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Analysis of protected cropping: an application of multiobjective programming techniques to Spanish horticulture*

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Summary

This paper deals with labour managed horticultural firms in Southeastern Spain. It tries to model the decision-making processes and the conflicts between profit maximization, risk minimization, leisure and seasonal labour as decision makers' objectives. A vectorial optimization model is developed and different farm types are analyzed. The selected location is Almeria, where the horticultural farms are studied by reference types which include all the possible family farms in the area. The model uses the Multiobjective Techniques to analyze the empirical problem. The analysis of risk incorporates some recent advances in the treatment of risk in linear programming. It is concluded that the compromise solution describes reality better than an income-maximizing or risk-minimizing solution.

1. Introduction

The characteristics of agricultural planning processes cannot be reduced to a single objective optimization. Over the last few years a new set of techniques known as Multiple Criteria Decision Making (MCDM) have appeared in operational research science. For an expository analysis of MCDM tech-

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niques within an agricultural planning context, see Bouzaher y Mendoza (1987) and Romero and Rehman (1985).

Multiobjective Programming (MOP) is based on the notion of nondominance; a nondominated solution is a point belonging to the feasible domain which achieves the same or better performance than any other solution being better at least for one objective. An objective is a measurable characteristic of the problem to which the decision maker assigns a desirable direction of improvement. The development of the efficient set (nondominated or trade-off curve) gives important knowledge on the structure of the conflicts between the different objectives. Cohon (1978) reviews the various techniques for generating the efficient set.

Once the trade-off curve has been generated, the second step of the MCDM problem is to define a specific solution or at least to reduce the size of the efficient set. Zeleny (1973) proposes a method known as Compromise Programming (CP) which reduces the efficient set into a smaller one called the compromise set.

The present paper analyzes a real case study of decision making for the protected cropping sector of Almeria. The analysis of real agricultural systems has shown the existence of more than one objective in the farmers' planning process (the pioneering work is Gasson 1973). In our empirical problem four different behavioural assumptions and four different objectives are analyzed.

In a recent review of the use of MCDM in natural resources management (Romero and Rehman 1987) thirteen applications of this approach to agricutural land use were reviewed. Most of these applications resort to goal programming as an operational tool. Compromise Programming is used only in one of the reported applications.

The present research differs from the commented applications mainly in the explicit recognition of risk in a behavioural model with multiple objectives. For this purpose the approach known as mean-PAD (Berbel 1988) is tested for the first time against a real decision making problem.

2. The horticultural industry in Almeria

Horticultural products reach Europe during the winter from greenhouses in Northern Europe and protected croppings farms in more temperate countries (mainly Mediterranean). Almeria (Southeastern Spain) has some natural advantages and is the most important vegetable producing area in Europe during the winter. Between 1955 and 1975 final agricultural production in Almeria increased by a factor of 32 in real terms. Almeria has 12,000 hectares dedicated to protected cropping and is the most important horticultural area in Europe.

The development of Almeria's horticultural industry is based on two

factors: climatology (3,000 hours of sunshine per year and no risk of frost) and small family farms as the production units. For a more detailed study of the sector see Berbel (1987).

The area is homogeneous in resources, techniques and social structure. Family farms account for 90% of the total output. Private ownership is the most common form of tenancy (90% of the total area). The average size is one hectare and the differences between the farm areas are mainly due to differences in the marketing channels. All other factors play a secondary role.

There are three marketing channels for Almeria products:

(1) Private trade and direct on-farm sale.
(2) Cooperative marketing. Some of the products (cucumbers, some melons, flowers) are directed to European markets. These export products cannot be sold at a competitive price in domestic markets, thus once the production is directed through the cooperative, it cannot be channelled easily to the national market.
(3) Big farms which sell directly to food chains; these farms represent less than 10% of the total production.

If we consider family farms, the marketing channel is a fixed factor in the short term because non-cooperative members cannot join a group in the course of the year. Cooperative members are growing products with better results through this channel and are not willing to change them.

Four reference farm types were chosen to model the behaviour of the family farm in protected horticulture. The reference types are classified by size and marketing channels. Labour is mainly supplied by the family but casual labour is available. There are constraints in the total land, rotation and total hired labour available during peak months.

3. Defining farmers' objectives

A family farm is a whole consumption and production unit; it is a special case of the labour managed firm. Although income is the main objective, there are other important ones such as risk avoidance, leisure and seasonal labour.

Income is measured as gross margin minus hired labour cost and interest on working capital. The disaster level or minimum income threshold is set as the total fixed cost plus some cash for family expenses. Risk is measured as the probability of not achieving the 'disaster level'.

Risk is incorporated to the model by using the lower partial moments inequality (Atwood 1985). The most widely used risk programming approach is the Safety First one (Kennedy et al. 1974). This approach maximizes income subjected to a constrained probability of failure; other methods which incorporate risk such as subjective expected utility or variance are criticized in Tauer (1983).

Inequality (1) is adapted from Atwood's technique, estimating the probability of returns being less than g (safety level) depending on $Q(k, t)$, which is the Kth partial moment with respect to t (parameter). We can use the first order moment to incorporate the inequality (1) into a linear program. This method improves the target MOTAD technique used by Watts et al. (1984) and Tauer (1983).

$$Pr\ (\text{Income} < g) \leq [Q(k, t)]/(t-g)k \qquad (1)$$

Thus, the conflict between risk and return can be analyzed by studying the trade-off curve between risk (probability of failure) and return (mean). The use of $Q(1, t)$ implies that there is a linear correspondence between this probability and the moment itself. A detailed explanation of this method (called the mean-PAD) can be seen in Berbel (1988).

Risk and return are the most frequent farmers' objectives found in the literature. Leisure is the third one, incorporated by using the variable 'own labour'; by minimizing the second we maximize leisure. Finally, we are interested in minimizing seasonal labour. This section has reviewed the objectives which our empirical research found in the area, others such as minimizing credit use, were considered but they were not included in the final model because of their lesser importance with respect to the four objectives previously described.

A good survey of empirical research on farmers' goal and objectives can be seen in Patrick and Kliebestein (1980). Our setting of goals is tentative and was obtained by extensive interviews (Berbel 1987). Objectives were not ranked because we wanted to find the predictive results when different behavioural hypotheses were combined.

4. Model formulation

We are interested in a classification of farms in order to develop a model for each particular class. The results will show the theoretical behaviour of each reference type. In the representative farm approach there is always a simplification of reality. In Almeria, big farms (more than 15 hectares) only account for 10% of the output and they grow specific crops such as flowers; these shall not be modelled. The problem of aggregation arises when the research is directed to supply-response analysis. Our main goal is the analysis of decision-making in horticulture and the comparison with real production is used as a way to test the validity of the model.

As Spreen and Takayama (1980: 150) suggest, 'production pattern of firms is the proper rule for aggregation'. In our case we classified the firms by size and by marketing channels. Type A, B and C, shown in Table 1, are

Table 1. *Representative farms: Characteristic values*

Types	A	B	C	D
Land (has.)	0.7	1	2	2
Number of activities	16	16	16	31
Monthly family labour	540	540	440	440
Maximum casual labour	160	160	960	960
Disaster level	2600	3500	7000	7500
% of farm area	9%	51%	20%	20%

Source: Berbel (1987).

non-cooperative farms; type D is cooperative so that crops such as cucumber and some melons can be grown in this type but not in type C (with the same land size). The different reference farms can be seen in Table 1.

In our system these are 31 different aggregate activities. Each activity is a 'combined crop', an autumn and a spring crop. Tomatoes, cucumbers, sweet peppers, squash, eggplants and green beans are autumn crops; melons and watermelons are spring crops. Some crops such as eggplant can be grown all year round.

The obvious resource constraint is land, second in importance is the number of possible crops which depends on the marketing channels of the farm: cucumber and some spring melons can be grown exclusively by farmers belonging to a cooperative. The total family labour is estimated at two labour units per year. Casual labour is constrained during the peak (winter) months, the sum of hired and family labour cannot exceed 700 hours per month and hectare from December to February.

The complete model is summarized in Table 2. The complete system is a matrix of 70 by 60. There are 4200 entries with 1500 non-zero values. The right hand side (RHS) has 60 entries and there are 4 different RHS vectors depending on the type of farm.

Labour (not including leisure) and seasonal labour are linked through equation (5). In fact, the first variable, TL, is 'total labour' (annual), from which by using a monthly coefficient k we can compute the monthly target for labour (8). The k's are equal to 0.8695 for all months and 0.4347 for August. This method is similar to the way in which MOTAD (Hazell 1971) computes the mean absolute deviation, and is taken from Romero et al. (1987). We deduce the negative (NS) and positive (PS) deviations from (8) and their sum gives us total seasonality (see objective function (4)).

Once total variability in labour is known (in absolute terms), family labour becomes 'total labour' minus total hired labour. The hired labour is determined through (6). In this equation positive deviations over monthly available labour is known, and this deviation will be equal to hired hours. Equation (7) adds up all the hired hours in variable HL. There may be other

Table 2. *Summary of the model*

maximize	GM = G∗X − (.3) HL − (.15) CR	(1)
minimize	PAD = Σ NY	(2)
minimize	OL = TL − HL	(3)
minimize	LS = Σ NS + Σ PS	(4)
subject to		
TL	= TW∗X	(5)
HL	= Σ PHL	(6)
L∗X − PHL	< MFL	(7)
L∗X + NS − PS	= k∗TL	(8)
YEAR∗X + NY	> T	(9)
PHL	< MHL	(10)
C∗X	< CR	(11)
R∗X	< LAND/2	(12)
Σ X	< LAND	(13)

where

GM	= Gross Margin (Th. Ptas)
G	= Vector of mean Gross Margins
X	= Vector of Activity Levels (ha.)
HL	= Casual Labour (hours)
CR	= Credit (Th. Ptas)
PAD	= Sum of Negative Deviations below 'T' (years 1 to 5)
YEAR	= Vector of Gross Margins for years 1 to 5
NY	= Vector of Negative Deviations for years 1 to 5
T	= Disaster Level (Prespecified Scalar)
OL	= Own Labour (hours)
TL	= Total Working Time (hours/year)
PHL	= Monthly Hired Labour
L	= Matrix of Hours per month, activity and hectare
MFL	= Vector of Maximum Available Monthly Family Labour
TW	= Total hours per activity (hours/year)
MHL	= Maximum Casual Labour per month (Dec. to Feb.)
LS	= Labour Seasonality
NS	= Vector of Negative Deviations from the monthly target
PS	= Vector of Positive Deviations from the monthly target
k	= coefficient for Monthly Labour Target
R	= Matrix with Rotation Coefficients
CR	= Credit (scalar)
C	= Matrix 6∗16 (or 6∗31) with the monthly cash flow
LAND	= Available Acreage

ways to build the model but we find the present one the most efficient in computational terms.

The last variable is credit use, which is estimated as 'maximum negative cash-flow', that will be the working capital financial requirements, and will be determined when 'CR' is minimized.

The four different behavioural assumptions analyzed are: Maximization

of income, minimization of risk, satisfaction and compromise (Zeleny 1982). The satisfying behaviour belongs to the Simon's 'bounded rationality' theory. This behaviour supposes that the decision maker looks for 'satisfactory choices instead of optimal ones' (Simon 1979: 501).

Compromise behaviour supposes that the decision-maker is interested in achieving a compromise between the three objectives: income, risk and leisure for the small firms, (this last criterion entails a minimization of labour seasonality in the two hectares farms).

5. Results

Our model analyzes two behavioural aspects of the farms: the evolution of cropping pattern when size varies and behaviour is constant and the changes in the farm plan within a given type when behaviour varies.

Before the four different behavioural assumptions upon the behaviour of the decision makers are analyzed, it may be interesting to see a conflict between two criteria in our empirical problem. As an example let us consider the conflict between risk (measured as probability of failure) and income (measured as gross margin) in type B farms. Figure 1 shows the trade-off

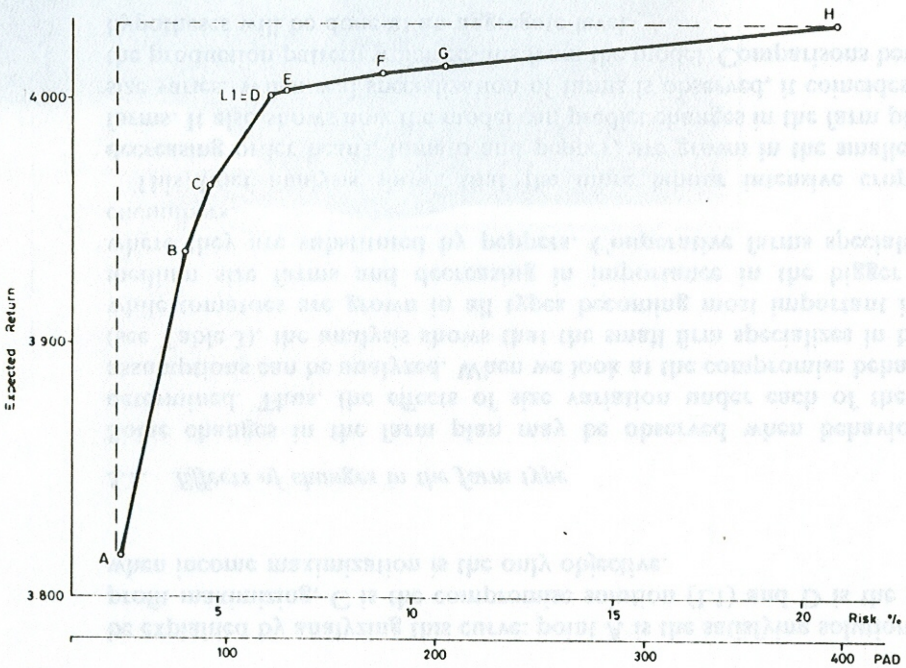

Figure 1. *Risk-return efficient set (Type B)*

curve where we can see how the marginal increase of income implies greater increase of risk when point 'D' (compromise solution for these two objectives) is surpassed. The profit maximizing solution will be point 'H' and the risk minimizing one 'A'.

Figure 1 shows the results obtained when the mean-PAD method is applied. The horizontal axis shows the PAD value and at the same time the probability of failure for this particular case. We can see how this probability is proportional to the PAD parameter, and the range being between 2% and 22%. The ideal point (Zeleny 1973) is the one in which both optima are achieved simultaneously, the compromise programming hypothesis is that the decision maker will try to get as close as possible to this ideal point. In our problem, depending on the notation of distance we get point D or some points in line *CD*. For a further study of compromise programming see Romero et al. (1987).

This type of analysis was done for each farm type and for the conflicts between risk and income and income and leisure. In both cases, the marginal income decreases sharply once some medium point was surpassed. Figure 2 shows marginal income with respect to own labour for type 'B' farms.

This curve shows how different behavioural assumptions will result in different solutions. Once we surpass point 'C', the marginal return is quite low (one third of the normal wage rate). Four behavioural assumptions can

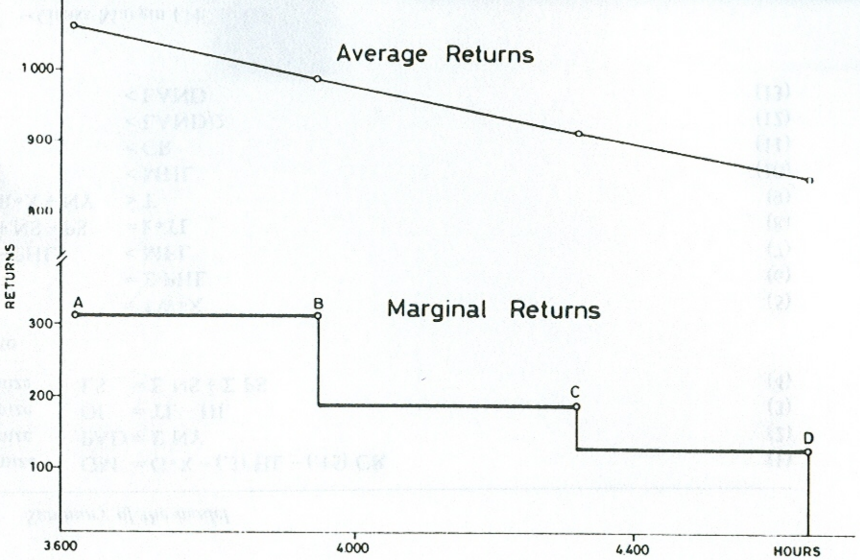

Figure 2. *Average and marginal income with respect to own labour (Type B)*

be explained by analyzing this curve: point A is the satisfying solution, B is profit maximizing, C is the compromise solution (L1) and D is the result when income maximization is the only objective.

5.1. *Effects of changes in the farm type*

Some changes in the farm plan may be observed when behaviour is determined. Thus, the effects of size variation under each of the four assumptions can be analyzed. When we look at the compromise behaviour (see Table 3), the analysis shows that the small firm specializes in beans, while tomatoes are grown in all types becoming most important in the medium size farms and decreasing in importance in the bigger ones where they are substituted by peppers. Cooperative farms specialize in cucumbers.

This brief analysis shows that the more labour intensive crops (in decreasing order beans, tomato and pepper) are grown in the smaller size farms. It also shows how the model can predict changes in the farm plan as size varies. When real specialization of farms is observed, it coincides with the production pattern which results from the model. Comparisons between hypotheses will be done at an aggregate level.

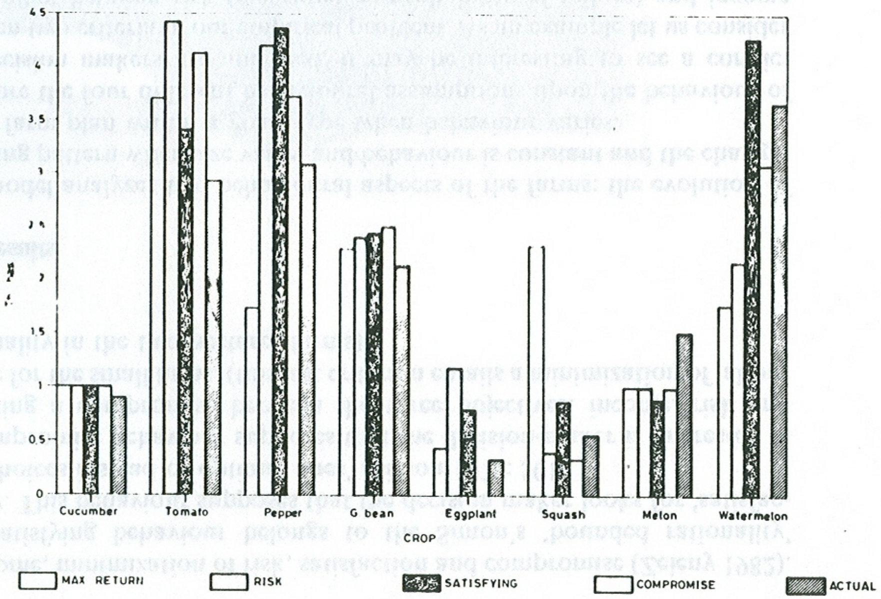

Figure 3. *Model solutions and actual areas: Almeria*

Table 3. *Activities solution under different assumptions*

Income Maximization

Type	Cucumber	Tomato	Pepper	G. Bean	Eggplant	Squash	Melon	Watermelon
A	—	25%	5%	25%	—	25%	—	20%
B	—	43%	9%	25%	8%	6%	—	8%
C	—	28%	4%	7%	—	29%	—	32%
D	25%	—	25%	6%	—	19%	25%	—
Estim.	1.000	3.720	1.740	2.300	450	2.335	1.000	1.775
Real (ha.)	910	2.929	3.092	2.147	343	562	1.528	3.669

Risk Minimization

Type	Cucumber	Tomato	Pepper	G. Bean	Eggplant	Squash	Melon	Watermelon
A	—	26%	26%	26%	2%	8%	—	12%
B	—	27%	27%	13%	12%	6%	—	14%
C	—	29%	30%	17%	—	—	—	24%
D	28%	22%	11%	7%	—	—	28%	2%
Estim.	1.000	4.440	4.210	2.400	1.180	410	1.000	2.190
Real (ha.)	910	2.929	3.092	2.147	343	562	1.528	3.669

Table 3. *Continued*

Satificing or Labour Minimization

Type	Cucumber	Tomato	Pepper	Green Bean	Eggplant	Squash	Melon	Watermelon
A	—	20%	6%	25%	—	24%	—	25%
B	—	26%	36%	23%	11%	—	—	4%
C	—	25%	21%	8%	—	14%	—	30%
D	25%	9%	25%	6%	—	4%	20%	11%
Estim.	1.000	3.420	4.370	2.450	800	870	890	4.290
Real (ha.)	910	2.929	3.092	2.147	343	562	1.528	3.669

Note: Types C and D, the objective is labour seasonality.

Compromise Solution (L1)

Type	Cucumber	Tomato	Pepper	Green Bean	Eggplant	Squash	Melon	Watermelon
A	—	25%	11%	25%	—	14%	—	25%
B	—	32%	22%	22%	—	—	—	22%
C	—	26%	29%	8%	—	5%	—	32%
D	28%	13%	26%	4%	—	—	28%	—
Estim.	1.000	4.140	3.730	2.500	0	350	1.000	3.100
Real (ha.)	910	2.929	3.092	2.147	343	562	1.528	3.669

Source: Berbel (1987).

5.2. *Effects of changes in the behavioural assumption*

After this analysis of conflicts between risk and income or income and leisure, the results can be more easily understood. If a given farm type is considered (e.g. type B), we see: how income maximization implies a plan with tomatoes (43%), green beans (25%) and the remaining crops about 8% each. Risk minimization results in a more diversified plan (as a means to minimize variability): tomatoes (27%), peppers (27%) and beans, eggplant and watermelon (around 13%).

When we proceed to study the less conventional assumptions, the satisfying solution is mainly tomatoes (26%), peppers (36%), and beans (23%). The increase in peppers can be explained as a consequence of it being a less labour intensive crop. The last assumption, compromise behaviour, results in a plan with tomatoes (32%), and peppers, watermelons and green beans (each 22%).

In short, from this analysis we see an enormous variation in crop patterns when the behavioural assumption varies. Crops such as peppers are grown less when income is maximized but increases its area when safety is the top priority. Squashes appear to be a risky and profitable crop diminishing in area as safety increases.

This variability in the cropping pattern which depends on the underlying behavioural assumption is an important outcome of the research, since it provides us with the evidence that further research on the real objectives and real decision makers' objectives and behaviour is necessary.

5.3. *Effects on aggregate results*

We have seen how the different farm types with different behavioural assumptions produce different crop plans. Thus, it is interesting to analyze the actual behaviour of Almerian farmers and the projected plan depending on which hypothesis is employed. Estimation of aggregate acreage in Table 3 and Figure 3 has been made by multiplying the solution for each type of farm in each specific behavioural assumption by the area estimated for each type (type A 700 ha.; B 5000 ha.; C 2000ha. and D 2000 ha.) and then by comparing the aggregate result with the average area of greenhouse crops in the last five years. Results prove to be quite close to reality (measured as the average area 1978/85).

Of the different assumptions analyzed, the compromise solution and the labour minimizing hypothesis yield results closest to actual cropping pattern. We assume that performance is measured by the mean of absolute deviations (MAD), proposed by Hazell and Porter (1986: 328). MAD values are for the compromise solution 506; for labour minimization 523; for risk minimization 746 and for income maximization 836. The last two hypotheses yield less satisfactory results with this measure. This outcome shows that the actual

behaviour of farms seems to be closer to 'bounded rationality' or the satisfying assumptions than to the pure neoclassical hypothesis. Income maximization rates better in some crops, but it seriously underestimates pepper or watermelon because those are less profitable but safer and less labour intensive crops.

A further explanation of the better performance of the compromise and satisfying behaviour hypotheses is given in Figure 2, which shows that marginal return to labour decreases quite sharply once the desired minimum income level is achieved.

6. Concluding remarks

A first outcome of this research shows some evidence which suggests that the actual behaviour of horticultural farms in Almeria cannot be described by a single objective maximizing hypothesis. Moreover, the need for multiple objectives in the decision process in this type of family farm is suggested. An important variability of production plans is observed when the behavioural assumption varies.

We also stress the need for further research in 'own labour' as an input itself, as well as in the income-risk-leisure trade-off. These three objectives seems to be the most important criteria in family farms when this type of firm is considered as the production unit.

The use of the compromise behavioural assumption in the income-leisure or risk-income conflicts implies some implicit utility functions which are in accord with the traditional utility functions assumed in the neoclassical consumer theory.The use of multiobjective techniques enables the practical use of these more realistic and complex behavioural assumptions.

The practical workability of the mean-PAD approach is demonstrated and a set of conclusions is reached which permit a better understanding of the behaviour of farmers in the protected cropping sector of Almeria. These conclusions can be considered as a useful basic tool to be used by policy makers interested in a suitable organization of this important agricultural sector.

Finally, we would like to remark that the use of the MCDM Techniques employed in this research does not require complex computations, as only a simplex algorithm needs to be implemented.

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Kmenta, J. (1971). *Elements of Econometrics*. New York: Macmillan.

Article in a book

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