“Proposal for a territorial assessment of the effects of agricultural policies with a georeferred mathematical programming model: a case study”

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Introduction

The primary sector has always had a fundamental role in human activities. In recent years, major industrialised and developed countries increased demand for the positive externalities generated by the agriculture, while they reduced the importance of the sector in terms of production of food.

The evolution of public intervention followed the change of the role of agriculture and has tried to propose instruments able to consider and balance both private and public interests. It is especially with the Mid Term Review (MTR) that policy maker has tried to implement a system of subsidies that bound the farmer to a series of activities related either directly or indirectly with the collective welfare. Moving from coupled aid to decoupled one linked to the respect of cross-compliance means changing the concept of public intervention. In this context, a useful evaluation tool should be able to analyse and to catch the changes in farmers behaviour by considering also the territory in order to locate the effects. The territory, as a matter of fact, is not only the place where the effects passively fall, but it is capable of interfering directly in the farmers decision-making process.

Therefore, the development of specific methodologies able to analyze farmers' behaviours and specific instruments linked to the territorial analysis could represent an important tool to assess agricultural policies effects both on enterprises and territory.

In this framework a methodology based on the Positive Mathematical Programming (PMP) and on the implementation of a Geographic Information System (GIS) seems to answer the several questions about the policies' assessment and land-use planning. The present research integrates this two methodologies.

PMP is used in a territorial model and it is based on the optimization of an objective function representing a farm gross margin while GIS allows to analyze territorial aspects and to locate the effects of the policy. This tool has been tested in a specific case study in order to analyse the effects of the CAP Reform (in particular decoupling, cross-compliance and modulation) on the primary sector and on farm land use potential changes. The innovative aspect of the research is the attempt to study the impact of agricultural policy through an optimization model that considers among its variables also the specific localization of farms. The final result is represented by the creation of georeferred maps in which the land use changes are evaluated and interpreted under the framework of multifunctionality, in terms of quantitative analysis regarding landscape and, abandonment risk and cattle distribution.

1 Methodology

The aim of the present work is to propose and to implement an integrated assessment tool. This instrument is the result of the interaction of a positive mathematical programming (PMP) module with a geographical information system (GIS). Thus, while with mathematical programming is possible to analyse farmer's behaviours, GIS is capable of representing the results graphically and, moreover, to provide territorial information useful both for the researcher in the phase of implementation of the model and for stakeholders during their territorial assessment path. The aim of the positive mathematical programming is to create a new non-linear model that is able to represent and calibrate the farm's output levels without the "calibration" constrain (1).

(1) $x_{nj} \le x_{Rnj}\ , per\ \ x_{Rnj} > 0,\ j=0,....,J_n$ where x_{nj}, x_{Rn} are, respectively, the vector of the possible outputs and the vector of the output levels achieved in a specific period. The new model can be used for the design of new policy scenarios in order to analyse the potential changes in the farmers' behaviours. PMP in composed by three phases:

- The objective of the first phase is to estimate the marginal costs of the outputs levels and the shadow price of land. In this step The first phase is defined by *N* linear programming models (PL), one for each company or group of companies in the sample, and an additional PL model for the entire sample.

  The model of PL of the n-farm has the following structure:

  (1) $\max(p_n x_n - c_n\, x_n)$

  with,

  (2) $A_n\, x_n \le b_n$

  (3) $x_{nj} \le x_{Rnj}\ , per\ \ x_{Rnj} > 0,\ j=0,....,J_n$
  $x_n \ge 0$

  Where p_n is the vector of prices from the *nth*-farm, c_n is the vector of variable costs "accounting" per unit of output derived from FADN database, A_n is the matrix of the coefficients of technical factors, b_n is the vector of the constraints of the availability of limiting inputs, and x_{Rn} is the vector of the output levels achieved.

  Each company presents *I* limiting inputs and *J* outputs. The vector of the use of land for each process is indicated by h_{Rn}. Land is the only limiting factor for the model and the *nth-A* matrix of technical coefficients is defined as $A_n = [n_{ij}]$ where $a_{nij} = h_{Rni} / x_{Rnj_n}$.

The model presents a very simple structure because there are not any constraints that characterize the classical LP models like the bonds of agronomic rotation, productions, sales, etc.. By contrast, the model has only two types of constrain: the so called structural (2) and calibration (3) constrain. The first bond obliges to respect the total availability of land, while the latter undertakes to respect the farmer choices expressed in terms of quantity of output. Each constrain is associated with the corresponding shadow price: the vector (y_n) to the productive factor (2), and the vector (λ_n) to the calibration constrains (3).

Thus, the problem (1) - (3) can be expressed in accordance with the following dual structure:

$$(4) \quad \min\,(b_n\; y_n + \lambda_n\; x_{Rn})$$

with,

$$(5) \quad A_n\; y_n + \lambda_n + c_n \geq p_n$$
$$y \geq 0,\ \lambda \geq 0$$

LP primary model for the entire sample is represented as:

$$(6) \quad \max(p\,x - c\,x)$$

With,

$$(7) \quad A\,x \leq \bar{b}$$

$$(8) \quad x \leq \overline{x_R}$$
$$x \geq 0$$

The LP additional model (N + 1) for the entire sample is defined taking into account all the resources of farms in the sample and all productive activities, as if the information appears to be related to a single big farm, this cost function represents the regional cost function.

The dual model is:

$$(9) \quad \min\,(\bar{b}\;\; \bar{y} + \bar{\lambda}\;\; \overline{x_R}\,)$$
$$y, \lambda \geq 0$$

with

$$(10) \quad A\,\bar{y} + \bar{\lambda} + \bar{c} \geq \bar{p}$$
$$y, \lambda \geq 0$$

The proceedings illustrated by the linear programming is done in order to obtain a consistent and accurate estimate of marginal cost associated with the level of production (x_R) for each activity. The vector of marginal cost for the *nth* farm is given by $(\lambda_n + c_n)$, while it is $(\bar{\lambda} + \bar{c})$ for the whole sample.

- The information extracted from phase 1 is used in this second part to reconstruct the whole cost function using data from all the N farms of then sample. The hypothesis is that the cost function has a quadratic form functional $C(x) = x' Q x / 2$, where Q is a symmetric matrix, positive and semi-defined. Given the structure of the LP model described above, the function of the marginal cost can be represented as:

  (11) $mc(x) \equiv \bar{\lambda} + \bar{c} = Q \overline{x_R}$.

  Since the cost function is a function of border for the sample of farmers as a whole, each single cost function is expressed by a non-negative deviation from the (11).

  In other words, each farm in the sample may not produce a given output at a lower cost than the cost indicated by the border cost function.

  Therefore, the nth-farm marginal cost function can be represented by $mc(x_n) \equiv \lambda_n + c_n = Q x_{Rn} + u_n$, where u_n is a vector of deviations from the regional cost function that identifies the nth-farm's demands for limiting inputs.

  Because in a given area not all farmers choice all production processes, the model requires further specification. This statement is solved by two sets of constrains.

  The first set of constraints covers the outputs activated, which will have a marginal cost equal to the marginal cost of the border. In this case, then, the relationship between the two marginal costs takes the following form:

  (12) $cm_{nk} \mid x_{Rk} > 0 : \lambda_{nk} + c_{nk} = Q_k x_{Rn} + u_{nk}$, $k = 1, \ldots, J_n$

  While for those activities which are not carried out:

  (13) $cm_{nk} \mid x_{Rk} = 0 : \lambda_{nk} + c_{nk} < Q_k x_{Rn} + u_{nk}$, $k = 1, \ldots, J - J_n$

  Now it is necessary to estimate the coefficients of the matrix *Q,* which defines the total cost variables of the positive programming problem. The Q matrix is estimated using the *maximum entropy approach*. In summary we can represent the coefficients of matrix Q, as indicated in (14), according to a certain probability $prob_{jj}^{s}$ $(s = 1, ..., S;\ j = 1, ..., J)$ that is associated with the range of supportive values w_{jj}^{s} is able to satisfy the basic condition: $\lambda + c = Qx$.

$$(14)\quad Q=\begin{bmatrix} q_{11}=\left[w_{11}^{1}\ldots w_{11}^{s}\right]\begin{bmatrix} prob_{11}^{1} \\ \vdots \\ prob_{11}^{s} \end{bmatrix} & \cdots & q_{1J}=\left[w_{1J}^{1}\ldots w_{1J}^{s}\right]\begin{bmatrix} prob_{1J}^{1} \\ \vdots \\ prob_{1J}^{s} \end{bmatrix} \\ \vdots & \ddots & \vdots \\ q_{J1}=\left[w_{J1}^{1}\ldots w_{J1}^{s}\right]\begin{bmatrix} prob_{J1}^{1} \\ \vdots \\ prob_{J1}^{s} \end{bmatrix} & \cdots & q_{JJ}=\left[w_{1J}^{1}\ldots w_{JJ}^{s}\right]\begin{bmatrix} prob_{JJ}^{1} \\ \vdots \\ prob_{JJ}^{s} \end{bmatrix} \end{bmatrix}$$

The conditions of matrix Q (positive, diagonal and semi defined are reached with the Cholesky decomposition, in which a square matrix is the product of a triangular matrix and a diagonal transposed compared to the first (15).

$$(15)\quad Q=LDL', \quad Q=R'R, \quad Q=LD^{\frac{1}{2}}$$

By maximizing the entropy function (15), where $\sum_{s=1}^{S} prob_{jj}^{s}=1$, the values of the parameters of the Q matrix will be estimated.

- The last phase of PMP model is usually called the calibration step. It is also associated with the analysis of policy scenarios.

The possibility of connecting a GIS module to the mathematical programming tool allows both to create farm types depending also on their territorial collocation and to locate the results of the maximization process.

The first step is represented by the creation of the farms map of the considered area. This operation is possible thanks to the elaboration of the V Agricultural Census made by Istat in 2000. As a matter of fact is possible to create georeferred database linked to the sheet map. Sheet map represent the minimum territorial unit to which attribute socio economic information. Nevertheless, the elaboration of the land use map Corine Land Cover (2000) allowed to consider the very Utilized Agricultural Area (UAA) within each sheet map. During this phase is necessary to do a restriction due to the fact that in a single sheet map more than one farm can coexist. In this case, the farm with the largest UAA was chosen.

In this framework, the aim of building the farms map is to make possible a farms classification depending on their territorial location. Indeed, once known the location of farms, it was possible to divide them depending on whether they are settled: in plains, hills or mountains. This operation is possible thanks to the elaboration of the digital elevation model (DEM). Another type of classification regards the agricultural utilized area. Thus, trough the elaboration of the georeferred database, it is possible to determine the farm classes depending on their size.

The final result of processing is the identification of N number of classes depending both on the spatial and dimensional characteristics of the farms. For each class a specific PMP model was implemented. The required information for the implementation of the PMP models are the land use of each farm group considered, the variable costs of each output, prices and yields. While the data about agricultural utilized area are taken directly from Istat database, all the other data comes from FADN database.

The effects of agricultural policy are analysed by comparing different scenarios. The first scenario is referred to the situation of 2004 under a coupled policy and it is called Scenario_1 (Sim_1). Thanks to this scenario it is possible to move from the year of reference (2000) to the year in which the Reform started (2004). This is possible by changing the prices of outputs. The second scenario describes the situation of 2004 under the MTR measures, Scenario_2 (Sim_2). For Scenario_1 and 2 a territorial constrain has been added to limit the increase of intensive arable land only to areas with slopes of less than 15%. The optimization of each farm models underlines the answers of farmers to the new policy. However, the importance of the territory to interfere in the farmers choices led to the need to develop a georeferred mathematical model able to consider territorial differences during the optimization process and to provide useful information for a more complete assessment of the effects of policies.

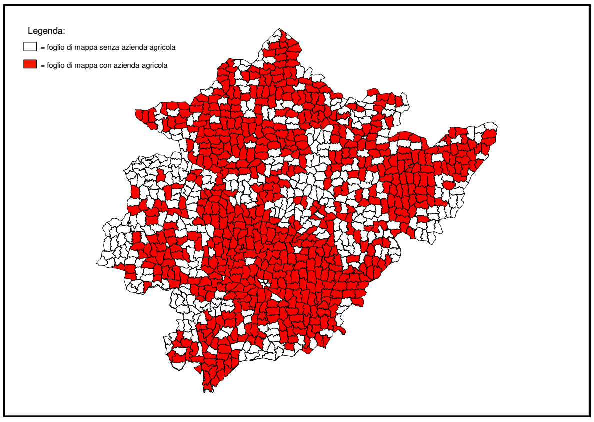
2 The case study

The georeferred PMP models were tested in a specific study case. The area identified is the Mugello, a territory near Florence, in Tuscany. The choice of this area underlines the willingness to consider a place characterized by marginality and where, therefore, it is even more necessary a precise and specific public intervention aiming to safeguard and sustain the multifunctional nature of farming.

The Mugello is made up of nine municipalities and covers an area of about 1127 square kilometres.

The landscape of Mugello is characterized by hills which degrade from pre-Appennino degrade up to the plains of the river Sieve. It is an anthropized area where agriculture and related activities represent the main socio-economic sector. The first step of the analysis regards the building of the farm georeferred database. The elaboration of the V Census of Agriculture made by Istat produced the figure 1, which represents the Mugello territory and the map sheets that contains a farm.

Figure 1 – Map sheets (red) which contain a farm.



Source: Our elaboration.

This procedure involves a loss of information (as illustrated in Table 1).

Table 1 – Loss of information (hectares) due to the construction of georeferred database

[redacted]

Source: Our elaboration.

Even if the loss in the number of farms in large (about 60%), with the adopted restriction it is possible to consider nearly 65% of the UUA. As regards individual crops, especially those that potentially could suffer more consequences as a result of decoupling of aid, namely wheat, barley and maize, are significantly represented in the information system (64% of wheat, 72% durum wheat , 65% barley, corn 58%). In this case it is possible to restrict the analyzed territory to the real agricultural utilized area of each map sheets by the overlay of the land use map obtained by the Corine Land Cover map[1]. Figure 2 shows the agricultural utilized area map divided into intensive crops (Yellow: cereals, oil, protein) and extensive (Green: forage and pasture grass). This map is associated a georeferred database that allows to classify farms and to conduct spatial analysis.

Figure 2 – Distribution of UAA in Mugello

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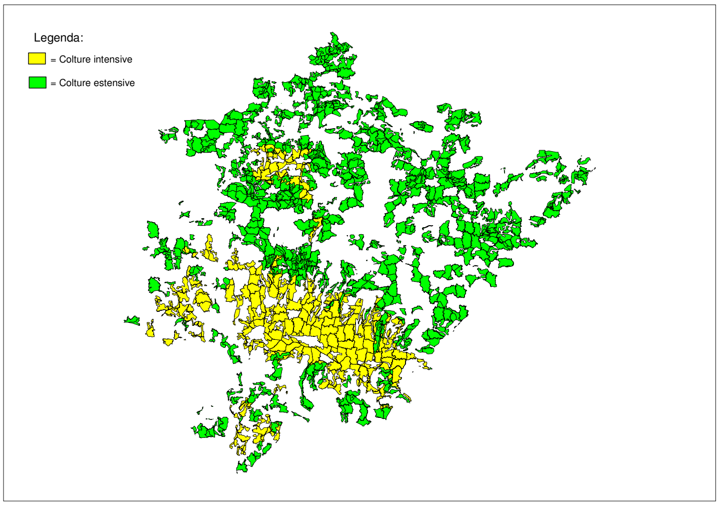
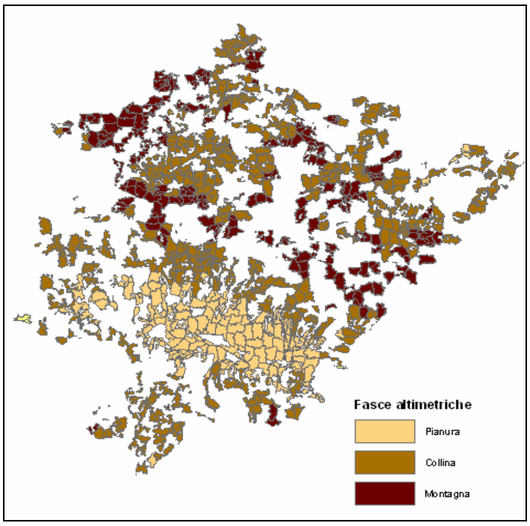
[1] Made in 2000.



Source: Our elaboration.

Once the farm georeferred database is built, it is needed to construct the PMP models. The first step for the implementation of the PMP models regards the definition of the N farm-groups. For that definition two characteristics were considered: the dimension of each farm and their location in plain, hill or mountain. The elaboration of the digital elevation model map and the agricultural utilized area map allows to define the farms location (figure 3).

Figure 3 – Location of the farms: plain, hill or mountain



Source: Our elaboration.

To achieve a good detailed analysis it was decided to split the farms in ten classes, according to the thresholds specified in the table 3.

Table 3 – Agricultural utilized area thresholds and numbers of farms of each classes

Tipologia	Dimensione Sau (ha)	Numerosità
Az001	< 5	783
Az002	da 5 a 10	334
Az003	da 10 a 20	215
Az004	da 20 a 30	109
Az005	da 30 a 40	67
Az006	da 40 a 50	49
Az007	da 50 a 70	47
Az008	da 70 a 100	32
Az009	da 100 a 300	54
Az010	> 300	8
totale		***1698***

Source: Our elaboration.

Thanks to the elaborations done, the whole universe of the Mugello farms were classified in thirty classes as result of their location and size. Thus 30 models of PMP have to be estimated in order to assess and to locate the impacts of the Mid Term Reform on the farmers behaviour.

Through the process indicated in the methodology paragraph, it was possible[2] to estimate 30 different Q matrixes and to implement 30 calibrated models, one for each farm class.

3 Results of the georeferred models

The optimized georeferred model generates economic results (gross margin, shadow prices of constraints), agronomy results (distribution of the various crops, not cultivated area) and livestock results (heads reared). The thirty models implemented have produced a lot of results and it seems necessary to reorganize them in order to facilitate the reading and understanding.

The first processing concerns the land use of Mugello and it is built on the transition from basic situation of 2000 with that of 2004 in a pre (Sim_1) and post (Sim_2) reform framework.

Table 2 expresses the composition of the UAA in hectares of the agricultural outputs (cereals, maize, oilseeds, protein crops, fodder) and highlights the differences between the reference year (base) and those obtained through simulations.

Table 2 - Change in the agricultural production system of Mugello due to different policy framework

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[2] Once known for each class the land resource allocation and the prices, the variable costs and the yields of the outputs of the reference year (2000).

				Mugello			
	Base (ha)	**Sim_1 (ha)**	**Sim_1-Base (ha)**	**variazione % su sau**	**Sim_2 (ha)**	**Sim_2-Sim_1 (ha)**	**variazione % su sau**
cereali	2490	2719	229	1.2%	2109	-611	-3.3%
mais	1754	2331	577	3.1%	1131	-1201	-6.5%
semi oleosi	310	560	250	1.3%	69	-492	-2.7%
proteiche	453	388	-65	-0.3%	302	-86	-0.5%
foraggere	13458	12467	-991	-5.3%	14779	2312	12.5%
altre	160	155	-5	-0.03%	132	-23	-0.1%
abbandono	0	0	0	0%	100	100	0.5%

Source: Our elaboration.

Regarding the evolution of production system the Sim_1 shows an overall increase in intensive crops such as cereals (+239 ha), corn (+577 ha) and oilseeds (+250 ha). On the other side, the more extensive production such as forage decreases (-991 ha).

With the introduction of MTR (Sim_2), however, the impact on crop goes in the direction of a general extension of production. There is, in fact, a decrease in COP production (-12% Sau), an increase of forage (+12.5% Sau) and abandonment of 0.5% UAA. The decrease is greater in oil crops (decrease of 88% compared to the situation before reform) and maize (52% decrease).

Table 3 considers separately the farms in plains, hills and mountains.

Table 3 – UAA changes of the farms in plains, hills, and mountains

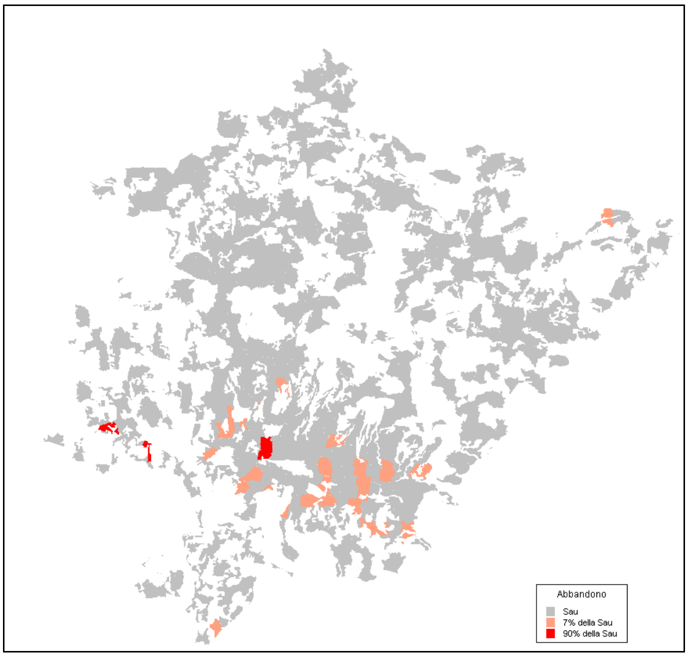
				Pianura			
	Base (ha)	**Sim_1 (ha)**	**Sim_1-Base (ha)**	**variazione % su sau**	**Sim_2 (ha)**	**Sim_2-Sim_1 (ha)**	**variazione % su sau**
cereali	1188	1148	-40	-0.9%	1101	-47	-1%
mais	1077	1427	350	8.0%	720	-707	-17%
semi oleosi	210	291	81	1.9%	19	-272	-6%
proteiche	293	241	-52	-1.2%	223	-18	0%
foraggere	1553	1220	-332	-7.6%	2174	953	22%
altre	38	30	-7	-0.2%	33	3	0%
abbandono	0	0	0	0.0%	100	100	2%
				Collina			
	Base (ha)	**Sim_1 (ha)**	**Sim_1-Base (ha)**	**variazione % su sau**	**Sim_2 (ha)**	**Sim_2-Sim_1 (ha)**	**variazione % su sau**
cereali	802	1088	286	3.8%	743	-345	-5%
mais	360	512	152	2.0%	183	-329	-4%
semi oleosi	58	194	136	1.8%	50	-144	-2%
proteiche	106	105	-1	-0.01%	76	-30	-0.4%
foraggere	6027	5480	-547	-7.3%	6318	838	11%
altre	70	69	-2	-0.03%	79	10	0.1%
abbandono	0	0	0	0%	0	0	0%
				Montagna			
	Base (ha)	**Sim_1 (ha)**	**Sim_1-Base (ha)**	**variazione % su sau**	**Sim_2 (ha)**	**Sim_2-Sim_1 (ha)**	**variazione % su sau**
cereali	503	561	58	0.8%	320	-241	-3.5%
mais	317	392	75	1.1%	228	-164	-2.4%
semi oleosi	42	75	33	0.5%	0	-75	-1.1%
proteiche	54	42	-12	-0.2%	3	-39	-0.6%
foraggere	5878	5766	-112	-1.6%	6287	521	7.6%
altre	9	7	-2	-0.03%	6	-1	-0.02%
abbandono	0	0	0	0%	0	0	0%

Source: Our elaboration.

Table 3 shows a different behaviour for the three territorial contexts. The coupled scenario Sim_1 determines a reduction of cereals in the plains (-40 ha) while in the hills and mountains this type

crop increases. Conversely, while hectares for corn rise a little in the hills and mountains (2% and 1% of UAA), they increase a lot in plains (+8% UAA). Regarding extensive crops, despite the overall decrease, you can see that this effect is more markedly evident in the plain and hill (-332 and -547 ha ha). With the introduction of medium-term reform, differences in the three territorial areas are mainly in the decrease of COP production. In fact, while in plain cereals suffer a contraction of only 47 hectares (equivalent to 1% of UAA), in the hills and mountains they decrease respectively 345 and 241 hectares (5% and 3.5% of UAA). In each area, however, it is very clear the growth of extensive crops. In particular in plains, where such increase reaches 22% of UAA.
The analysis of the simulations at the level of farm type allowed to highlight a certain uniformity in behaviours except for the abandonment of land. In this regard, it is interesting to focus attention on those farms that could produce problems because they abandon part of its farmland in consequences of the MTR. The results of the model at farm type scale show that the abandonment is limited to only two cases and regards about 100 hectars, Figure 4.

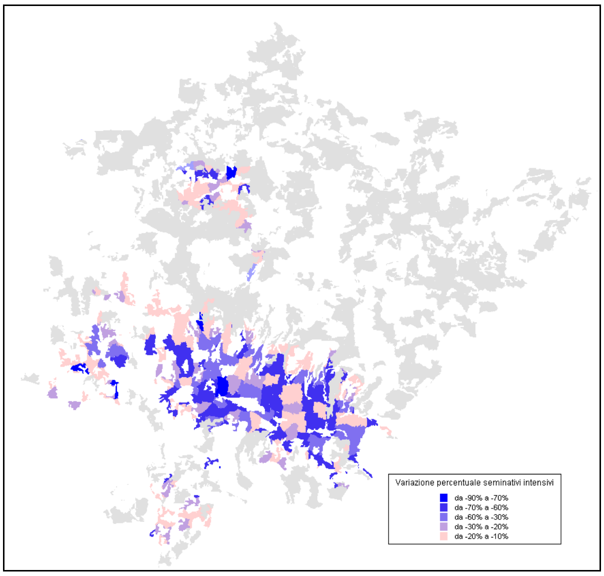
Figure 4 – Abandonment of UAA (% of UUA)



Source: Our elaboration.

At the same time, it is interesting to use the information system in order to identify the impact on the landscape due to the decrease of COP production. Figure 5 shows how and where this decrease is more evident.

Figure 5 – Location of variation of crops COP after the introduction of MTR (% of UUA)



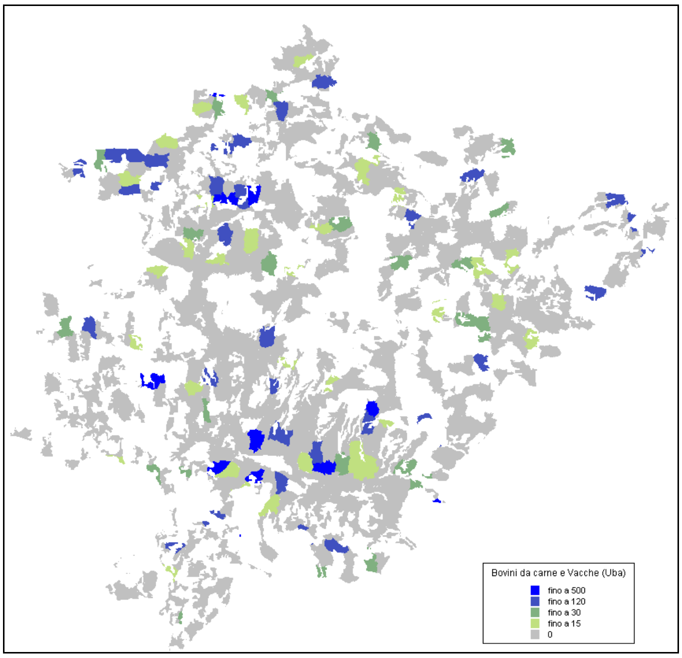
Source: Our elaboration.

Figure 4 and 5 show how the effects of abandonment of UAA and contraction of COP production are in a well-demarcated and specific area. This situation amplifies the effects on the landscape and increase the issues.

In order to give to the policy maker a strategic information in his planning path, it is interesting to note the territorial distribution of cattle, Figure 6.

In this case, the location of cattle could be helpful in public decision to predict, for example, any kind of structural investment to facilitate the marketing plan or specific actions against the problem connected with the excessive grazing.

Figure 5 – Distribution of cattle (head) after the Cap Reform.



Source: Our elaboration.

The results showed until now represent only a part of the georeferred information that can be obtained with the proposed model. These elaborations want to demonstrate the effectiveness and the potential of the model proposed for decision support, for monitoring and for assessing the possible problems related to the changes of policies.

4 Comments

After reviewing the state of the art of the instruments so far adopted to support the policy makers in the assessment of agricultural policies, we have chosen to implement an integrated model based on positive mathematical programming and the territorial approach. Until now, in fact, the evaluation instruments did not consider the territorial aspects in detail. In addition, the policy analysis did not provide an indication of the location of the effects and, when there was an attempt to give this information, it never reached such a detail to permit specific analysis on environmental or social components. The analysis proposed has been able to manage and localize the changes caused by the CAP reform on the behaviour of the various farm types considered. What emerges from an initial reading of the results is that Cap Reform produced a general increase of agricultural land used for extensive crops, forage and grass pastures. At the same time the Reform caused a deep decrease of COP crops. More specifically, 40% of COP crops disappear and at the same time the most extensive arable (forage and pasture grass) increase by 19%.

The elaborations made showed that this behaviour was generally more stringent in the plains, where the ratio of arable land and extensive COP has suffered the largest increase.

The data on the distribution of agricultural land, associated to the absence of a general abandonment of surfaces and the results of farms economic performance, it leads to the first important conclusion: the new structure of agricultural policy was able to influence the behaviour of farmers, but did not cause, even in a marginal area like Mugello, the feared widespread abandonment of farming.

On the other hand, from the point of view of production, simulations conducted may induce some concern for the decline in intensive crops, particularly cereals, for the impact on the prices of food for livestock and for human. As regards economic performance, the transition to a model of agriculture more extensive, with a consequent reduction of variable costs, the increase of cattle and the reduction of the other types of livestock, produced a general improvement of the value of farm objective function. The positive mathematical programming model outlined a farmer of Mugello that with the introduction of the decoupled system could make his own choices in a way more in line with the market. In this way, their skills, knowledge and resources were better rewarded.

The territorial analysis showed, however, as the decrease of COP crops is concentrated in a specific area of Mugello and, therefore, the effects on the landscape are more accentuated.

In conclusion, the proposed model seems a serious attempt to give the public decision a useful tool for the evaluation of agricultural policy. As a matter of fact, the tool allows to highlight the changes in the behaviour of farmers and locate where these behaviours produce major effects. However, according to the proposed approach, the territory is not only the place where the effects fall, but also it participates actively in the definition of the those effects.

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