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University of Minnesota
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Universita degli Studi di Padova
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SESSION V: AGRICULTURAL AND ENVIRONMENTAL HAZARDS

PAPER 4: MULTI CRITERIA ANALYSIS IN FARM MANAGEMENT FOLLOWING THE COMMON AGRICULTURAL POLICY REFORM: AN APPLICATION OF MULTI-OBJECTIVE INTEGER LINEAR PROGRAMMING

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MULTI CRITERIA ANALYSIS IN FARM MANAGEMENT FOLLOWING THE COMMON AGRICULTURAL POLICY REFORM

AN APPLICATION OF MULTI-OBJECTIVE INTEGER LINEAR PROGRAMMING

Paolo Rosato and Giuseppe Stellin[1]

Introduction

Operational research has always had a good reputation in farm management. In particular, mathematical programming methods have proved useful as they simulate farm reality well and can therefore forecast the implications of decisions. Models which organise basic data consistent with economic theory have long been used to confront real production with policy trends. They obviously give an approximate representation of the real farm but, in virtue of their rational system, can provide the analyst with a useful simulation of the economic-productive environment and an acceptable description of the reactions of farmers to changes in the technical and economic variables of production processes (Hazell and Norton, 1986).

Mathematical programming models can also be useful for evaluating the environmental impact of agriculture (Rosato and Giupponi, 1993). In fact, trends in agricultural practices estimated with farm economic models can be used as input for environmental simulation models (Marani, 1988) with the aim of revealing the probable impact on natural resources. In this context, multi-criteria analysis models (MCA) have recently been developed with the aim of simulating the behaviour of the decision maker in a more articulate way (Marangon, 1993).

It is common knowledge that a farmer doesn't generally choose on the basis of a single parameter but with reference to a multi-factorial utility function of which the well known maximising of profits is only one of the components and, often, not even the most important. It must also be stressed that if a choice has to be made on the basis of a single criterion, this is not an economic choice but a technical problem of measurement and research (Zeleny, 1982). The economic problem of the decision exists when there is more than one conflicting goal to be pursued contemporarily and reasonable compromises must be identified.

Numerous studies have demonstrated that a compromise between conflicting goals is ever-present in farmers' decisions[2]. In Italy, there is lively interest in this type of analysis, but it is still little used. The first works where multiple goals in farm management were taken into consideration appeared in the mid-eighties (Polelli et. al., 1984; Basile and Fanfani, 1985), using quadratic programming to take income variability into account. Since then contributions of a mainly methodological nature have appeared (Rosa, 1987; Rosa, 1989; Spronk and Matarazzo, 1992) and only since the early-nineties have the first applications at a farm (Marangon, 1990; Marangon, 1992; Ciuchi and Pennacchi, 1990) and territorial level (Dosi and Rosato, 1991) been published.

There are various reasons for the limited interest of Italian agricultural economists in these methods, but they can probably be traced to the lack of credit given to linear programming (LP) which forms the methodological and operative basis of multi-criteria analysis models of the continuous type. Furthermore, the Italian agriculture scene is so complex and so deeply ingrained with non-economic factors that attempts at mathematical formulation have often been in vain as many of the parameters of choice in the decision-making process are essentially qualitative and related to life-style, so difficult to formulate in LP models.

Part 1 - Methodological aspects

1.1 MCA methods

MCA methods, like the problems of farm choices, can be divided into two categories: 1) multi-objective analysis (MOA); 2) multi-attribute analysis (MAA).
The former is part of the evolution of traditional LP models and retains most of the structure. MOA methods support the resolving of continuous problems where pre-defined solutions do not exist but the choice-making process coincides with the identification of the best alternatives. In this case we have solutions implicit to the model, as they are infinite and identified from the system of constraints of the model itself.
The MOA model is expressed mathematically by:

$$\text{Optimise } \{f_1(x), \ ,f_n(x)\}$$

with

$$g_j(x) \leq b_j$$

where x is the vector of the decision variable, $f_i(x)$ is the level of goal achievement (n) of the decision maker, $g_j(x)$ is the resources (b_j) use level.
The most important of the MOA methods is the goal programming (GP), which simulates a decision-making process which attempts to satisfy predetermined goals at the same time. In GP the search for the optimal solution is by minimising the differences between level of achievement of the defined goals and their forecast levels. This can be done in different ways, depending on the structure of the preferences of the decision maker. In fact it is possible to have a decision maker who pursues his goals simultaneously, with different intensity, or else a decision maker who attributes an absolute priority to each one. In the former, the variant defined as "weighted" (Weighted GP - WGP) is adopted, while the "lexicographic" version (Lexicographic GP - LGP) is used in the latter. An interesting variant of the classic form of GP is MINMAX GP with which it is possible to simulate the behaviour of a decision maker wishing to minimise the only maximum weighted shift in respect to the defined objectives.
GP is a widely used method as it combines the optimising logic of LP with the necessity of assuming more evaluation criteria. However, it has been criticised more than once as the solutions it provides are often identical to those obtainable with the corresponding LP models. Furthermore, in LGP it is impossible to estimate the trade-off between the pursuing of defined goals with different priorities and more importantly, the efficiency of the solutions provided is not guaranteed. Nevertheless it has more than once been spotlighted as a correct specification of the models (especially for defining goals and respective foreseen levels) and rational use of the analysis of sensitivity can substantially mitigate the inconveniences.
Processes such as the weights method, the constraint method, NISE, multi-criteria simplex and many others (Zeleny, 1982; Cohon et al., 1979) also belong to the MOA category and are used when the decision maker, unable to specify the forecast levels for the parameters of choice, pursues a number of goals. These procedures identify the efficient solutions from among the technically feasible ones.

An interesting development of these methods, called compromise programming (CP), allows the set of efficient solutions to be analysed in a way coherent with the preferences of a rational decision maker (Zeleny, 1973). The basic assumption is that the decision maker aspires to get as close as possible to the ideal solution, solving the model separately for each decisional parameter. The solution of a CP model implies the definition of a function of distance between efficient solutions and ideal solutions. It has been demonstrated (Romero, 1991) that this distance does not necessarily have to be intended in the Euclidean sense but rather as an equation that represents the perception of the decision maker as faithfully as possible.

Multi-attribute analysis, instead, guides choice in the case of alternatives (n), previously determined (A_1, A_2, .., A_n), evaluated on the basis of a finite number (m) of attributes (C_1, C_2, .., C_m). Mathematically the problems of MAA can be represented as follows:

Choose: $\{A_1, A_2, .., A_n\}$

as a function of:

$C_1, C_2, .., C_m\}$

The choice, therefore, is made by identifying the alternative which maximises a multi-attribute utility function f(C), where C is the vector of the attributes.

MAA methods have never gained much success in farm agricultural planning and, when they have been applied, their use has been more or less an approximation of the continuous methods.

The fundamental reason is that it is always assumed that the function of substitution between production processes in agriculture is continuous. This is only partly justified. If the availability and/or the optimal economic dimension of some investments (especially machinery) is taken into consideration, continuous change in the choice of productive systems and therefore in the use of resources is not possible. Often, therefore, the problem of choice becomes discrete. These methods have had major success in territorial (Scarelli and Venzi, 1989; Scarelli and Venzi, 1991; Stellin and Rosato, 1990) and forestry planning (Merlo and Muraro, 1986).

Many methods exist that can aid the choice between predetermined and efficient alternatives to maximise benefit to the decision maker. Although they share the coded informative basis in the *pay-off* matrix, they differ substantially in terms of quantity and quality of information required.

In general, discrete methods can be separated into two main groups. The first utilises ordinal functions, without requiring the attribution of weights (w_i) to the criteria of choice. The second group uses utility functions and normally requires a precise definition of weights and/or supplementary information on the preferences of the decision maker.

Exclusionary Screening, Conjunctive Ranking and Copeland's Social Welfare Function belong to the first group, while the most widely used methods of the second are the Weighted Average Method and Electre (Goicoechea et al., 1982).

1.2 New problems

The reform of the European Community agricultural policy (EC Reg. 1765/92) poses problems of choice which require the adaptation and/or development of the methods used up to now.

In particular, the decision process involves many new components, only partly manageable with the continuous methods traditionally used in farm management.

In fact, the choice of land utilisation nowadays consists of two distinct phases even if they cannot be ranked chronologically.

- a phase dedicated to the choice between the general scheme and the simplified scheme with grant aid (EC Reg. 1765/92) and the choice between traditional and low environmental impact cultivation (EC Reg. 2078/92);
- a phase dedicated to the choice of land use (e.g. how much maize, soybean, sugarbeet etc. to cultivate):

The former phase can be resolved with the help of MAA, while MOA methods are useful in the latter.

The need therefore arises to find modelling solutions which can unite choices of the discrete type (e.g. grant scheme) and continuous type (e.g. crop system) as well as the many criteria that define management processes in a single context. One solution could be multi-objective integer linear programming.

This paper presents a farm model that simulates the discrete problem of choice between the general scheme and simplified scheme with grant aid and between traditional (intensive) and eco-compatible methods of production and, at the same time, the continuous problem of choice of crop system. The model also considers, apart from the necessity of maximising income, the need to limit yield variability. Lastly, given the difficulty of attributing weights to the different decisional parameters, a method is proposed for ranking some of the efficient solutions.

1.3 The multi-objective integer linear programming model

The general formulation of a model incorporating the problems of choice described above is the following:

1) OPTIMISE $Z = f_k(x_{ij})$

with

2) $\sum_{i,j} a_{hij}\, x_{ij} \leq b_h$
3) $\sum_i x_{ij} = T_j$
4) $\sum_j T_j = 1$
5) $T_j = 0/1$ (integer variable)

where

$f_k(x_{ij})$ is the objective function;
k = criteria of choice (objective for i and attribute for j);
i = production processes;
j = farming systems;
a_{ij} = resource utilisation;
b_h = resource availability;
T_j = variable which identifies the farm system alternatives.

Equation 1) summarises two distinct functions: a) the multi-objective which guides the choice of crop system; b) the multi-attribute with which the farm system is identified (grant scheme and eco-compatibility of the production processes). In substance the criteria taken as decisional parameters have the significance of objectives and attributes. This assumption could be an over-simplification; in fact it is reasonable to suppose that the attributes which govern the choice of system can differ quali-quantitatively from the goals which govern the choice of crop system. In this case the $f_k(x_{ij})$ must be re-formulated as $g[f_w(x_j), f_v(x_j)]$ where w are the attributes and v are the goals.

Alternatively it is possible to adopt distinct criteria which are researched case by case in relation to the nature of the goals and attributes. For example an attribute that signifies aversion to institute the medium and long-term constraints of the eco-compatible system (duration 5 and/or 20 years) could be assimilated into an added discount on the expected income.

Where this is not possible, the best solution would seem to be to resolve the model in two stages: the first where the crop system within each farm system is evaluated, in respect to the goals pursued by the decision maker in each system; the second by which, on the basis of the results of the first stage, the different systems hypothesised using the appropriate attributes are analysed.

Equation 2) represents the matrix of the technique and the constraints of available resources.

Equations 3), 4) and 5) summarise the process used to formulate the aspects relating to the finite choices. 3) introduces the constraint of land availability within a given farm system. 4) establishes that the sum of the different land uses must be equal to 1. 5)establishes that the availability of land for the different systems can only be an integer. The combined action of equations 4) and 5) ensures that only one of the possible farming systems is activated and therefore, by means of equation 3), land is only made available for the production processes of that system. In this way the solution of the model gives the farm system and the associated crop system expressed in relative terms.

1.4 Ranking of the efficient angle solutions

The resolving of MCA models in general and MOA in particular, requires the definition of an objective function representing the preferences of the decision maker. This function, in most of the methods developed so far, requires the attribution of suitable weights to the decisional parameters.

This attribution is a far from simple operation as it is extremely difficult to describe the preferences of the decision maker and it is even more problematical to allocate a quantitative estimate. These difficulties are well documented in the literature (Zeleny, 1982) and, among other things, are the major stimulus for the development of new MCA methods, especially those of an interactive nature (Spronk and Matarazzo, 1992).

At the same time, methods for choosing solutions independently of information supplied by the decision maker, have also been developed. These criteria are based exclusively on the hypothesis of rational behaviour of the decision maker. The most important of these methods is the Paretian criterion, by which the solutions are selected as function of the performances furnished in respect to the decisional parameters.

Naturally, these methods are efficient when the rules which characterise them are general and equally shared, as happens with the Paretian criterion. It must also be recognised that these rules are solvers of not particularly difficult situations, that is to say where solutions exist which optimise all the decisional parameters at the same time. Where conflict exists between the goals pursued, the problem cannot be resolved without the contribution of the decision maker; this is given by expressing weights representing his preferences within the traditional MOA methods and the formulation of the acceptability of solutions gradually proposed in interactive-type methods.

That being said, a certain interest exists in identifying processes for selecting the efficient solutions without the contribution of the decision maker.

One of these processes is based on the determination of the stability of the solution with the varying of the weights. This stability can be calculated by measuring the interval of variation of the weights which produce that determined solution and therefore, in the case of linear and additive goal functions, measuring the maximum variations of slope which identify the same solution. Geometrically this interval will be greater the more acute is the angle subtending the vertex of each solution.

Once the efficient angle solutions[3] have been identified, these can be ranked on the basis of the probability p to be extracted in a hypothetical lottery where the weights are selected randomly. The analysis therefore aims to identify the solutions intrinsically favoured by the matrix of the technique in respect to the goals pursued by the decision maker, around which the choices of the real farmers are usually concentrated (Rosato, 1991).

Fig 1 illustrates the method of calculating the parameter p where the usual problem of bicriterial choice is represented, to minimise parameter X and maximise parameter Y and where the dashed line shows the frontier of efficiency and P_i the vertexes.

The problem is to rank the solutions identified by each vertex on the basis of p. The probability p(i) can be calculated with the following equation:

$$p(i)= (2\pi-\hat{\imath})*2\pi^{-1}$$

where $\hat{\imath}$ is the angle to the vertex of each angle solution.

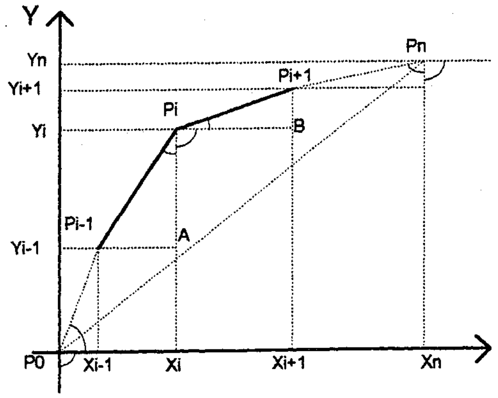
The angles to the vertex can be calculated by the following equation:

$$\hat{\imath} = P_{i-1}P_iA + AP_iB + BP_iP_{i+1}$$

therefore:

$$\hat{\imath} = \mathrm{arctg}[(X_i- X_{i-1})/(Y_i - Y_{i-1})] + \pi/2 + \mathrm{arctg}[(Y_{i+1} - Y_i)/(X_{i+1} - X_i)]$$

Figure 1



The process is fairly simple to implement where there are two considered parameters as the problem can be simulated geometrically on a Cartesian plane.

Solving problems involving three or more decisional parameters is more complicated as the approach must be adapted to the space with n dimensions, where n indicates the number of decisional parameters.

The question can be split in two phases:

a) the ranking of the vertexes of the efficient frontier; b) the calculation of the probability associated to each vertex.

A solution to the first aspect could be the following:

1) all the angle solutions are identified (vertexes of the efficient surface area);

2) the lines connecting the vertexes of the frontier of efficiency are defined (edges of the convex side of the solid towards the ideal solution representing the acceptable solutions);

3) the length of the connections identified in the preceding point are calculated;

4) the angles to the vertex are measured (using the obtainable triangles);

5) the angles of each vertex are summed up;

6) the vertexes are ranked, and therefore the subtending solutions, by the sum of the angles to the vertex.

To estimate probability p(i), it is possible to use the extension of the angle concept described above to that of the volume of the sphere centred on the vertex i and infinitesimal radius[4]. In this case we have:

$$p(i) = (V_{sf}-V_{sp})^{*}V_{sf}^{-1}$$

where V_{sf} is the volume of the reference sphere and V_{sp} is that of the portion of the sphere defined by the frontier of efficiency.

Part 2 - An example

2.1. Introduction

The methodology described in the preceding section was applied to a case study to verify it's practical use. A small farm on the Venetian plain was used, where crop operations are carried out almost completely by contractors, with the owner exercising a purely organisational function. The choice was made as this type of farm is widespread in the Veneto region, involving a good part of the utilised agricultural surface (UAS).

It is also very important from the environmental point of view as it is diffuse in areas which are also compromised by housing and non-agricultural industries, where the environmental implications of its production processes are more evident.

The cropping system is extremely simplified and limited to maize and soybean (also as second crop), sugarbeet, wheat and, more rarely, alfalfa.

The technical and economic data used in the model were taken from a trial conducted as a part of CNR-RAISA research at Dossetto farm, which belongs to the Ente di Sviluppo Agricolo del Veneto, situated at Vallevecchia, Caorle.

2.2 The model

The model is multi-objective and simulates the behaviour of a farmer who aims to maximise the gross margin, calculated by subtracting explicit costs from income, and minimise the risk of the cropping systems.

The aversion to risk was represented by means of a MOTAD type formula (Hazell, 1971) where yield variability is used in place of that of gross margin. To eliminate the scale effect, the yields of the different crops were standardised[5]. The basic hypothesis was that the perceived risk is essentially technical and mainly regards yields. This assumption was valid in the situation before the recent EC common agricultural policy (CAP) reform where the prices of the principal agricultural products could be taken as fairly stable. With the CAP reform they will be linked to those of the world market and it will therefore be necessary to consider price as well as yield variability. In the model, it was nevertheless considered appropriate to exclude this aspect because, during the transition phase the wide price variations must be seen as contingent and not linked to market trends. It was therefore hypothesised that the farmer, prudently, refers for the time being to the expected average prices with the reform fully in effect.

The maximisation of gross margin and the minimisation of risk was represented in the model by means of the linked minimisation of percentage differences in respect to the ideal solution obtained optimising the model separately on the basis of the two goals.

The following parameters dictated by the CAP reform were inserted into the model:

a) the type of income subsidy;

b) the possibility of adopting crop practices with low environmental impact.

Regarding income subsidy, the general scheme was separated from the simplified one, differentiating the expected grants and introducing the compulsory set-aside of 15% of the land under cereals and oil seed crops. The eco-compatible alternative was designed in compliance with the accompanying measures to the EC regulation 2078/92.[6]

As regards decision variables, the model was designed to select the type of farm system (general or simplified scheme and traditional or eco-compatible cultivation techniques) and the related cropping systems.

The principal constraints to which the farm choices were subjected concerned rotation requirements, chemical inputs and compulsory set-aside.

Some accounting equations were introduced to provide, directly with the solution, the state of some useful parameters for the economic and environmental evaluations. In particular, sales returns, amount of grants, production costs, yield levels, fertilisation (nitrogen and mineral phosphorus) and a ground cover index indicative of the environmental impact of the crop system[7], were calculated.

2.3 Results

The model was resolved using the branch and bound algorithm (Lawler and Wood, 1966) which first identified all the angle solutions of the frontier of efficiency in respect to the decisional parameters hypothesised by means of the NISE (Cohon et al., 1979).
The solutions were then ranked according to the methodology described in section 1.4.

2.3.1 Simulation of the EC market reform of agricultural products (EC Reg. 1765/92)

The solutions are reported in table 1 and shown on the plan of the goals in figure 2.
At high levels of aversion to risk the general scheme is favoured, while when gross margin maximisation becomes more important the simplified scheme prevails. The crop system is consistent with the farm system. In fact, optimising risk, combinations of the crops with low yield variability are favoured, in particular the cultivation of wheat, and soybean as first and second crop. Diminishing the aversion to risk in favour of gross margin maximisation, there is initially a slight expansion of soybean as second crop and, successively, a change of the farm system in favour of the simplified scheme which determines an appreciable expansion of soybean as main crop on land previously put to set-aside. Further increases of income involve a reduction of oil seed crops in favour of maize, initially as first crop and then as second crop. Along the whole frontier of efficiency, the model always proposes an intensive cropping system with ample use of catch crops. This is justified by the price-level holding of agricultural products (especially cereals) on the Italian market, mainly because of the devaluation of the lira in the second half of 1992.

Table 1. Efficient angle solutions in the simulation of the market reform (partial model, Reg. EC 1765/92).

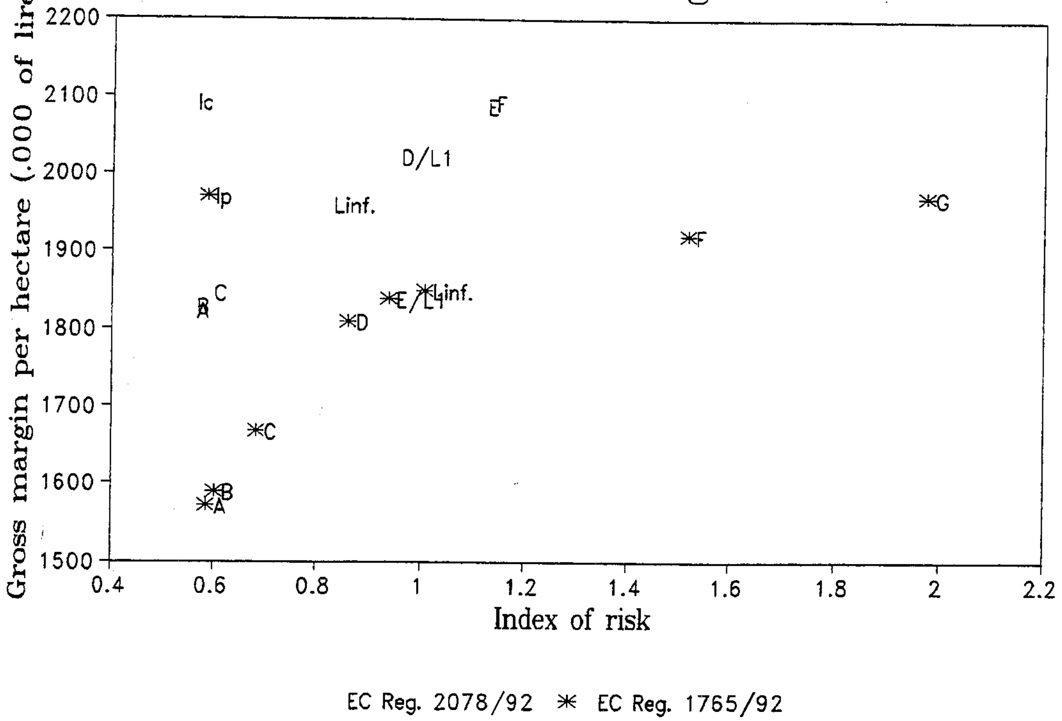
	EFFICIENT SOLUTIONS							
	A	**B**	**C**	**D**	***E/L*₁**	***L*∞**	**F**	**G**
FARM SYSTEM (*)	GS	GS	SS	SS	SS	SS	SS	SS
Soybean (%)	15.2	15.2	25.0	4.2				
Soybean 2° crop (%)	40.8	50.0	50.0	50.0	50.0	42.2	19.1	
Maize (%)				20.8	25.0	25.0	25.0	25.0
Maize 2° crop (%)						3.8.0	30.9	50.0
Wheat (%)	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
Sugarbeet (%)	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Alfalfa (%)								
Set-aside (%)	9.8	9.8						
Gross margin (.000 lire/ha)	1571	1588	1667	1810	1839	1849	1921	1971
of which from grants (%)	35.8	35.5	37.0	33.9	33.4	33.2	32.0	31.1
Index of risk	0.586	0.602	0.685	0.860	0.938	1.009	1.518	1.975
N fertilisation (kg/ha)	106	106	110	164	175	183	237	275
Ground cover index	32.5	29.4	24.2	24.2	24.2	23.9	21.6	20.0

*) GS = general scheme; SS = simplified scheme

The importance of wheat in all the farm systems identified is worth noting. There are two reasons for this, the possibility of planting a second crop and the lower yield variability of wheat in comparison to maize, which is affected by frequent dry summers.

Aversion to risk privileges solutions where the percentage of gross margin coming from grants is greater (general scheme and/or wide areas under oil seed crops) as these are not exposed to risks connected to the cultivation.
Regarding income, a variation in gross margin is noted from little more than one and a half million a hectare to nearly two million , with a percentage of around 11% compared to the average. On the contrary, the index of risk range is much wider (around 60%). This means that prominent variations in the risk of cropping systems and farm system are accompanied by modest variations in income. It is therefore not difficult to determine acceptable compromise solutions.

Figure 2 – Efficient angle solutions



These solutions are probably to be found where the frontier of efficiency is nearest the ideal solution, therefore around the solution subtending the most acute angle.
In fact the ranking procedure of the efficient angle solutions indicates that solution E (table 1), determined, amongst other things, by a compromise programming model with metric and unitary weights, is privileged. The crop system corresponding to that area foresees the adoption of the simplified scheme, the cultivation of wheat on 50% of the UAS and maize and sugarbeet, in equal amounts, on the remainder. A strong presence of second crops is also expected, especially soybean.
It is also demonstrated that this solution allows goal achievement levels of above 50% for both the decisional parameters. It must be taken into account that if compromise programming is considered an appropriate solution to the decisional problem, the solution L_∞ (metric infinite) is identified as second solution, which is oriented towards income maximisation. In this case the compromise set identified provides for a crop system structurally similar to the preceding one, but which also includes a second maize crop. The ranking of the vertex solutions on the basis of the width of the subtending angle identifies a very similar set of solutions to that identified using compromise programming with unitary weights. This means that solutions exist which are intrinsically favoured in respect to the decisional parameters, independently of the attributed weights in the latter.

Taking the environmental implications estimated with the indicators described above, contrasting trends are found. Nitrogen treatments, obviously, increase with the expansion of cereals, from little more than 100 units/ha to 275. The ground cover index is instead, much more stable. In fact the interval of variation doesn't go above 27.5% in respect to the average. The variations in ground cover index are essentially caused by the substitution of soybean with maize (which can be harvested later than soybean) and to the adoption of the simplified scheme which doesn't include the obligatory set-aside. It should be noted that the trend of nitrogen distribution is contrary to that of the ground cover index

Table 2. Ranking on the basis of the angles subtending the vertexes of the frontier of efficiency in the model without an eco-compatible alternative (partial model).

Ranking	Solution	Angle	p(i)
1	E	153.8	57.3
2	G	159.0	55.8
3	D	161.6	55.1
4	A	165.3	54.1
5	F	175.0	51.4
6	C	177.5	50.7
7	B	177.8	50.6

2.3.2 Simulation of the EC regulation 2078/92

In the solutions which include the possibility of adopting eco-compatible agricultural practices subsidised by the EC, the basic trend emerges which privileges the simplified scheme when the priority is to maximise gross margin (see table 3). This trend also emerges analysing crop distribution. Along the whole frontier of efficiency wheat and sugarbeet are forecast in a stable manner, always at the maximum limit allowed by agricultural requirements.

At low inclination to risk the cultivation of soybean prevails, with a modest presence of alfalfa. Gradually increasing the importance of income favours the expansion of maize. Initially to the cost of alfalfa and wheat and then on set-aside land and on part of that under soybean, reaching the maximum allowed by rotational restraints. Further income increases are achieved by substituting part of the soybean with wheat.

The advantage of adopting eco-compatible agricultural practices remains stable, being preferable along the whole frontier of efficiency (see figure 2).

This is essentially due to two reasons, both linked to the performances of eco-compatible agriculture in respect to the decisional parameters. Firstly, the expected subsidies following the adoption of eco-compatible agricultural practices are higher than the consequent reduction in income, so that, on average, the gross margin attainable with the eco-compatible alternatives is around 10% higher. Secondly, the risk index of crop distribution reduces by 20% on average, because of the significant increase in the proportion of the gross margin coming from direct grants, which are not afflicted by technical risk and which pass from 34% to 48.5% on average.

Table 3. Efficient angle solutions in the simulation of eco-compatible agriculture (complete model, EC Reg. 2078/92)

	EFFICIENT SOLUTION						
	A	B	C	L_∞	D/L_1	E	F
FARM SYSTEM (*)	EAG	EAG	EAG	EAS	EAS	EAS	EAS
Soia (%)	33.0	33.0	33.0	24.4	17.8	9.6	9.0
Soybean 2° crop (%)							
Maize (%)		0.3	3.2	22.0	33.0	33.0	33.0
Maize 2° crop (%)							
Wheat (%)	31.0	31.1	29.0	28.6	24.2	32.4	33.0
Sugarbeet (%)	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Alfalfa (%)	1.4	0.9					
Set-aside (%)	9.6	9.7	9.8				
Gross margin (.000 lire/ha)	1824	1829	1847	1960	2022	2088	2092
of which from grants (%)	53.1	53.2	53.5	46.7	45.3	43.8	43.8
Index of risk	0.551	0.553	0.584	0.816	0.944	1.112	1.128
N treatment (kg/ha)	50	51	54	91	107	118	119
Ground cover index	46.8	47.1	47.7	42.6	42.8	42.4	42.3

*) EAG = eco-compatible agriculture under the general scheme; EAS = eco-compatible agriculture under the simplified scheme.

On the whole, the eco-compatible solutions dominate the traditional ones, as is also demonstrated by the fact that the ideal solution to the complete model (Ic) dominates that of the partial model (Ip) in a Paretian sense. The adoption of eco-compatible techniques also notably reduces the interval of variation of the decisional parameters (the index of risk by -58.5% and the gross margin by -33%). Furthermore, it should be noted that the frontier of the efficient solutions (see figure 2) of the complete model is significantly less curved than that of the partial model. It follows that, with eco-compatible agriculture, intrinsically favoured solutions in respect to the decisional parameters do not exist at a farm level. Therefore, if the function of utility of the decision maker is linear and additive, the intermediate solutions are not so much favoured, but rather the limit ones, as is also seen in table 4 where the ranking is spaced, alternately, along the whole frontier of efficiency. In this case the procedure demonstrates the impossibility of formulating privileged solutions in the absence of information on the weights attributed by the farmer to the decisional parameters.

In intermediate situations of risk and profitability a univocal tendency to favour one type of crops more than the other does not exist. This is essentially due to the fact that the measures provided for by Reg. 2078/92 have diverse effects on the crops grown and on yield variability. For example, they only marginally modify the crop techniques for oil seed crops while they strongly affect cereal fertilisation. It therefore follows that there is a wide interval in which the advantage of adopting one or other farm system is fairly controversial. With every probability, further specifications are necessary for the goal function, including the farmer's sensitivity towards the environment.

Finally, as regards the environmental implications, the considerations made for the partial model are valid. It should anyway be noted that the nitrogen treatments are on average more than halved while the ground cover index is almost doubled.

Table 4. Ranking on the basis of the angles subtending the vertexes of the frontier of efficiency in the model with the eco-compatible alternative (complete model).

Ranking	Solution	Angle	p(i)
1	F	148.0	58.9
2	B	151.1	58.0
3	A	170.1	52.7
4	E	172.0	52.2
5	D	173.7	51.7
6	C	175.1	51.4

Conclusions

The aim of this work was to analyse the problem of adapting farm multi-criteria analysis models in the light of the recent reform of EC agricultural policy. It has been demonstrated that the reform has noticeably increased the need for instruments to aid choices of a discrete type. Whereas in the past these involved only some aspects of management, they now pervade the entire system as access to grants presupposes choices of a dichotomous nature (general or simplified scheme and eco-compatible options). Furthermore, these discrete choices are strictly connected to those of the continuous type like crop distribution, as crop profitability, which typically modifies crop planning, is dependent on the type of grant scheme selected. It has been demonstrated possible to unite all these aspects in a unitary programming model with obvious advantages over the usual practice of treating continuous and discrete choices separately. These advantages can be summarised in the simplification of the procedure for resolving the decisional problem and the possibility of conducting dual analysis on all variables contemporarily.
Taking the first aspect, it is evident that, to formulate a problem of multi-criteria choice with both discrete and continuous type components, it would be necessary to build as many multi-objective models as there are discrete alternatives and subsequently, a multi-attribute model to compare the solutions to the preceding models. Programming with integers allows all the aspects of the problem to be united in a single model.
The second aspect is more important; if one admits the existence of factors which modify the decision variables, both continuous and discrete contemporarily, it is evident that a complete analysis of the dual problem is possible only with a model which includes all the variables in play. A typical example is the rate of exchange of the ECU, which, influencing the amount of the grants, operates differentially, both on crop distribution (continuous variable), and on the more profitable grant scheme (discrete dichotomous variable).
Having demonstrated that with multi-criteria analysis models it is fairly difficult to describe precisely the objective function of the decision maker, it was attempted to develop a process capable of identifying privileged solutions, independently of the types of preferences of the decision maker, by analysing exclusively the shape of the frontier of the efficient solutions. The process is based on the ranking of the angle solutions in function of the probability of being selected, attributing weights randomly to the decisional parameters. Interesting results were obtained, but some caution is needed in it's use and it requires further computational refinements, especially regarding it's extension to problems with more than two decisional parameters.

When the frontier of efficiency is well curved towards the ideal solution or, anyway towards the direction wished for by the decision maker, the ranking proposes fairly similar solutions to those supplied by the commonly used methods (WGP, CP etc.) in a wide interval of variation of weights. In this case the frontier of efficiency presents solutions with a very acute subtending angle and therefore the form of the objective function has a limited influence on the determination of the optimal solutions. When, instead, the line of the efficient solutions is flattened it is not possible to identify solutions intrinsically favoured from the technical-economic point of view and it becomes necessary to carry out more detailed analysis of the weights to be attributed to the decisional parameters.

The example tested confirmed the efficiency of the modelling techniques as well as the merits and limits of the proposed ranking method.

The tendency to privilege the general scheme in the presence of high aversion to risk emerges from all the simulations carried out, while when it becomes more important to maximise gross margin, the simplified scheme prevails. Crop distribution is consistent with the trend of the farm system: optimising risk, the practices with low yield variability and widespread cultivation of legumes become privileged. Diminishing the aversion to risk in favour of maximising gross margin, there is a progressive substitution of legumes with summer cereals. The importance of wheat and sugarbeet in all the farm systems should be noted. The aversion to risk also favours those solutions where the amount of gross margin coming from the grants is on average higher as this is not exposed to cultivation risks. The advantage of adopting eco-compatible crop practices remains stable.

Regarding the possibility of identifying intrinsically favoured solutions, univocal indications only emerge in the case of traditional agriculture, while the reality of eco-compatible agriculture is more elusive. This is due to the fact that the frontier of the efficient solutions of the model with the eco-compatible alternative is significantly less convex than that of the model of traditional cultivation. This is due to the relative stability of the crop division along the frontier of efficiency because of rotational constraints, the increase of the part of the income deriving from grants and the diminution in the variability of the expected cereal yields caused by the extensification of production. In this case the procedure demonstrates the necessity for more detail on the weights attributed by the farmer to the decisional parameters.

Regarding lastly the environmental implications, it is demonstrated that nitrogen fertilisation increases with the requirement for gross margin and that, with the eco-compatible agriculture, it would be halved on average. The ground cover index presents a contrary trend and, with the adoption of EC Reg. 2078/92, is almost double that of traditional agriculture. These results, even with the limitations of the approximation of the indicators used, demonstrate the need for further research on the most appropriate methodologies for estimating the environmental impact of agricultural practices, as well as on the effects produced by the measures as they are put into action.

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Footnotes

[1] Department of Territory and Agroforestry Systems at the University of Padova.

[2] This has been demonstrated in numerous studies as well as the fundamental one by Gasson (1973), such as Smith and Capstick (1976), Harper and Eastman (1980), Cary and Holmes (1982), Mantino (1990), Fairweather and Keating (1994), etc.

[3] Angle solution means that which identifies a variation in the trade-off between the goals pursued by choice. This solution always corresponds to a vertex of the frontier of efficiency.

[4] In that the sphere must only include the area immediately surrounding a vertex, excluding all the others.

[5] Given a variable X, statistical standardisation is done by calculating the transformed $Y=(X-\mu)/\sigma$, where μ and σ represent the average and the standard deviation of the variable X, respectively.

[6] These measures provide for cultivation practices which guarantee a yield reduction of at least 10% and assign an annual compensation of 135 ECU/ha for cereals and oil seed crops and 225 ECU/ha for sugarbeet.

[7] The ground cover index was calculated taking the number of days in which the land remains bare against the average monthly rainfall of the last thirty years. This parameter indicates the probability of soil, nutrient and pesticide loss.