The Regional Multi-Agent Simulator (RegMAS)
Assessing the impact of the Health Check in an Italian region

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The Regional Multi-Agent Simulator (RegMAS)

Assessing the impact of the "Health Check" in an Italian region

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Abstract

Agent-based models (AMB) allow to conceive social systems as the result of individually-acting agents. When they are applied to agriculture, they can simulate the fundamental behaviour at the micro-level of the individual farmers, without the need of aggregating them in "representative" agents.

RegMAS (Regional Multi Agent Simulator) is an open-source spatially explicit multi-agent model framework specifically designed for long-term simulations of effects of policies on agricultural systems. Using iterated conventional optimisation problems as agents' behavioural rules, it allows for a bidirectional integration between geophysical and social models where spatially-distributed characteristics are taken into account in the linear programming problem of the optimising agents as individual resources.

The model is applied to asses the impact of the Health Check, the imminent further Common Agricultural Policy (CAP) reform, on farms structures, incomes and land use in a hilly area of a central Italian region (Marche).

Our results suggest that the Health Check, while increasing the farmer profit net of CAP support, is substantially neutral on the overall farmer incomes, also through a reduction of the off-farm labour.

Neverless, a limited negative effects may arise in the farms numerousness, with the consequence of a land abandonment that is noticeable only on mountain areas, where distances between farmers are greater.

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1 Introduction

With the 2003 Reform, the Common Agricultural Policy (CAP) underwent a major regime change, with a substantial migration from coupled payments and market intervention (and distorting) measures to farm-specific decoupled support based, at least in Italy, on historical payments. During the last year (2008), further modifications of that Reform, the so-called Health Check (HC), have been proposed by the European Commission (EC) and will probably enter into force in 2009.

Farm-based modelling approaches allow for a direct representation of such changes in CAP regime, therefore seem better suited than partial or general equilibrium models (like ESIM, FAPRI/AGMEMOD or GTAP) to analyse their impacts (Heckelei & Britz, 2005). In particular, mathematical programming, and more specifically Positive Mathematical Programming (PMP) models, are widely used within the scope of agricultural political analysis (Paris, 1991; Arfini, 2000). However, modelling representative farmers, they miss the interaction between them that is instead considered in Agent-based models (AMB).

RegMAS (Regional Multi Agent Simulator) is an open-source spatially explicit multi-agent model framework, developed in C++ language specifically designed for long-term simulations of effects of agricultural policies on farm structures, incomes, land use, etc..

More specifically, RegMAS conceives rural social systems (and in particular agricultural ones) as complex evolving systems, made of an heterogeneous set of "agents" (that is, farmers) whose behaviour is generated by a profit-maximisation, Mixed-Integer linear Programming (MIP) problem; they compete in the land-market and use purchased resources to increase their competitiveness (mainly through scale effects).

Differently from similar models, the spatial dimension is initialised from real land-use data, using satellite information, and plots are explicitly modeled in the agents' problem as individual resources. As common in GIS, spatial information is organised in layers to facilitate its usage within the model (Figure 1). This approach allows very detailed analysis along the spatial dimension, as farmers decisions can be based on individual plot properties and result of farmers' activity can be directly observed and, for example, evaluated on an environmental point of view.

In the present paper we demonstrate the use of RegMAS by evaluating the effect of the imminent CAP reform known as Health Check.

In particular, we are interested to observe how measures specifically designed to maintain a neutral aggregated offset, as the regionalisation (which was already admitted in 2003 Reform but then adopted by very few countries), may shift public support across different types of farmers and areas, eventually generating aggregate modifications on the whole area. The focus here is on the effect that new "parameters" applied to the political instruments introduced in the 2003 Fischler reform, as the Single Farm Payment (SFP) passing from the historical based to an area-based flat payment and stronger modulation.

The paper is structured as follow. Section 2 describes the methodological approach underlying RegMAS. After a short introduction of agent-based modelling applied to agricultural systems (2.1), it focus on two key points: farmers behaviours (2.2) and land allocation (2.3). The case-study region is then presented in Section 3, together with the steps required to derive a "virtual" region on which the simulations are eventually ran. Section 4 illustrates the hypothetical policy scenarios under which results are generated.

From these simulations we obtain a large set of information, including status of individual farms, environmental effects (soil use, land abandonment, agents and objects location), as well as aggregate results. Nonetheless, to better emphasise the possible impact of HC on the case-study area, we prefer to report and discuss some selected mostly aggregated evidence (5). Section 6 concludes.

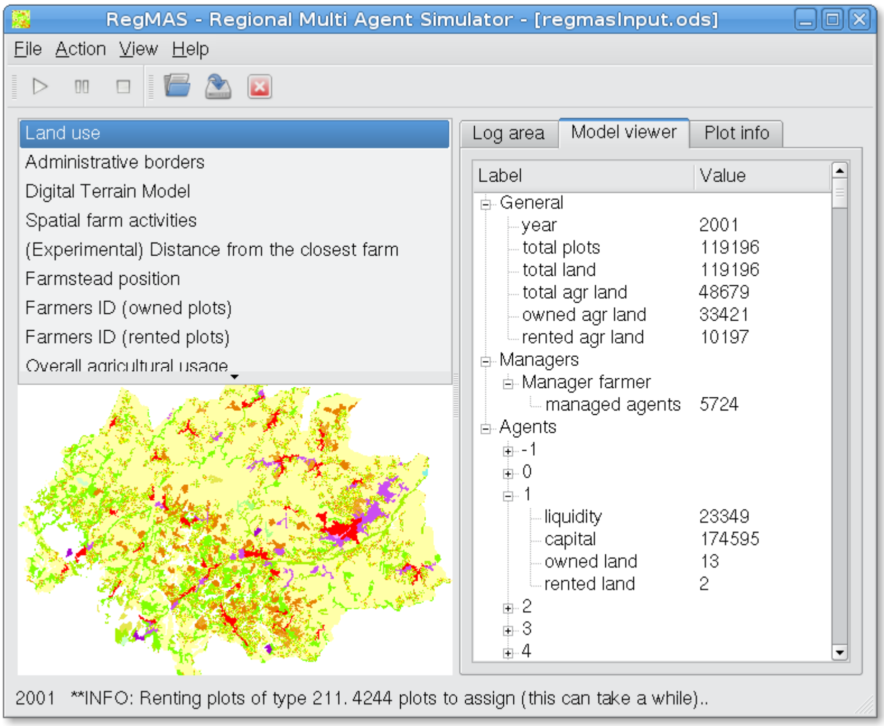
2 Methodological approach

2.1 Overview

Spatial explicit Agent-Based Models (ABM) within the specific agricultural domain was pioneered by Balmann (1997) with the Agricultural Policy Simulator (AgriPoliS) model.

ABM allow representing social systems as the result of individually-acting agents. When they are applied to agriculture, they can simulate, at the micro-level, the fundamental behaviours of individual farmers, without the need of aggregating

Figure 1: RegMAS user interface showing the case-study region



them in "representative" agents. Furthermore ABM can catch the iterations of the heterogeneous farms when competing over common finite resources, e.g. land.

Boero (2006) and Parker (2003) have review several ABM involving land use changes in various scientific areas, including agricultural economics, natural resource management, and urban simulation, but this section will briefly describes AgriPoliS as RegMAS borrows many concepts from it, *in primis* the utilisation of a profit-maximisation algorithm to derive farmers behaviours.

In AgriPoliS agents are mainly farmers[1]. They have their own goals; in AgriPoliS, the farmer's objective is the maximisation of household income. To achieve this objective, farmers solve a MIP problem that, in some aspects, is specific to each farmer. Outside the linear programming problem, they can also decide to rent other agricultural plots or to release rented land.

Using a mixed integer linear programming approach to simulate each agent behaviour on one hand is very flexible, as it can cover the whole range of farm activities, from growing specific crops to investing in new machinery or hiring new labour units. Furthermore, it is simple to add new regional-specific activities.

On the other hand, however, linear programming techniques require a long calibration phase to assure a balanced choice of farm activities, avoiding unrealistic outcomes [2].

Any farmer in the model is a real farmer whose data are taken from farm-level datasets (in Europe, FADN) and explicitly associated to a spatial location. Due to privacy-protection regulations, however, researchers doesn't normally have access to the real farm localisation. Therefore, farms have to be randomly distributed along the virtual region. Space (i.e. location) is important in the model because it influences transport costs and indirectly makes the farmers interact each other, e.g. by competing for the same land plots.

AgriPolis, as it takes into account many aspects of a real farm, is a very complex model, with lot of code dedicated to cover specific aspects (e.g. quota markets, generational changes, multi-years investments). A detailed description of AgriPolis can be found in Happe et al. (2004) or in Kellermann et al. (2007). While Happe et al. (2004) focus is on the methodological advantage of using ABM in agriculture as compared with other instruments as partial and general equilibrium models on one side and individual farm-level models on the other, Kellermann et al. (2007) details the latest implementation of AgriPoliS (2.0). In addiction to this two papers, Sahrbacher et al. (2005) describes AgriPoliS implementation over several case-study regions and Lobianco (2007) presents an adaptation of AgriPoliS for the Mediterranean regions, further adding some general background on agent-based modelling and to its motivations.

As AgriPoliS, RegMAS is spatially explicit, a characteristic that can not be neglected when modelling the agricultural sector. For example the spatial het-

[1]Other agents in the model perform some specific tasks, e.g. managing land or coordinating product markets.

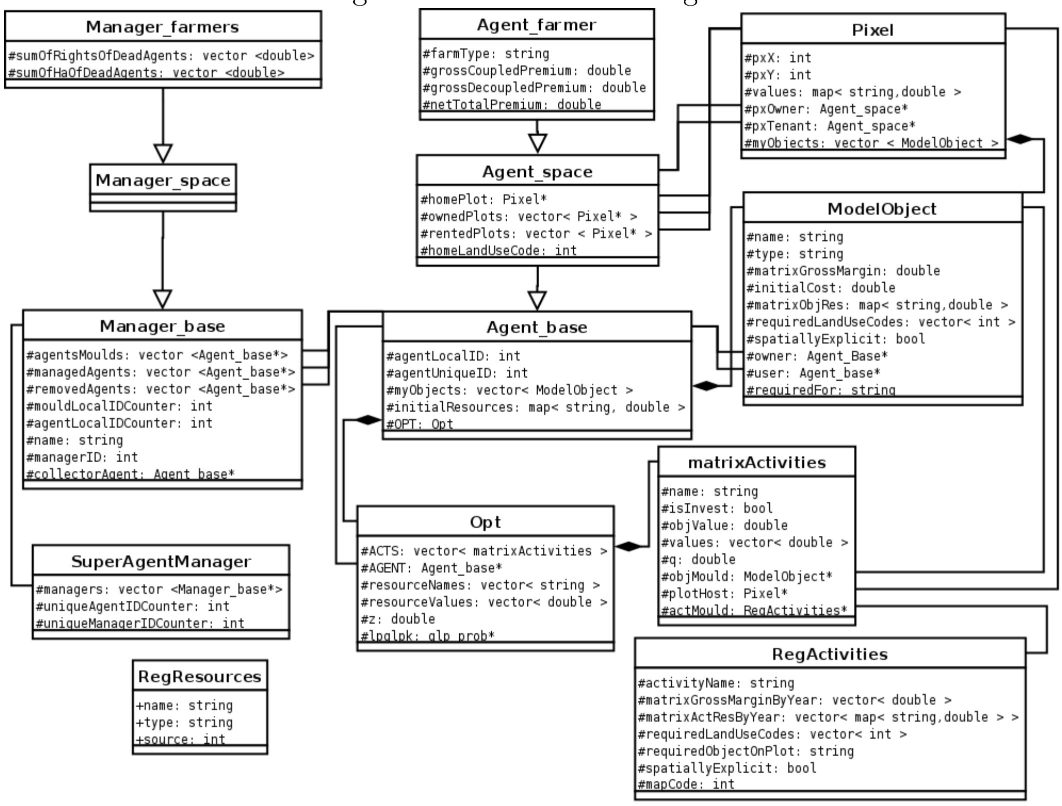
[2]RegMAS introduces a sub-region mode to help researchers to roughly calibrate their model before running a real (and slower) simulation.

erogeneity allows the model to associate on each plot a different rental price and investigate possible land abandonment phenomenas even when the land is *on average* profitable.

Differently from AgriPoliS, the spatial dimension is initialised from real land-use data, using satellite information, and plots are explicitly modeled in the decision matrix as individual resources.

As a further distinction, RegMAS has been designed from the ground-up to explicitly consider farmers as one type of several possible type of agents. In RegMAS farmers have sensitivity of the overall environment, including extra-agricultural variables. On a technical point, “farmer” agents derive from a more general type of “spatial” agents that in turn derive from a “base” type. Each agent type has its own “manager” agent that dialogue with a “Super Agent Manager”. The formers are a sort of interface “agent side” while the latter implements the same interface on the program core side. In this way the model core doesn’t need to know anything about agents internal logic. While this approach allows for rapid development of different agent types (only specific characteristics need to be modelled) at current RegMAS development stage only farmer agents are fully implemented. Figure 2 shows the Unified Modelling Language (UML) diagram of the main classes and their relations.

Figure 2: UML classes diagram



2.2 Farmers behaviour

Farmers autonomously make their decisions solving the following MIP problem:

$$
\begin{array}{lrll}
max & Y = & \sum_{i=1}^{C+I} GM_i * x_i & \\
s.t. & & & \\
& \sum_{i=1}^{C+I} a_{i,j} * x_i \leqq & b_j & \forall j = 1, ..., J \\
& x_i \geqslant & 0 & \forall i = 1, ..., C+I \\
& x_i \in & int & \forall i = C+1, ..., C+I
\end{array}
\tag{1}
$$

where:

i	activities index	Y	profit
j	resources index	GM_i	gross margins
C	continuous activities	x_i	production (unknown) quantities
I	integer activities	$a_{i,j}$	technical coefficients
J	constraining resources	b_j	capacities (RHS)

Individual activities and resources to include in the model are left to the RegMAS users. Currently we implemented models where, very synthetically, all aspects of running a farm are considered, including financial and labour activities. While on specialised linear-programming models this activities can be very detailed, in agent-based models the necessity of considering different type of farmers and the fact that each of them has its own mathematical problem to solve, limit the analysis to very aggregated activities (Figure 3).

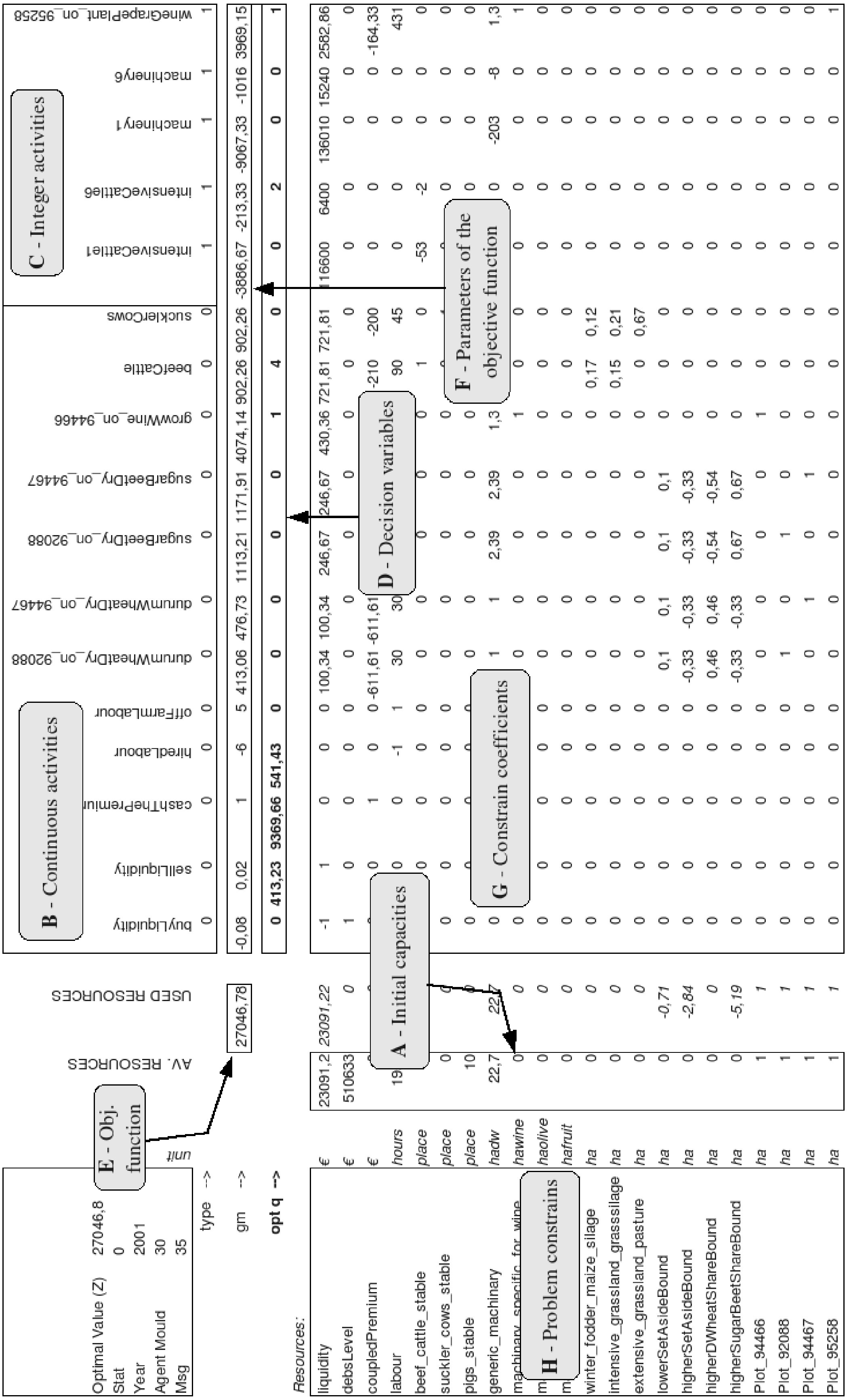
Farmers optimise their problem any time they bid for renting a land plot in order to calculate its shadow price, or plan for new investments, or finally produce using the given assets.

From FADN data we can establish the initial farm's endowment: financial assets, availability of land, machinery, animals and so on. From a linear programming point of view, these data represent the right terms of the constrain equations (A in Figure 3). Any farmer choose from a list of activity options. They can be divided in two categories: activities that can be run entirely within one year (B) and activities that generate results over multiple years (investments, C). Investments are bounded to be integer and the same investment type is available in different size-options, allowing scale-effects to emerge in the model (e.g. bigger investment objects have smaller costs or smaller labour requirements per single unit). As an important consequence agents can evolves during simulation as their production decision will depend on the investments acquired in the previous years. Section 2.2.2 details the farmers finance modelling, including how investments enter the MIP problem together with yearly activities.

To solve this problem the farmers chose the quantities (D) of the various activities that maximise the objective function (E). In our case, this is the maximisation of household incomes, and the gross margins of the various activities are the parameters of the objective functions(F).

Finally, the matrix of the constraint coefficients (G) links the available activities (B+C) with their technical requirements (H).

Figure 3: Example of the agent's Mixed Integer Programming Problem (excerpt)



RegMAS can take into account changes of resource endowment and activity gross margins, generated either endogenously to the MIP core, in case these changes occur as a consequence of the solving procedure (e.g., an investment improves the number of available activities) or exogenously to it, in case these changes occur in other parts of the model (e.g., renting/releasing land, or as a consequence of market prices changes).

Paris (1991); Arfini (2000) present respectively an in-deep analytical description and a literature review of linear programming techniques applied to farm problems.

2.2.1 The space dimension in the optimisation problem

As result of the spatial explicitness the farmer maximisation problem slightly change, as it takes into account plots as individual resources and each spatial activity is specified for each plot. The optimisation problem becomes:

$$\begin{array}{llll} max & Y = \sum_{i=1}^{N+S*P} GM_i * x_i & & \\ s.t. & & & \\ & \sum_{i=1}^{N+S*P} a_{i,j} * x_i \leqq b_j & \forall j = 1, ..., R+P & \\ & b_j = 1 & \forall j = R+1, ..., R+P & \\ & a_{i,j} = 1 & \forall \quad i > N \vee i = N + (j - R) & \\ & x_i \geqslant 0 & \forall i = 1, ..., N + S * P & \end{array} \qquad (2)$$

where:

i	activities index	Y	profit
j	resources index	GM_i	gross margins
N	non-spatial activities	x_i	production (unknown) quantities
S	spatial activities	$a_{i,j}$	technical coefficients
R	constraining resources	b_j	capacities (RHS)
P	individual plots		

As the number of plots available to a farmer increases, the matrices would grow to a size that would be hard to compute even for modern calculators.

Before adding the activities to the matrix we hence developed a procedure that checks for consistency of the activity with the plot land use and eventually with the presence of the necessary objects (an example could be that wine growing activity could not be made on grassland or if vineyard are not available)[3].

Despite the higher computational costs, using individual plots in the decision problem allows spatial activies to be "filtered" by the farmers based on characteristics of their associated plot. Currently, this is implemented in order to change the gross margins to include transport costs from the farmstead to the plot and to take into account the plot's altitude (under the hypothesis that mountain plots are

[3]The Reference Manual has a pseudo-code that details the steps the model does to add activities to the MIP problem, available at `http://regmas.org/doc/referenceManual/html/classOpt.html`.

less productive than plain ones). This GIS-alike functionality allows a full linkage between the social and the geophysical parts of the model.

Similar advantages arise on the output side: when the land use is kept implicit in the matrix decision matrix (e.g. farmers are presented with the "agricultural_land" total resource rather than with each individual plots) the spatial location of production remain undefined[4]. When instead the farm optimise a matrix with an *activity_x_plot* structure, the model can allocate the corresponding chosen activity to its associated plot. A simple function can then modify the values of the layers for that plot, e.g. to track where farmer production happen or to change the plot fertility.

2.2.2 Financial aspects

In RegMAS models investments require liquidity that can be obtained using open-credit line that can grow up to a model-fixed share of the capital (e.g. 80%).

Each year the farmer optimise the quantity of money to ask to the bank. There isn't an end-term for farmers to give back the money as the "bound" is rather as the debit share of the capital.

Differently from AgriPoliS there is no difference from short-term loans and long-terms one. This is because loans are completely decoupled from investments. On the other side, there is no needs to assume a constant share of investment covered by the loan: the individual farmers are free to implicitly optimise the share of the investments covered by loans depending on their financial situation.

Liquidity is calculated as follow:

$$\begin{aligned} liquidity_t &= liquidity_{t-1} + productionProfits_{t-1} + decPayments_{t-1} \\ &\quad - withdraws_{t-1} - \sum_{n=0}^{N} invCosts_{t-1,n} - sunkCosts_t \end{aligned} \tag{3}$$

To calculate the liquidity available to farmers at the beginning of a specific year we sum to the liquidity available on the previous year all the revenues and costs occurred in the previous year and we detract the sunk costs farmers need to pay before producing. In particular $sunkCosts$ are costs generated from previous choices, like multi-year rental costs or investment maintenance costs; $productionProfits$ are the results from the MIP optimisation, already including coupled premiums and off-farm activities; $withdraws$ are the money required by the farmers to support their own private life. They are calculated as a fixed portion of the profits plus a minimum level that depends from the size of the farm (measured in family annual work units):

[4]Various algorithms could be used in a post-procession fashion to assign production to a particular plot. One of them is discussed in Brady & Kellermann (2005). It supposes that farmers, given a certain mix of production activities, try to spread them in the smaller possible number of fields, maximising their size. However, land is considered fully homogeneous within the same soil type.

$$\begin{aligned} withdraws &= perCapMinWithdrawal * AWU \\ &\quad +max(0, profits * withdrawalProfitShare) \end{aligned} \tag{4}$$

The whole capital is in turn calculated as the sum of the liquidity, the investments current value and the land capital:

$$capital_t = liquidity_t + \sum_{i=0}^{I} investmentCurrentValue_{i,t} + landCapital \tag{5}$$

with I is the number of owned investments. The current value of investment objects may depends from the kind of investment itself, but currently it linearly decreases for all object types.
landCapital is, at least for now, fixed and read from the farmers' data file.

Finally, an important MIP resource that RegMAS calculate each year for each farmer is the debit level. If the liquidity can be thought as a buffer, the debit level should be considered as a threshold, expressed as the share of the whole capital that farmers can't overpass.

2.2.3 MIP solver

In RegMAS MIP problems have to be computed for each individual farm and in several steps during each simulated period, resulting in levels of thousands computations for period. It follows that the speed of the solving algorithm becomes a critical factor. As in RegMAS plots enter the problem individually, matrices can become quite large, however they are very sparse allowing specialised software to solve the problems in terms of fractions of second.

In fact, RegMAS use external libraries to solve this problems. RegMAS class **Opt** is responsible to establish the direction of the objective function (in our case, a maximisation), the set of bounds, objective coefficients and constrain coefficients. At this point the problem "object" is solved calling an external Dynamically Linked Library (DELL).

RegMAS uses the open-source GNU Linear Programming Kit (GLPK) (Makhorin, 2007) that employs a two-phase revised simplex method (that is guaranteed to find the optimal solution, if one exist) to retrieve continuous solutions, and then apply a Branch & Bound method in case of an integer optimisation.

GLPK recently added an interior-point algorithm, but we found it to be still too unstable at this time.

2.3 Land allocation and land market

An obvious problem when dealing with spatially explicit agent based models is the localisation of the agents and of their spatial objects. The problem is complicated by the fact that there is already an informative layer, consisting of the land use, and we have to keep this layer consistent with the model, applying the farm allocation over it.

Firstly, farms are assigned a random location picking up a plot compatible with their assets, starting from the less common. The idea is that rare land use types have the precedence over common land use types to minimise distances from them to the farmsteads. Hence, if a farm has, for example, both fruit land and arable land, the farmstead will be placed within a fruit land type.

Subsequently, plots are assigned to the closest farm that has still an uncompleted capacity for that specific soil type, giving precedence to owner plots in comparison to rented ones.

This is not a optimisation algorithm as plots are not assigned to farms in a way that minimise the total *plots_x_farmsteads* distance. But on the other hand also the real world situation is far from an optimal land defragmentation, as physical bounds and hereditary rules often split the farmer land in various disconnected plots.

During the simulation farmers can bid to rent new plots. The importance of the rental market within ABM in agriculture is pointed out in Kellermann et al. (2008) where different assumptions on modelling land markets are tested.

Currently (as in AgriPoliS) RegMAS doesn't allow for land transfer nor for direct *farmer-to-farmer* renting contracts. Instead, farmers can only rent land owned by an anonymous agent that collect the land arising from farms leaving the model and from the initial pool of rented plots to make it available in a bid to the farmer offering the highest price.

Farmers asked to bid offer a share of their shadow price for such plot, to take into account of fixed and variable negotiation costs and overheads. The shadow price for the new plot is calculated simply performing two MIP problem optimisation, with and without the plot, and calculating the difference.

While AgriPoliS can use some optimisation techniques as land is homogeneous within the same soil type, the full heterogeneity of plots in RegMAS prevents using such algorithms, making this process very computationally intensive. Therefore RegMAS offer the option to limit the bidding process to farmers within a certain distance from the plot.

Once the plot is assigned to a farm a new rental contract is established for a random period (within user defined limits) and the plot, eventually together with its spatial objects, enters the farmer's MIP problem as a new resource.

3 The case-study region

Our simulations are carried on a hilly region of central Italy, Colli Esini (Marche region), including 24 LAU2 municipalities and approximately 50,000 UAA, hosting in 2001 around 6000 farms. Its main characteristics, how it can be observed from its Land Use map shown in Figure 1[5], is to have a well-established homogeneous agricultural area on the east and a more heterogeneous, mixed agro-forestry areas on the south-west.

Actually, the computer simulation is ran on a "virtual" region based on this region and more specifically built upon the following datasets:

Quantitative regional data Aggregated data of the region, normally available from the Census.

Individual farmer detailed data Individual farmers are used in the model as "bricks" to build a simulation region and the crucial information here become the individual farms production factors. In order to obtain satisfactory congruence between the real and the simulated region, a basket in the magnitude of tens of farmers data is often necessary[6].

Technical coefficients and prices Technical coefficients, production prices and factor prices are needed to link the activities pool with the resource pool and to establish the objective function.

Land use map As RegMAS is fully spatial explicit, it requires a detailed map of land uses (in Europe this is available from the Corine Land Cover project[7]).

The specificness of this virtual region (and its differences with a real one) is the fact of being composed uniquely of "typical" farms, while still having its aggregated values as close as possible to the region under study.

Typical farms are a subset of all the farms in the region for which detailed data is available (e.g. because member of the FADN network). These are weighed with a scaling coefficient that minimise the difference between the simulation region and the real one (Eq. 6).

$$\min \sum_{k=1}^{K} \left(\frac{\sum_{n=1}^{N} (FADN_{n,k} * UC_n)}{REGIO_k} - 1\right)^2 \quad sub \quad UC_n \geqslant 0 \quad \forall n \tag{6}$$

Where:

Indices:	Variables:
$n = \{1...N\}$ Individual farms	$FADN_{n,k}$ FADN data
$k = \{1...K\}$ Characteristics	$REGIO_k$ Regional aggregated data
	UC_n "upscaling" coefficient

[5]The map is part of the Corine Land Cover and it follows its legend, where yellow represent agricultural areas, red urbanised areas and green natural areas.

[6]The exact number depends on three parameters: *(1)* the number of elements that should be compared between the real and the simulated regions, *(2)* how good the typical farms reflect the total of the farms in that region and *(3)* the statistical discrepancy that the user is willing to accept.

[7]`http://dataservice.eea.europa.eu/dataservice/metadetails.asp?id=950`

This procedure is called "upscaling" and it is well documented in Kellermann et al. (2007), while a practical implementation is discussed in Sahrbacher et al. (2005)[8].

The upscaling can be conveniently obtained using the quadratic solver embedded in Excel, like shown on Fig 4 [9]

Figure 4: Regional upscaling using Excel

B6 =SUM(H6:AE6)

	A	B	C	D	H	I	J	K	L	M
1	MARCHE		COLLINE MEDIA VALLE ESINA		Total farm n	Tot UAA	irrigated UAA	Number of farms in different size unit		
2								< 1 ha	1 – 2	2 – 5
3	Plot size -->	0,5		Regional data -->	5726	49092,78	2012	1054	943	1680
4	Typ farms -->	21		Sum of fadn farms -->	5517	48732	2013	1083	576	1761
5				relative deviation -->	-0,03650017	-0,007359	0,000248509	0,027514231	-0,38918346	0,048214286
6	**Target func. -->**	**0,227998685**		quadratic relative deviation -->	0,00133226	5,416E-05	6,17567E-08	0,000757033	0,151463763	0,002324617
7	**Fadn data**									
8	farmID	ote	fam	**upsc_coeff**						
9	1234567890123	1310	1	**0**	1	66	0	0	0	0
10	1234567890124	1310	1	**0**	1	11,5	4	0	0	0
11	1234567890125	1420	1	**0**	1	28	0	0	0	0
12	1234567890126	1310	1	**0**	1	15	0	0	0	0
13	1234567890127	1310	1	**0**	1	6	0	0	0	0
14	1234567890128	1420	1	**0**	1	5,5	0	0	0	0
15	1234567890129	1310	1	**370**	1	4,5	2	0	0	1
16	1234567890130	1420	1	**0**	1	15	5	0	0	0
17	1234567890131	1420	1	**0**	1	27	0	0	0	0
18	1234567890132	1443	1	**0**	1	21,5	0	0	0	0
19	1234567890133	1420	1	**0**	1	25,5	4	0	0	0
20	1234567890134	1420	1	**0**	1	28	0	0	0	0
21	1234567890135	1443	1	**0**	1	14	5	0	0	0
22	1234567890136	6030	1	**0**	1	19,5	2	0	0	0
23	1234567890137	1310	1	**0**	1	17	3	0	0	0
24	1234567890138	3110	1	**0**	1	6	0	0	0	0
25	1234567890139	3110	0,867	**67**	1	9,5	0	0	0	0
26	1234567890140	6030	1	**0**	1	9,5	0	0	0	0
27	1234567890141	3110	1	**0**	1	3,5	0	0	0	1
28	1234567890142	3110	1	**0**	1	4,5	0	0	0	1
29	1234567890143	3400	1	**0**	1	5	0	0	0	1
30	1234567890144	6050	1	**1**	1	27	0	0	0	0
31	1234567890145	3400	1	**0**	1	15	0	0	0	0
32	1234567890146	6030	1	**0**	1	5,5	0	0	0	0
33	1234567890147	6040	1	**85**	1	3	2	0	0	1
34	1234567890148	6030	1	**0**	1	5	0	0	0	1

4 Scenarios

Simulations discussed in this paper start from 2001, in order to include the reference period. Such period is 2001-2003 for most activities [10]; over those years, the model "collects" the subsides received by each farm, then automatically calculates the single-farm payment (SFP) due to any different farmer and finally assigns the SFP to farmers.

More in detail, the model keep track for each farmer of three vectors: the **dRights**, **dYears** and **dHa**.

[8] Both paper refer to the preparation of a simulation region for AgriPoliS, but the methodology can be equally applied to RegMAS.

[9] A template/example file can be downloaded from the documentation wiki, at `http://www.regmas.org/doc/doku.php?id=model:other:upscaling`

[10] The exception is the olive oil sector, where, due to its higher yield fluctuation, the reference period is extended to 2004.

The **dRights** are the average entitlements that a farmer "own" for the decoupled payment, differentiated by each specific production activity. It is already averaged by the number of years of the reference period. In a similar way the **dHa** are the average hectares that have generated the entitlements for the specific activity. Finally **dYears** are the years for which these averages have been calculated.

Using an activity-specific flag to indicate the reference period, every year the model update the entitlements for each agent and each activity:

$$\begin{aligned} dRights_t &= (dRight_{t-1} * dYears_{t-1} + newRight)/(dYears_{t-1} + 1) \\ dHa_t &= (dHa_{t-1} * dYears_{t-1} + newHa)/(dYears_{t-1} + 1) \\ dYears_t &= dYears_{t-1} + 1 \end{aligned} \tag{7}$$

where $newRight$ is the coupled premium obtained by the farmer on the specific activity for that year (only if the activity flag is in "registration" mode for that year). In this way different products may have different reference periods, even not continuous.

When due, the model assigns back the entitlements to each farmer in terms of SFP. Starting from version 1.1, RegMAS can distinguish between history-based SFP (Eq. 8) and area-based SFP (Eq. 9):

$$dPayment = \sum_{i=1}^{N+S} dRights_i * dRateCoef_i \tag{8}$$

$$dPayment = (\sum_{i=1}^{N+S} \sum_{y=1}^{A} dRights_{i,y} * dRateCoef_i / \sum_{i=1}^{N+S} \sum_{y=1}^{A} dHa_{i,y}) * \sum_{i=1}^{N+S} dHa_i \tag{9}$$

where $N + S$ are all the activities; $dRateCoef_i$ counts for eventual partial decoupling. and A are the number of agents in the model. Please note that the farmer can still benefit for a given year/activity of a mixed of coupled and decoupled premium.

This farm-based modelling approach allows for a very detailed implemention of the various policy instruments that can be hardly achieved with conventional equilibrium models. Beside macro-economic and general, policy-specific parameters (e.g., modulation), RegMAS allows to dynamically set activities' gross margin, matrix coefficient (see Figure 3) or decoupling entitlements along the temporal dimension.

We used such flexibility to build the two following scenarios:

Decoupling scenario (*dec*)

In this scenario, the introduction of historically-based SFP starts in 2005, the modulation on payments over 5000 euro rises from 3% in 2005 to 5% in 2007. All major payments are decoupled but quality premiums remain (for durum wheat and *ex* art. 69) and these are treated in the model as coupled subsides.

This scenario approximately matches the actual implementation of the 2003 Fischler CAP reform, including the Italian national decisions in terms of decoupling options and art. 69.

Health Check scenario (*hc*)

The *hc* scenario is equal to the *dec* scenario till 2008, but from 2009 onward it assumes the following changes:

Modulation It becomes much stronger, starting from 2009 and following table 1. Particularly payments below 250 euros are totally dropped;

Set aside Mandatory set-aside minimum share (10%) is abolished from 2009;

Regionalisation From 2010 the SFP calculation changes following the area-based implementation (also known as “regionalisation”) where the unit-value of the subsides are averaged. Our implementation of the regionalisation does not allow the redistribution of the subsides to farmers without eligible land;

Full decoupling Since Italy has already opted for full decoupling in 2003, the only novelty is the decoupling of the specific durum wheat payment (40 euros) starting from 2010, on the base of the 2005-2008 reference period.

While the durum wheat payment is decoupled the other quality payments, *ex* art. 68, are maintained.
This scenario is aimed at implementing the Health Check reform, as know by the preparatory legislation acts by the EU Commission [11].

Table 1: Modulation bands(*Health Check* scenario)

total farm payment (euro)	2008	2009	2010	2011	2012-2015
0 - 250[a]	0	100	100	100	100
250 - 5.000	0	0	0	0	0
5.000 - 100.000	5	7	9	11	13
100.000 - 200.000	5	10	12	14	16
200.000 - 300.000	5	13	15	17	19
300.000 - +∞	5	16	18	20	22

[a] Payments over 250 euros are not affected by this modulation band.

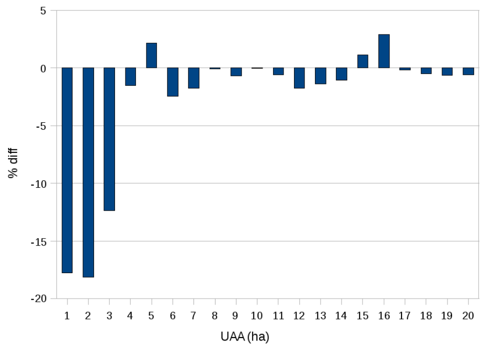
[11] COM (2008) 306, *Proposal for a Council Regulation*, 20 May 2008

5 Selected results

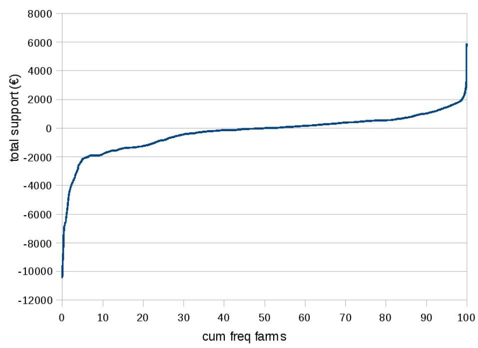
Tables 2 to 5 present the outcomes on the simulated region under the *dec* and *hc* scenarios, when we run the model till 2015, showing first the overall results and then results subdivided by farm size classes[12].

In particular the number of farms seems only marginally influenced by the contingent policy option. During historical periods (1990-2003) the yearly abandonment rate in Italy has been of 2.32% (Eurostat), while we report slightly higher rates in our region for period 2008-2015 in the two *dec* and *hc* scenarios (respectively 3.30% and 3.35%). While the differences between the two scenario seems small, it increases when we look down by farm size. The smallest group of farm seems much more influenced by the *hc* scenario (Figure 6(a). This is likely an outcome of the suppression of smaller payments (250 euros). In fact, while these small payments represent only the 0.68% of the total support (referring to 2008) if we consider only farms within 3 hectares they represent 22.36% of the support involving 68.15% of those farms.

Figure 5: Farms results, *hc* vs *dec* (2015)



(a) size effects (cum nFarms by size)



(b) redistributive effects: winner and losers

Effect of modulation on farmers becomes evident when we look at the farm profits with CAP payments. While the net farm profit, without considering the CAP support, increases along all classes, probably due to a higher production freedom following the drop of mandatory set aside and further decoupling of durum wheat, the farm profit once including the CAP support strongly reduce the gains.

Adapting the production to more intensive crops (e.g. substituting set aside areas) requires also more job, subtracting it from off-farm activities that in this region are particularly important. Consequently total incomes, composed of farm profits plus off-farm activities, seems at the end to remain steady between the two scenarios.

[12]These simulations have been conducted with Version 1.3 of RegMAS software. Readers can replicate them downloading RegMAS at `http://www.regmas.org`.

Table 2: Main results

	dec_2015	hc_2015	% var dec 2015–2008	% var hc 2015–2008	% var 2015 hc–dec
number of farms (n)	4,304	4,288	-20.9	-21.2	-0.4
avg. size (UAA ha/farm)	10.97	11.01	23.5	24.0	0.3
quitted farms (n)	1420	1436			
abandoned land (%)	3.25	3.27			0.5
farm profits (euro/farm)	10,981	11,386	12.1	16.2	3.7
farm profits w/CAP (euro/farm)	16,068	16,202	15.7	16.6	0.8
incomes (euro/farm)	20,942	20,982	7.6	7.8	0.2
off-farm labour (h/farm)	975	956	-12.6	-14.3	-1.9
total agr labour (AWU)	2,884	2,928	-12.5	-11.2	1.5

Table 3: Main results (small farms - [0-3] ha)

	dec_2015	hc_2015	% var dec 2015–2008	% var hc 2015–2008	% var 2015 hc–dec
number of farms *(n)*	405	355	-73.9	-77.2	-12.35
avg. size *(UAA ha/farm)*	2.2	2.3	16.4	19.0	2.22
farm profits *(euro/farm)*	4,069	4,196	-9.2	-6.3	3.14
farm profits w/CAP *(euro/farm)*	4,726	4,582	-3.2	-6.1	-3.04
incomes *(euro/farm)*	9,679	9,484	-17.4	-19.1	-2.01
off-farm labour *(h/farm)*	991	980	-27.6	-28.4	-1.03

Table 4: Main results (middle farms - [4-15] ha)

	dec_2015	hc_2015	% var dec 2015–2008	% var hc 2015–2008	% var 2015 hc–dec
number of farms *(n)*	3,004	3,092	-2.4	0.4	2.93
avg. size *(UAA ha/farm)*	7.0	7.1	0.7	2.6	1.89
farm profits *(euro/farm)*	8,963	9,119	-5.5	-3.9	1.74
farm profits w/CAP *(euro/farm)*	11,960	11,936	-4.5	-4.7	-0.20
incomes *(euro/farm)*	16,608	16,566	-4.7	-4.9	-0.25
off-farm labour *(h/farm)*	929	926	-5.1	-5.5	-0.38

Table 5: Main results (large farms - [>16] ha)

	dec_2015	hc_2015	% var dec 2015–2008	% var hc 2015–2008	% var 2015 hc–dec
number of farms *(n)*	895	824	10.4	1.6	-7.93
avg. size *(UAA ha/farm)*	28.4	29.0	-4.4	-2.3	2.24
farm profits *(euro/farm)*	20,884	22,781	-1.3	7.7	9.09
farm profits w/CAP *(euro/farm)*	34,987	36,789	-3.8	1.2	5.15
incomes *(euro/farm)*	40,586	42,170	-3.6	0.2	3.90
off-farm labour *(h/farm)*	1,120	1,076	-2.4	-6.2	-3.91

5.1 Regionalisation redistributive effects

The regionalisation of the SFP is expected to introduce significant redistributional effects between farmers. However this effects are interconnected with the other policy changes that the Health Check introduces.

Comparing the two scenarios on 2015[13] and considering the whole subsides (still coupled payments+SFP), the number of farms that loose money compared to those that "win" money is slightly smaller (46.43% again 51.31%). However the average gain (647.35 euro) is much higher than the average loss (1146.18 euro). While there are exceptional cased losing over 10000 euro or gaining over 5000 euros, the 92.4% of farms is within the ±2000 range and 47.24% of them are within the 500 euros one. Figure 5(b) shows quite clearly that the distribution is asymmetric, especially at its tails, where the left tail is much stronger than the right one, due to the modulation.

5.2 Validation

RegMAS models comprises some limited but important stochastic components.

Specifically the stochastic behaviour derives from the following operations performed by the models:

- alignment of Corine Dataset with Census datasets (reclassification);
- initial farmer spatial allocation and land allocation;
- random objects age at beginning of simulation;
- random rental contracts age at beginning of simulation;
- collection of free plots in the rental process.

RegMAS takes advantage of modern programming languages that allow to specify if the random number generator seed should be re-initialised at each run or kept fixed. If the seed remain fixed simulations are guaranteed to return the same output over the same input and consequently differences in the outputs can be ascribed uniquely to differences in the input. We use this approach to compare the two scenarios and, in particular, to investigate results shown by the same farms.

However results obtained in this way derives from a particular, even though fixed between scenarios, random extraction.

Therefore we repeated our simulations changing each time the seed to assess the reliability of our results, or, in other worlds, to check how much they derives from the specific set of assumptions made in the input and how much from the stochastic components of the model.

Our repetitions seems to indicate that results are very stable but, as expected, their variability strongly depends from the size of the experiment (Table 6).

On small region border effects and a much smaller set of simulated farmers lead to a much higher variability. The possibility of using relatively large regions is a strong point of RegMAS compared with other simulation toolkits that, using an

[13]This results take into consideration only those farms that are still in the model on both scenarios. There is however a limited number of farms that reach 2015 only in one scenario.

interpreted language, are much slower (e.g. Castella et al. (2005) use the Cormas Toolkit (Bousquet et al., 1998) to perform its simulation, but on a relatively small 50x50 grid).

Table 6: Results reliability (5 repetitions, hc_2015)

	full region (48,679 UAA)			sub-region (931 ha UAA)		
	u	d.s.	CV	u	d.s.	CV
number of farms (n)	4,294	11.9	0.0028	87	2.8	0.0320
avg. size (UAA ha/farm)	10.98	0.0	0.0027	10.7	0.4	0.0410
quitted farms (n)	1,430	11.9	0.0083	23	2.8	0.1196
abandoned land (%)	3.31	0.0	0.0139	0.8	0.2	0.2187
farm profits (euro/farm)	11,340	55.3	0.0049	12,834	353.1	0.0275
farm profits w/CAP (euro/farm)	16,148	53.5	0.0033	17,394	274.7	0.0158
incomes (euro/farm)	20,929	48.3	0.0023	20,762	63.9	0.0031
off-farm labour (h/farm)	956	9.4	0.0098	392	59.0	0.1505
total agr labour (AWU)	2,928	26.4	0.0090	87	4.0	0.0465

5.3 Territorial consequences

Figure 6 summarises the land usage within the region in the Health Check scenario in 2015, showing in red abandoned plots, that is, that are either unrented or unused by the tenants. While we used a very conservative coefficient to establish altitude influence over the gross margin (2% every 100 meters), we can nevertheless observe that the majority of abandoned plots tend to be in the most hilly part of the region. An important role seems to be played by the fragmentation that this area has with non-agricultural areas, increasing the average distance and so the transport costs compared with homogeneous agricultural areas in the east part of the region. On these areas the land freed by small farms that, especially in the *hc* scenario, quit the agricultural production, may be too far to be used by remaining farms, leading to land abandonment.

As our simulations do not take into account the increase in the producer prices happened in the past few years, the fact if this increase could slow down the farm quitting phenomena and so the resulting localised land abandonment is still an open question.

Table 7: abandoned plots (2015)

	dec		hc		hc-dec	CV
	ab. plots	%ab. rate	ab. plots	%ab. rate	% diff	
0-200m	769	2,312	774	2,327	0,65	0,028
200-400m	679	4,995	678	4,987	-0,15	0,010
400-900m	135	7,508	139	7,731	2,96	0,028

6 Conclusions

We used RegMAS, an open-source, spatially explicit agent based modelling framework, to asses the possible impacts of the Health Check (regionalisation and further modulation, in particular) on the heterogeneous structures, farmer incomes and land use of a central Italian region (Marche). RegMAS allows economical agents (that is, farmers) to contemplate spatial-explicit information within the formulation of their behaviours (in our case, income maximisation) and to asses the economic, social as well as environmental outcomes of these behaviours on whole area. Our preliminary results seem to indicate that the Health Check, while increasing the farm profit net of CAP support, may slightly reduce the overall farmers incomes, also through a reduction of the off-farm labour, and that these effects may be greater on small and large farms compared with middle-size ones. Allocation of land freed by quitting farms depends on distance from neighbouring farmers, and in some internal areas this land may eventually be abandoned.

Figure 6: Land abandonment (*Health Check* scenario, 2015)

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