modelling platform, one of the main objectives is deriving variable cost by activity explicitly so that the agent's (farm's) behaviour relies on the rational ground and is mathematically formulated accordingly.

3.2 A Brief Overview of Calibration Methodology

ABMs are well-known for their capacity to model individual farm behaviour while respecting farm heterogeneity. In contrast to computable general equilibrium (CGE) and partial equilibrium (PE) agricultural trade models which incorporate agricultural products at more aggregated levels and use a representative approach, ABMs have the capacity to model mixed activities at the farm level. Therefore, the derived information from the modelling exercise arises also at the farm level,

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[1] Seemingly unrelated regressions, entropy and highest posterior density estimation methods are also used in recovering the true disaggregated crop-specific input costs from aggregated crop-specific input costs at the farm level.

so that structural and policy impact analyses can be tailored to provide farm-based solutions. When compared to PE agricultural sector models, which in general employ linear programming (LP) to represent a farm typology, region and aggregate product activity, ABMs again have the advantage if positive mathematical programming (PMP) is used rather than LP. This is because PMP allows for both individual farm level and aggregate level modelling (regions and farm typologies etc.). The implication of using typology farms is that the model does not capture differences between farms in the same region, as the differences in technology and costs disappear in the averages. In addition, economies of scale are not taken into account and the “farm-type” that the model creates might not represent the observed reality.

PE agricultural sector models that employ mathematical programming (MP) were traditionally evolved from LP models which used information obtained directly from farms [1]. The main characteristic of this approach is that they can utilize the duality theory explicitly to describe primal and dual information in detail for each farm, either by considering revenues and costs regarding farming practices and/or by linking product markets and input factors. However, some disadvantages are also encountered with the LP methodology and for this reason, LP is found unsatisfactory for the analysis of farm policy. One of the limitations that come with LP is the difficulty of obtaining statistically representative economic and technical information directly from farms regarding their production choices. Another limitation is that agricultural databases do not provide information on technical coefficients in relation to production processes. A third limitation arises when farms specialize in a low number of production activities or operate under many constraints, in which the approach leads to ill-posed production problems [2]. Moreover, LP solutions are so-called corner solutions and models cannot be calibrated to observed production situations, making them normative rather than positive [3]. The last one also calls for the “inefficiency of farmers” due to the distance between observed reality and the model solutions.

These limitations called for a methodology embracing the capabilities and advantages of the LP approach while overcoming the mentioned limitations and disadvantages [2][4]. Moving from normative to a positive approach and from LP to non-linear programming models was started with PMP (initial works Heady and Egbert [5]). From there two different approaches were implemented, one focusing on the capacity to calibrate farm decisions [4], the second focusing on the capacity to estimate variable costs for each activity. Later, Paris and Howitt [2] combined the two into a much more detailed and powerful model with calibration and variable cost estimation at its centre.

The general idea of PMP is adding one additional constraint to the specified problem to bind LP to observed activity levels which is called calibration constraint. With this constraint, the associated dual information of the problem allowed the specification of a non-linear objective function, such that the observed activity levels are reproduced by the optimal solution.

Cafiero [6] criticized the PMP developed by Howitt [4], and Paris and Howitt [2] as the approach might risk neglecting relevant part of the economic and technological constraints that farms consider in the decision-making process. The tautological content of PMP was also criticized by Heckelei and Wolff [7] and Heckelei and Britz [8] as the positive constraints included in the first phase force the model to reproduce information already known. Further criticism of the standard PMP approach was brought by Henry de Frahn et al. [9], Heckelei [10], Judez et al. [11], as the cost function estimation is carried out using the maximum entropy approach that requires arbitrary support value to be implemented, which might introduce a bias in the policy simulation phase. Another drawback of the standard PMP approach is the difficulty to estimate the **Q** matrix (input use) that considers all the observed activities when no information is available related to the activity costs. Further discussions regarding the drawbacks and suggestions for solutions for the problems of the standard PMP can be found in [12][13][14][15].

3.3 Modelling Supply Side in the AGRICORE Platform

The AGRICORE modelling platform can be considered a supply-side model in which output and costs are derived endogenously and all demand factors are exogenous in the system (Figure 2). The supply side has a recursive structure, and the model is calibrated using the PMP approach employing variable input matrix, current output level and binding constraints (land and machinery). Calibration provides shadow prices of both outputs and variable inputs [2] and the reproduction of observed land allocation by activity and output levels. While this feedback into the net profitability problem of the farm, farm output is used to calculate the total supply in the market. This structure of the supply side applies to all livestock and crop products.

At this stage, it should be mentioned that there are several options to obtain market prices:

First, these can be calculated as market equilibrium prices for each output by solving simultaneously the exogenously given total demand and endogenously derived total supply. Second, the prices can be received from an already existing source which will be the case in the AGRICORE. Among these external sources, the following can be distinguished:

- An external database containing historical market price series and price forecasts (possibly for several alternative future scenarios).
- An external PE or CGE market model that AGRICORE's agent-based simulation module can interface with. The connection between ABMs and PE and CGE models is one of the key issues being addressed jointly by the 3 projects of the AGRIMODELS cluster (BESTMAP, MINDSTEP and AGRICORE). However, is an unresolved complex task that presents several challenges, such as how to upscale from the ABM to the higher-level external model, the computational demand or the calibration and validation of the linkage.

These market prices, after being converted into farm gate prices, could be fed back into the net profitability problem of the farm.

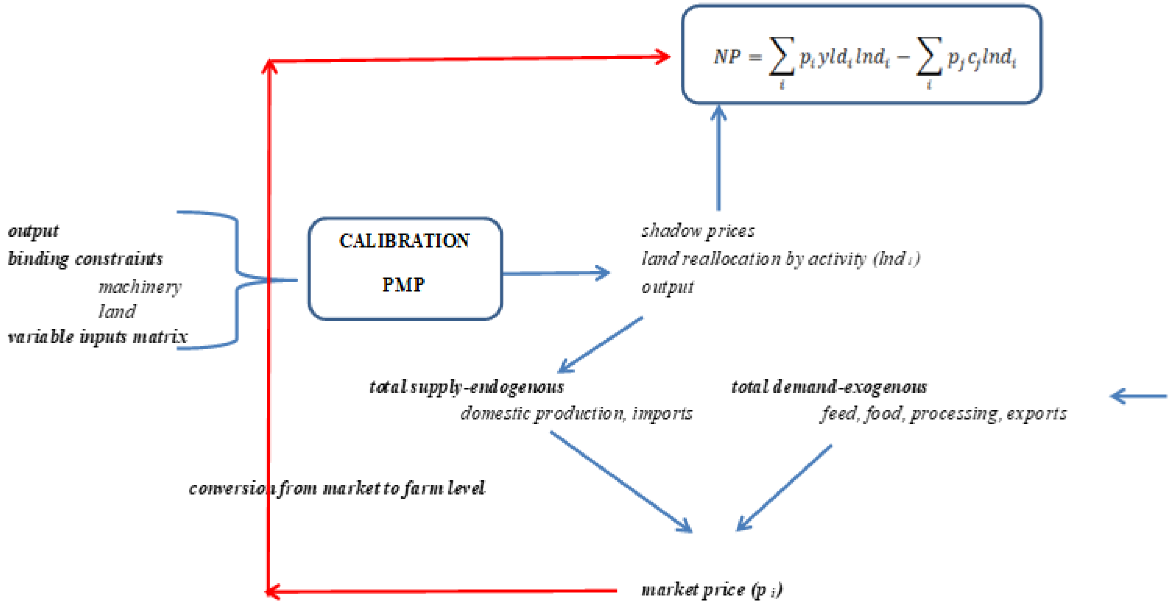

Figure 2 Modelling Supply Side Interactions in the Agricore Platform

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[2] Input markets cover all chemicals, feeds, seeds, manure, mechanization, irrigation, land and labour. The land is handled in the land market module and explained in Deliverable 5.2 of the project. Explanations regarding labour and machinery are presented in this paper. For the rest of the variable inputs, shadow prices are derived.

To overcome the described main problem in the standard PMP procedure, namely the absence of activity-based variable costs, the AGRICORE ABM follows the PMP approach introduced by Paris and Howitt [2] and then further expanded by Heckelei [10], Heckelei and Wolff [7];Arfini et al.[3]. Below the approach used in AGRICORE is summarised, using the exact notations used in Arfini et al. [16].

Paris and Arfini [17] use a two-phase procedure, first to estimate an accurate and consistent measure of the marginal cost associated with the vector of the realized level of activities and secondly to reconstruct the marginal cost function using a specification that is linear in its parameters. The basic form of the PMP methodology and its dual problem are introduced through Equations 1 to 5.

The primal model (eqs. 1-3):

$$\max_{x_n \geq 0} (\boldsymbol{p}'_n \boldsymbol{x}_n - \boldsymbol{c}'_n \boldsymbol{x}_n) \tag{1}$$

$$subject\ to$$

$$\boldsymbol{A}_n \boldsymbol{x}_n \leq \boldsymbol{b}_n \tag{2}$$

$$x_{nj} \leq x_{Rvj},\ \ for\, x_{Rvj} > 0,\ j = 1, \dots, \mathcal{J}_n \tag{3}$$

The dual model (eqs. 4-5):

$$\min_{y \geq 0, \lambda \geq 0} (\boldsymbol{b}'_n \boldsymbol{y}_n + \boldsymbol{\lambda}'_n \boldsymbol{x}_{Rn}) \tag{4}$$

$$\text{subject to}$$

$$\boldsymbol{A}'_n \boldsymbol{y}_n + \boldsymbol{\lambda}_n + \boldsymbol{c}_n \geq \boldsymbol{p}_n \tag{5}$$

In this setting:

$\boldsymbol{p}_n$ is the vector of output prices faced by the n-th farm,
$\boldsymbol{c}_n$ is the vector of observed accounting costs per unit of output,
$\boldsymbol{A}_n$ is the matrix of fixed technical coefficients involving limiting allocable inputs,
$\boldsymbol{b}_n$ is the vector of availability of limiting allocable inputs (for ex. land)
$\boldsymbol{x}_{Rn}$ is the vector of realised output levels (a nonnegative vector)
$\boldsymbol{y}_n$: vector of shadow prices (associated with allocable input constraints) (nonnegative)
$\boldsymbol{\lambda}_n$: vector of differential marginal costs (corresponds to calibration constraints) (nonnegative)

There are $\boldsymbol{I}$ allocable inputs and $\boldsymbol{\mathcal{J}}_n$ products for each farm. Land is the only limiting input [3] and its allocation is indicated by $\boldsymbol{h}_{\boldsymbol{R}_n}$. The $\boldsymbol{n}$-th matrix $\boldsymbol{A}_n$ of technical coefficients is defined as $\boldsymbol{A}_n = [\boldsymbol{a}_{nij}]$, where $a_{nij} = h_{Rni}/x_{Rnj_n}$. Equations (2) and (3) represent structural and calibration constraints respectively [4]. The marginal cost is composed of the specific explicit accounting cost $\boldsymbol{c}$ (which is not known) and the differential marginal cost $\boldsymbol{\lambda}$. The associated marginal cost function for all the observed farms can be represented as $mc(\boldsymbol{x}) \equiv \bar{\boldsymbol{\lambda}}_{LP} + \bar{\boldsymbol{c}} = Q\bar{\boldsymbol{x}}_R$, where the upper line identifies the information related to the whole sample of farms.

The literature provides a few solutions as contributions to PMP formulation for the above problem of lacking accounting costs. Heckelei and Heckelei and Wolff for example propose

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[3] In AGRICORE this includes land and its associated machinery.
[4] See Paris and Howitt [2] for further interpretation of the model.

directly imposing the first-order conditions on the cost function estimation phase [5]. An alternative PMP approach is proposed by Mattas et al. [18] as using the endogenous information available for all farms belonging to the FADN database [6] and changing the formulation of PMP models to be used in a different context. Later, Arfini et al.[3] proposed another alternative in which the information available in the FADN database is used as a guide for the correct estimation of the explicit variable activity costs. He also proposed to merge the first and second phases of the PMP approach defined through equations (1)-(5).

The merged PMP problem is given in equations (6)-(8) that recover the part of the information [7] that cannot be directly collected at the farm level but contributes to the decision-making process of farmers in a more or less conscious way. The problem is used to reveal the vector $\boldsymbol{\lambda_n}$ which represents the additional marginal cost for each farm considered by farmers in defining a certain production plan with the explicit cost.

$$\min_{\boldsymbol{u}_n, y_n, l_n, \boldsymbol{Q}} \left\{ \sum_{n=1}^{N} \frac{1}{2} \boldsymbol{u}'_n \boldsymbol{u}_n + \sum_{n=1}^{N} \left(b_n y_n + \boldsymbol{\lambda}'_n \overline{\boldsymbol{x}}_n + \boldsymbol{c}'_n \overline{\boldsymbol{x}}_n - \boldsymbol{p}'_n \overline{\boldsymbol{x}}_n \right) \right\} \tag{6}$$

subject to

$$A'_n y_n + \boldsymbol{\lambda}_n + \boldsymbol{c}_n \geq \boldsymbol{p}_n \; (\boldsymbol{w}_n) \tag{7}$$

$$\boldsymbol{c}_n + \boldsymbol{\lambda}_n = \boldsymbol{Q} \overline{\boldsymbol{x}}_n + \boldsymbol{u}_n \; (\boldsymbol{z}_n) \tag{8}$$

$\boldsymbol{Q}$ is a symmetric positive semidefinite matrix consisting of variable input factors. $\boldsymbol{w_n}$ and $\boldsymbol{z_n}$ are the shadow prices associated with equations (7) and (8), respectively. $\boldsymbol{u_n}$ is the vector of marginal cost deviations per farm (the distance between the marginal cost $\boldsymbol{c_n} + \boldsymbol{\lambda_n}$ and the marginal cost $\boldsymbol{Q}\overline{\boldsymbol{x}}_n$ of a non-linear cost function such that in (8). The above model integrates the first and second phases of the standard PMP approach using the PMP dual properties. The constraints of the model (7)-(8) concern the equilibrium conditions with marginal costs greater than or equal to marginal revenue and the relationship by which a linear cost function is shifted to a quadratic cost function. The Lagrangian representation and first-order conditions are given in equations (9)-(12):

$$\begin{aligned} L = {} & \sum_{n=1}^{N} \frac{1}{2} \boldsymbol{u}'_n \boldsymbol{u}_n + \sum_{n=1}^{N} \left(b_n y_n + \lambda'_n \overline{\boldsymbol{x}}_n + \boldsymbol{c}'_n \overline{\boldsymbol{x}}_n - \boldsymbol{p}'_n \overline{\boldsymbol{x}}_n \right) + \\ & + \sum_{n=1}^{N} \boldsymbol{w}'_n \left(\boldsymbol{p}_n - A'_n y_n - \boldsymbol{\lambda}_n - \boldsymbol{c}_n \right) + \sum_{n=1}^{N} \boldsymbol{z}'_n \left(\boldsymbol{\lambda}_n + \boldsymbol{c}_n - \boldsymbol{Q} \overline{\boldsymbol{x}}_n - \boldsymbol{u}_n \right) \end{aligned} \tag{9}$$

$$\frac{\partial L}{\partial \boldsymbol{u}_n} = \boldsymbol{u}_n - \boldsymbol{z}_n = \boldsymbol{0} \tag{10}$$

$$\frac{\partial L}{\partial \boldsymbol{\lambda}_n} = \overline{\boldsymbol{x}}_n - \boldsymbol{w}_n + \boldsymbol{z}_n \geq \boldsymbol{0} \tag{11}$$

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[5] External information regarding fixed factors is needed. The approach is useful for FADN regions but external data may not fit FADN farm sample.

[6] Different farm types at different territorial levels are considered.

[7] The information may take on different meanings as price expectations, specific production preferences and technological skills of the individual farmers and these are obviously lacking in FADN and, can be derived through the PMP properties.

$$\frac{\partial L}{\partial y_n} = b_n - A_n \boldsymbol{w}_n \geq 0 \tag{12}$$

The present PMP approach overcomes the tautological procedure of the standard PMP approach and provides all the necessary information on the total marginal cost that is useful for the simulation phase. The partial derivatives (10) indicate that the deviation terms, $\boldsymbol{u_n}$, are equal to the dual values, $\boldsymbol{z_n}$, linked to the equation (8). Because the problem attempts to minimize the squares of the farm cost, the deviations $\boldsymbol{u_n}$and $\boldsymbol{z_n}$ should assume very small values close to zero. The KKT condition (11) can be rewritten as $\boldsymbol{w}_n - \boldsymbol{z}_n \leq \overline{\boldsymbol{x}}_n$, showing that the difference between the two shadow prices associated with equations (7) and (8) should be less than or equal to the realized outputs. In this respect, if the shadow price of the equation representing the equilibrium condition can be interpreted as the shadow output quantity, then $\boldsymbol{w}_n \approx \overline{\boldsymbol{x}}_n$. Furthermore, as affirmed for the KKT condition (11), $\boldsymbol{z_n}$ can be viewed as a small term close to zero, and thus, it can be stated that $\boldsymbol{z}_n \approx \boldsymbol{\varepsilon}$.

Rearranging this information, the KKT condition (11) becomes $\boldsymbol{w}_n \leq \overline{\boldsymbol{x}}_n + \boldsymbol{z}_n$, corresponding to the calibration constraint of the standard approach, which implies that models (6)-(8) correctly replicate the standard PMP specification without the explicit calibration constraints. Taking the previous considerations into account, the KKT condition (12) can be interpreted as the structural constraint related to land use. Moving b_n to the right-hand side of equation (12) and changing the sign, the corresponding equation (7) is obtained.

3.4 Binding Conditions/Resources for Production: Land and Capital Markets

The AGRICORE model considers land (and the associated machinery required to operate that amount of land) and capital as the main resources that may become binding constraints for production and allocation of resources to various activities both in the short- and long period. The land market module is described in Deliverable 5.2.

In agricultural modelling, agricultural machinery [8] can be considered according to the main purpose of the modelling exercise. If analysing the effects of structural changes is the main aim, the use of machinery is categorized as a technology element and as one of the main factors of production. However, if the main aim of modelling is policy assessment, machinery can be handled as a parameter that impacts the farmer investment decision [9]. In the former approach, the capital market used in the technology (machinery) is endogenized in the cost function. The substitution between capital and labour is introduced as a change in the production technology [10]. In partial equilibrium models (which can be agent-based or not), a simplified feature of mixed integer programming enables the introduction of production technology changes [11]. In both, partial and general equilibrium type models, ratios between machinery and capital demand can be introduced through a constant Leontief parameter. In the latter approach, investments can be a part of the farm's profit (or income) maximization problem, or it can be modelled separately by shifting resources from agricultural production to investments or vice versa. Machinery is a part of the total farm investment and, therefore, machinery depreciation, rate of return to machinery, and interest on loans used to buy the machinery, should be contemplated to compute the financial position of the farms.

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[8] In most cases, agricultural machinery is a composite variable that joins separate machines in farms based on annual used hours of each and/or on their power, etc.

[9] Of course, both approaches can be used together as well.

[10] More elaborate explanations can be followed from the documentation of any CGE model.

[11] See Louhichi et al., 2017 [19]

The AGRIPOLIS and REGMAS modelling platforms provide two different approaches for incorporating investment in the model. In the AGRIPOLIS platform, the investment decision is given as part of a planning program. The agent's planning horizon is one period and the next period's investment decision is based on a comparison of the opportunity cost of investment (capital inputs) and expected household income. Therefore, before the investment takes place, its expected average return is calculated and if it creates a positive change in expected household income then the farm realizes the investment.

In the REGMAS platform, farm activities are chosen from two categories which are activities that generate costs and income within one year and activities that generate returns over multiple years (i.e. investments). The agent's profit maximization problem solves for the optimal quantities of these various activities. For investment, the farm should have enough liquidity and in order to increase liquidity, farms are allowed to borrow from the credit market. Borrowing is constrained by the farm's total capital value and the farm optimises the amount of money it borrows on the credit market based on its financial situation and the exogenous credit cost (i.e., the interest rate).

In the AGRICORE platform, the available agricultural machinery, which is a part of farm assets and total investment decision, is also introduced as a binding condition for production, as part of the technology. Therefore, machinery has a role both in the short- and long-period optimisation problems of the farm. In the short-period machinery endowment (obtained from FADN) is introduced as a constraint and a fixed cost in the optimization problem. In the long-period purchase of machinery is constrained by the available budget of the farm which consists of current income and acquired loans. While the existing and new machinery is part of farm assets, the interest to be paid become part of the liabilities. Equations (13)-(19) present the machinery acquirement conditions as part of fixed and current assets.

$$FA_{t+1} = (1 - dep_t)FA_t + B_t^L + B_t^M \tag{13}$$

$$CA_{t+1} = D_{t+1} + R_t^M + R_t^L: \tag{14}$$

$$B_t^L + B_t^M < D_{t+1} + L_{j,t} \tag{15}$$

$$R_t^M + R_t^L < ST_t \tag{16}$$

$$-(M_t - R_{t-1}^M) \cdot PRM_{min} \leq R_t^M \tag{17}$$

$$-(M_t - R_{t-1}^M) \cdot PSM_{min} \leq B_t^M \tag{18}$$

$$-(M_t - R_{t-1}^M) \cdot PM \leq B_t^M + R_t^M \tag{19}$$

In equation (13) evolution of fixed assets (FA) is explained by depreciated value and buy or sell reaction of land (B^L) and machinery (B^M). In a similar fashion evolution of current assets (CA) is explained by portfolio deposits (D) and rent or lease reaction of land (R^L) and machinery (R^M), equation (14). In equation (15) the budget constraint (money in bank-D plus new loans-L) to purchase land and machinery is given. Renting land and machinery is possible only within short-term liabilities (ST), equation (16). The amount to be expected from leasing own machine hours to third parties is limited by the number of available machine hours owned and the amount to be expected from both selling machine hours is limited by the number of available machine hours owned, equations (17)-(18) respectively. Finally, the amount to be expected from both leasing and selling machine hours to third parties is limited by the number of available machine hours owned, equation (19).

3.5 Labour Market

The main point regarding the labour market, in agricultural modelling aiming at modelling the effects of structural change and/or policy changes, is twofold. The first decision to be made is about allowing or not to model off-farm employment opportunities and the second is about how agricultural labour use will be determined.

Off-farm employment opportunities [12] may become important in two different contexts. If the main problem of the farm is income maximization, then preferably modelling off-farm employment opportunities, for the household members, should be allowed so that farmer's utility maximization problem can take into account the off-farm incomes. Secondly, off-farm employment opportunities may trigger farmers to opt for alternative sources of income, moving away from agricultural activities.

When it comes to determining agricultural labour use two options appear as to whether endogenize [20][21][24][25] the labour market or incorporate it exogenously [22][23][26]. If the latter is chosen as the main approach, then a fixed labour ratio (coefficient) can be used, depending on the type of output, and labour cost is calculated as a fixed wage rate. This approach assumes no restrictions on labour supply and no differentiation is introduced between family and non-family labour force. If the former approach is chosen, then a differentiation should be introduced depending on whether the labour is supplied by the market or by the member of a family hold. Their respective wages should be differentiated as well as based on the demand and supply conditions in the respective labour markets.

In AGRICORE, agents aim at finding the profit-maximizing output distribution in a short- to long-period perspective and non-agricultural economic activities are out of farmers' concerns. In addition, labour is not considered as a limiting factor on output, both in the short- or long period. These assumptions lead to the adoption of a rather simple approach: modelling the labour market in which off-farm employment is not possible and a fixed ratio of labour use is foreseen depending on the type of agricultural product. The annual fixed labour use (for a mix of activities on each farm) is composed of both family and non-family workers, and family members over 18 years in each agent (family) is naturally accepted to fulfil partly the required labour force. The rest is assumed to be paid labour. Labour cost is calculated by using an average wage rate in the geographical region where the farms are located.

The data for output-based labour demand is obtained from DG-AGRI and the weighted average wages are given in FADN database as the imputed cost of unpaid labour.

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[12] See for example Happe et al. [20] and Mohring et al. [21] which allow for an off-farm employment opportunity, and for example Beckers et al. [22] and Bert at al. [23] which do not allow for off-farm employment opportunities.

4 Input and Output Prices

There are a few points to consider when discussing input and especially output prices in agricultural modelling. The first one is about whether the model is using past, current or expected prices. Past and current prices are mostly provided by well-known databases, however in ABMs we might collect more local prices from local markets. Price expectations can follow a naïve approach or not, and mathematical formulation brings the difference between the two. In most cases, adaptive and rational expectations are the mostly chosen approaches to formulate the expected prices.

The second one is about whether there will be a need to calculate market prices other than farm-level prices. If there is a need for both prices, then the link should be put between the market, which will represent the border prices, and the domestic prices. Domestic prices should be differentiated with respect to producers and consumers. Trade and transport margins and producer, consumer and trade policy parameters are used for putting the mentioned links and differentiating the domestic prices.

The third point to consider is whether supply and/or demand are endogenously or exogenously modelled. Output (both crops and livestock) markets can become totally or partially endogenous in the ABMs. In most cases, only the supply side is endogenous and domestic producer prices are formulated depending on time, expectations, margins and policies. If both the demand and supply sides are endogenous, then domestic prices can be solved as an outcome of the equilibrium conditions. However, this is not practical to calculate at the farm level. Therefore, calculating equilibrium prices can be a solution to derive aggregate market prices. Then, the link between the border and domestic prices should be put and the resulting domestic prices should be differentiated as explained. Another option to find output prices could be using shadow prices as an outcome of the optimization problem. In this case, the convergence, or divergence, between shadow and actual market prices must be observed.

One last point is whether the farm, in a particular market product, is a price-taker or a price-maker. This would certainly affect the link between the border and domestic prices.

Two good examples of different pricing approaches are used in the SWISSLAND and AGRIPOLIS modelling platforms, which are among the ABMs.

In SWISSLAND nominal producer prices are based on the individual-farm prices obtained from the bookkeeping system. These prices are differentiated with respect to final users who might be households and other agricultural producers. In the base year, producer prices are a three-year average and all prices are based on expectations derived from the previous year's prices. Therefore, in each year prices are multiplied by the previous year's annual relative price trends and in addition, they are specified as a function of world prices, exchange rates, transport costs, and country-specific policies that affect prices [21]. In SWISSLAND input prices are prescribed exogenously and are based on historical trends.

The market model used in SWISSLAND can be defined as an applied recursive partial-equilibrium, multiple-commodity model of agricultural policy. It is built as a reduced-form model to capture economic behaviour regarding producers, consumers and trade by using the variables for production activities, consumption, exports, imports, stocks, world prices, and domestic producer and consumer prices. The behavioural functions are modelled such that quantities and prices clear the market.

In AGRIPOLIS, markets for products, capital, and labour, are coordinated via a price function with an exogenously given price elasticity and a price trend. The optimization problem produces the vector of shadow prices which are interpreted as the actual prices. But for the future, the prices are expected to stay constant. Therefore, dynamic effects of market and demand developments are neglected. The agents follow adaptive expectations (myopic behaviour) while planning decisions. They foresee all prices as a weighted geometric average of actual and expected prices and agents base their planning decisions on these expected prices.

On the demand side, for each period, the agent determines a market price for all produced outputs and therefore the agents make use of a number of price functions [20]. The demand function for agricultural products assumes neither a fully elastic nor a fully static demand; for most products, the price is specified as a function of the initial price of the product, price trend over time and price variation depending on the cumulative quantities produced by farm agents. In other word, as for the aggregate market behaviour the market-clearing condition is not imposed in the AGRIPOLIS model.

The approach used to determine output and input prices in the AGRICORE model can be viewed as a mixture of the approaches used in the SWISSLAND and AGRIPOLIS platforms. The recursive approach used to calibrate the supply side uses already existing output prices. The solution of the PMP problem provides shadow prices of outputs and inputs, which the latter is used for input costs. Modelling the demand side is not a priority in the AGRICORE project, therefore the demand items are exogenous. The platform will be used to derive market equilibrium prices by simultaneously equalizing endogenously determined aggregate supply to exogenously taken aggregate demand. The market prices might feedback into agents' optimization problem if effects of price dynamics are wanted.

5 Concluding Remarks

Modelling structural and policy changes in the agricultural sector is always a challenge. Based on developments in the CAP, environmental and sustainability concerns and the significance of demographic factors, we may conclude that farm agents' behaviour gains importance and hence modelling platforms that prioritize individual agents' behaviour, and the interactions among them, could be more appropriate to use. Given this assumption, however, this is not an easy task to fulfil. In particular, modelling input markets endogenously is difficult due to the lack of data and to non-divisibility of some inputs by agricultural production. The time horizon concerning financial and economic optimization is different and modelling both in one platform is a serious challenge. Another challenge is modelling the heterogeneity of the farms particularly if it is sourced from the physical conditions of the localities. Last but not least is the difficulty in aligning the economic, financial and environmental data at the farm level especially as these are collected by different institutions with changing priorities.

Considering the above-mentioned challenges, the AGRICORE model has some unique features. The first one is the PMP approach followed to model the supply side and agent behaviour. The second might be the time horizon involved in modelling which allows interactions between short- and long-period in a 7-year cycle by feedback relations. Finally, the inclusion of a biophysical module to model effects locality-specific characteristics can be the other distinguishing feature.

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For preparing this report, the following deliverables have been taken into consideration:

Deliverable Number	**Deliverable Title**	**Lead beneficiary**	**Type**	**Dissemination Level**	**Due date**
D6.1	AGRICORE architecture and interfaces	IDE	Report	Public	M23
D6.6	Software Quality Assurance measures for AGRICORE	AAT	Report	Public	M15