The impact of reforming the Common Agricultural Policy on the sustainability of the irrigated area of Central Italy. An empirical assessment by means of a Positive Mathematical Programming model

Raffaele Cortignani[1], Simone Severini[2]

[1] Universita della Tuscia di Viterbo, Facolta di Agraria – DEAR Via S.C. De Lellis, snc I-01100 Viterbo, Italy, phone IT-0761357241, fax IT-0761357295, e-mail: cortignani@unitus.it

[2] Universita della Tuscia di Viterbo, Facolta di Agraria – DEAR Via S.C. De Lellis, snc I-01100 Viterbo, Italy, phone IT-0761357241, fax IT-0761357295, e-mail: severini@unitus.it

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Raffaele Cortignani and Simone Severini

Università della Tuscia di Viterbo, cortignani@unitus.it; severini@unitus.it

Facoltà di Agraria – DEAR

Via S. C. De Lellis, snc

I – 01100 Viterbo, Italy

Phone: IT-0761-357241

Fax: IT-0761-357295

http://www.agraria.unitus.it/docenti.asp?azione=scheda&idDoc=104&idCat=363

Abstract

The Common Agricultural Policy (CAP) is a major driver of the environmental and social sustainability of the agriculture in the European Union (EU). Under the 2003 CAP reform, most direct payments to agricultural producers were decoupled from production.

This work assesses the possible impact of the CAP reform on the sustainability of an irrigated area of Central Italy with particular attention being paid to decoupling. The analysis has been conducted using the Positive Mathematical Programming (PMP) method that directly estimates the cost function parameters by imposing the first-order conditions of the farm model under consideration.

The analysis assesses the impact of the CAP reform on farm cropping patterns, water and chemical use, labour use and economic results. By referring to this set of indicators it is possible to investigate the likely effect of the CAP reform on the environmental, social and economic sustainability of the considered farming systems.

The results of the empirical analysis mainly show a reduction in water and chemical input use, an increase in the economic results of farms, but also a reduction of the labour.

Key words: Common Agricultural Policy; Sustainability; Positive Mathematical Programming**;** Farmers' behaviour; Irrigated agriculture; Decoupling.

1. Introduction

The European Common Agricultural Policy (CAP) has had a significant impact on land use because it has directly interfered with the farmers' management decisions on how to use their farmland and other resources.

Most of the studies analyzing the impact of the CAP reform by means of the mathematical programming models do not account for the overall sustainability of farming that also requires the consideration, at the same time, of changes in social and environmental parameters (Gomez-Limon, Sanchez-Fernandez, 2010).

This work assesses the possible impact of the CAP reform on the sustainability of an irrigated area of Central Italy, paying particular attention to decoupling. The analysis has been carried out using the Positive Mathematical Programming (PMP) method that directly estimates the cost function parameters by imposing the first-order conditions of the considered farm model (Heckelei, 2002; Heckelei and Wolff, 2003; Arfini and Donati, 2008). However, the approach has been extended and adapted to conduct the analysis on an irrigated area of Central Italy served by an Irrigation Board where 1,000 farms are located in an area covering approximately 8,000 ha of Utilised Agricultural Area (UAA).

2. Background

In recent years, the Common Agricultural Policy has been affected by major changes including the decoupling of subsidies from the quantity produced and of the use of land by introducing the so-called *Single Payment Scheme* (SPS)[1]. This approach, that will remain a major cornerstone of the CAP for years to come[2], was initiated with Reg. EC n. 1782/2003 in 2005[3], and focused mainly on the decoupling of cereals, oil and protein crops (COP) payments. However, it was extended later to

[1] In a group of EU Member States a different version of this scheme is applied. This version, named Single Area Payment Scheme, is based on decoupling direct payments as the SPS.
[2] The basic features of it have been reconfirmed by the recent "Health Check" reform of the CAP (Reg. EC n. 73/2009 of January 19th, 2009. OJofCE L30 of the 31.01.2009).
[3] In some Member States such as Spain, this reform took place in 2006.

other sectors, namely sugar, fruit and vegetables. In the sugar sector it has been decided to gradually decrease the supported prices of sugar (and beet) prices and to compensate farmers by introducing direct decoupled payments. In the fruit and vegetable sector, the EU has decided to decouple the direct payments granted to some horticultural crops such as tomato for processing. This change is expected to considerably reduce the convenience of these crops where the direct payment used to account for a non-negligible share of farm revenues. This crop is very important in many irrigated areas of Italy such as in this considered study area. This is the case not only because it generates a relevant part of farm income, but also because it uses a relevant part of the irrigation water and seasonal labour of the study area.

Decoupling is affecting the composition of the agricultural production in the European Union (EU) in various ways. However, it is reducing the relative profitability of those crops that have received coupled payments (e.g. cereals), while it is increasing the relative profitability of those crops that have not received such payments (e.g. fodder crops).

The economic analysis of the effects of policy reforms on the farming sector is one the major fields in agricultural economics results, even because it has been stimulated by the frequent reforms of agricultural policy and by the request for evaluating the expected impact of such changes formulated by policy makers.

The link between farm and policies is becoming increasingly important in the general framework of model-based policy impact analysis. This is the reason why farm-level mathematical programming models which are able to represent the farmers' behaviour towards changes in policy have become an important and widely used tool for analyses in agricultural economics. The basic motivation for using programming models in agricultural economic analysis is straight-forward because this kind of model is based on neoclassical economic theory which perceives economic agents as optimizers (Buysse et al, 2007).

The use of such models has considerably spread in recent years. In recent times, due to methodological developments, researchers have moved from the classical linear or quadratic programming to the most recent Positive Mathematical Programming (PMP) (Howitt, 1995; Arfini and Paris, 1995; Paris and Howitt, 1998). One advantage of the PMP is certainly that it requires a limited set of data and uses them to perfectly calibrate the model to the reference period. From its formal presentation (Howitt, 1995) up to now, the PMP has been improved in terms of methodology and has been adapted to various areas of analysis to try and make the best use of available data and to capture some relevant aspects of the farmers' behaviour (Heckelei and Britz, 2005). In particular, while the standard PMP approach is based on a three phase procedure, a new approach to calibrate and estimate programming models based on the first order conditions of the desired model specification (Heckelei, 2002; Heckelei and Wolff, 2003; Arfini e Donati, 2008) has been proposed and applied recently. This topic is fully developed in the next paragraph.

Furthermore, recent efforts are also aimed at the adaptation of the PMP to the investigation into the use of resources such as irrigation water that could have implications on the environmental sustainability of the farm sector (Blanco et al., 2004; Cortignani and Severini, 2008; Iglesias and Blanco, 2008; Cortignani and Severini, 2009).

3. Methodology

The PMP methodology, developed to calibrate agricultural supply models (Howitt, 1995; Arfini and Paris, 1995; Paris and Howitt, 1998), provides the recovery of additional information from observed activity levels in order to specify a non-linear objective function[4]. This attempt to combine econometrics and mathematical programming models creates a new and promising field of empirical investigation (Buysse et al, 2007).

The *Standard* approach involves three phases: 1) Specification of a linear programming model bound to the observed activity levels by calibration constraints; the dual values of which are used to derive an estimate of the unaccounted (or additional) production activity costs to be used in the

[4] The activities are generally the land devoted to each crop or the resulting produced quantities. These variables are generally relatively easy to record at farm level even in those farms with limited book-keeping.

second phase; 2) Estimation of a quadratic variable cost function assumed to capture all farming conditions not modelled in an explicit way in the objective function or structural constraints of the linear model; 3) Formulation of a quadratic programming model including the variable cost function in the objective function. This model exactly reproduces the farmers' choices (i.e. production pattern) observed in the base year and can be used to perform simulations on several parameters of the model, including product and factor prices, subsidies and resource availability. The variable cost function is assumed to be quadratic because this form is relatively easy to work with and has the desirable property of having increasing marginal cost functions.

Denoting the crops by j , the quadratic programming model can be compactly written as:

$$\text{Max}\, Z = \sum_j (p_j - AC_j(x_j))x_j$$

$$s.to \sum_j A_{i,j}\, x_j \le b_i \qquad (\lambda_i) \qquad (1)$$

$$x_j \ge 0$$

where Z denotes the objective function value; x_j represents the production activity levels (hectares allocated to crop j); p_j denotes average revenue per unit of activity; $A_{i,j}$ represents the scalar element of a matrix of coefficients in the resource/policy constraints (index i); b_i is the vector of available resource quantities; $AC_j(x_j)$ denotes average variable cost function per unit of activity and has the following form:

$$AC_j(x_j) = d_j + \frac{1}{2}\sum_i Q_{ji} x_j \qquad \text{with } j = i \qquad (2)$$

where d_j and Q_{ji} are parameters to be estimated. Note that parameters Q_{ji} are elements of the symmetric positive semi-definite matrix and are associated with the quadratic terms of the variable cost function.

Multiple sets of cost function parameters satisfy the first order conditions of the problem (1). In the early specification, the parameters have been simply obtain by setting all off diagonal elements of *Q* to 0 (e.g. Arfini and Paris, 1995) and assuming:

$$d_j = c_j \;; \quad Q_{jj} = \frac{\mu_j}{x_j^0} \tag{3}$$

where c_j are the observed accounting costs and μ_j are the dual values recovered by means of the following calibration constraints:

$$x_j \leq x_j^0 (1 + e) \qquad [\mu_j] \tag{4}$$

where x^0_j are the observed activity levels and *e* is a small positive number (Howitt, 1995). Subsequently, other specifications have been used including one that provides the incorporation of exogenous elasticities to recover the parameters of the marginal cost function (Heckelei and Britz, 2005). The off-diagonal elements of *Q* are set to zero and land allocation elasticities with respect to own gross margins (ε) are considered (Gocth, 2005)[5]. Because the partial derivative of the land demand function $\frac{\partial x_i}{\partial gm_i}$ is equal to Q_{jj}^{-1}, the exogenous land allocation elasticity can be used to calculate *Q* as:

$$Q_{jj} = \frac{1}{\varepsilon_j} \frac{gm_j^0}{x_j^0} \;; \qquad d_j = c_j + \mu_j - Q_{jj} x_j^0 \tag{5}$$

where gm_j^0 are the unitary gross margins of the activities observed in the base year.

Heckelei and Britz discussed a general and theoretically consistent approach to calibrating and estimating agricultural programming models based on first order conditions of the desired model specification and without the use of dual values on calibration constraints. This approach promises to be theoretically equivalent but empirically more flexible than previous models with the explicit allocation of fixed factors (Heckelei, 2002). Recently also Arfini and Donati (2008) adopted a similar method using data from the Farm Accountancy Data Network (FADN).

[5] It is worth noting that ε are equal to land allocation elasticities with respect to changes in gross margins if the yields are constant and the gross margins are defined per unit of land.

Our method has similarities with both the Heckelei/Wolff and Arfini/Donati approaches. Therefore, we would like to summarize the main aspects of these approaches before presenting our approach.

a. The Heckelei and Wolff approach

The method proposed by Heckelei and Wolff (2003) uses the Generalized Maximum Entropy (GME) approach (Golan, Judge and Miller, 1996) covered by the restrictions needed to determine the appropriate curvature of the cost function. The GME is used frequently when the number of observations is lower than the number of parameters to be estimated (ill-posed problems). However, the GME can also be used in well-posed problems because it allows a flexible incorporation of out of sample information such as supply elasticities (Heckelei, 2002).

Considering that the data refer to several years (t = 1, ..., T), the GME problem is specified as follows[6]:

$$\max_{w_t, d, Q, L, \lambda_t} H(w_t) = -\sum_{t=1}^{T} w_t' \ln w_t - w^{\varepsilon\prime} \ln w^{\varepsilon}$$

s. to

$$gm_t - \lambda_t A - d_t - Q(x_t^0 - Vw_t) = 0 \qquad (7)$$

$$A'(x_t^0 - Vw_t) = b_t \qquad (8)$$

$$Q = LL' \qquad con\ L_{j,i'} = 0 \quad \forall\ i' > j \qquad (9)$$

$$V^{\varepsilon} w^{\varepsilon} = \left[\left(Q^{-1} - Q^{-1} A (A'Q^{-1}A)^{-1} A' Q^{-1}\right) \odot \left[\frac{gm^0}{x^0}\right]'\right] \qquad ($$

$$\sum_{s=1}^{S} w_{j,t,s} = 1 \qquad (11)$$

$$\sum_{s=1}^{S} w_{j,i,s}^{\varepsilon} = 1 \qquad (12)$$

[6] We use different symbols that in the original paper to ensure a greater homogeneity with the other approaches presented later.

where $H(w_t)$ is the level of entropy, the errors vector (Vw_t) is re-parameterized as the expected value of a discrete probability distribution by defining V support matrix and w_t probabilities vector; elasticities ($V^{\varepsilon}\ w^{\varepsilon}$) can be re-parameterised in the same way as the error terms by defining V^{ε} support matrix and w^{ε} probabilities vector[7]; gm_t are the gross margins of each activity; λ_t is the shadow price of land over several years; A is the technical coefficients matrix; d_t and Q are respectively the parameters associated with the linear term and the quadratic term of the cost function; x_t^0 are the observed levels of activity in different years; L is the lower triangular matrix by the Cholesky decomposition. Notice that λ_t, d_t and Q are all estimated simultaneously by means of the considered approach.

Equation (7) imposes the first order conditions of the observed activities (*Marginal Revenue = Marginal Cost)* and (8) ensures that the land allocated to different crops in each year is equal to the total available land. Equation (9) ensures the proper curvature of the cost function and (10) is the combination between the elasticity re-parametrization ($V^{\varepsilon}\ w^{\varepsilon}$) with the Jacobian matrix that contains the partial derivates of the land demand functions $\left(\frac{\partial x_i}{\partial gm_i}\right)$ and the matrix $\left[\frac{gm^o}{x^0}\right]$ defines as the sample mean of gross margin ($\overline{gm}^{o}$) divided by the sample mean of observed land allocation ($\overline{x}^{0}$) . Equations (11) and (12) relate to the probability law (where *s* is the number of support values).

Notice that all available information covers several years and that only one cost function with parameters Q for all periods is estimated. The error vector can be interpreted in different ways: an error in the measurement of the variable, an error of the optimization process, a limit to achieving

[7] The intuition behind the objective function is that the entropy criterion pulls towards the centre of the elasticity support range, in opposition to the error terms of the data constraints. The smaller the elasticity support range, the higher the penalty for deviating from the support centre. Consequently, the width of the support range reflects the precision of the *a priori* information (Heckelei and Wolff, 2003).

optimal allocation determined by specific economic circumstances or a combination of these factors (Heckelei and Wolff, 2003).

b. The Arfini and Donati approach

Arfini and Donati (2008) have proposed an extension of the method described above which is very useful for using the data of the Farm Accountancy Data Network (FADN). Their approach in terms of methodology and structure is consistent with the PMP approach that was previously proposed (Arfini and Paris, 2000), but overcomes the first phase. The salient aspects of the method are:

- the cross-sectional data are used to estimate an overall cost function associated with a whole Technical Economic Orientation (frontier cost); each farm in the sample will be characterized by the same cost function and a $\boldsymbol{u}$ errors vector able to reflect its distance from the cost frontier;
- the decomposition of the $\boldsymbol{Q}$ matrix according to the Cholesky factorization[8] ($\boldsymbol{Q} = \boldsymbol{LDL'}$) to achieve an appropriate curvature of the cost function;
- in the $\boldsymbol{Q}$ matrix both the $\boldsymbol{c}$ specific costs and the $\boldsymbol{\mu}$ dual cost are considered;
- the first order conditions of the observed and of the non-observed activities are both taken into consideration;
- the variable $\boldsymbol{x}$ refer to the produced quantity.

Other relevant aspects of this work are: the use of ordinary least squares as an estimation method and that the $\boldsymbol{c}$ specific costs for each activity are estimated from the total cost per farm. These are important features when working with the European FADN data base where specific costs for each activity are not available.

The estimation model is specified as follows:

[8] The two different forms of the Cholesky decompositions are related in the following way : replacing the « ones » on the diagonal triangular matrix $\boldsymbol{L}$ of $\boldsymbol{Q} = \boldsymbol{LDL'}$ with the square roots of the corresponding diagonal elements of D allows us to write $\boldsymbol{Q} = \boldsymbol{LL'}$.

$$\min_u LS = \frac{1}{2} u'u \quad (13)$$

s. to

$$c + \mu = R'R\, x^0 + u \qquad se\; x^0 > 0 \quad (14)$$

$$c + \mu \leq R'R\, x^0 + u \qquad se\; x^0 = 0 \quad (15)$$

$$c'x^0 \leq TC \quad (16)$$

$$u'x^0 + \frac{1}{2} x^{0'}(R'R)x^0 \geq TC \quad (17)$$

$$c + \mu + A'\lambda \geq p \quad (18)$$

$$b'\lambda + \mu'x^0 = p'x^0 - c'x^0 \quad (19)$$

$$R = LD^{\frac{1}{2}} \quad (20)$$

$$\sum_{n=1}^{N} u_{n,j} = 0 \quad (21)$$

where *LS* is the sum of square errors ***u***, *TC* are the total variable costs of each farm. The equations (14) and (15) define the relationship between the marginal costs related to a linear function (left hand) and the marginal costs related to a quadratic function (right hand) for the observed and non-observed activities respectively. Equations(16) and (17) use information on total variable cost to estimate the activity specific cost vector (***c***), considering that the quadratic cost function level cannot be lower than the total variable cost level. Number (18) considers the first order conditions (*Marginal Revenue* ≤ *Marginal Cost*) and the equation (19) ensures that the value of the objective function of the dual problem is equal to that of the primal problem. Finally, (20) and (21) respectively require the necessary conditions for the Cholesky factorization (needed to impose the proper curvature of the cost function) and that the sum of the ***u*** errors is equal to zero.

c. Approach Used

From a methodological and structural point of view, the approach used in the empirical analysis has common aspects to both approaches described above. On one hand, we have used the MEG as

Heckelei and Wolff did because it allows the easy and flexible use of prior information such as supply elasticities. On the other, the estimated errors have a function similar to that used by Arfini and Donati. In fact, the cross-sectional data has been used to estimate a homogenous quadratic cost function for the whole area and in order to consider the differences in preferences land local conditions in different sub-areas (l). This is taken into account by the error terms. Finally, it considers that there are some non-observed activities in some sub-areas.

The estimation model can be formalized as follows[9]:

$$\max_{(w, \mathbf{d}, \mathbf{Q}, L, \lambda)} H(w_l) = - w_l' \ln w_l - \mathbf{w}^{\varepsilon\prime} \ln \mathbf{w}^{\varepsilon}$$

s. to

$$gm_l - \lambda_l A - d_l - Qx_l^0 - Vw_l = 0 \qquad if\ x_l^0 > 0 \qquad (23)$$

$$Q = LL' \qquad with\ L_{j,i'} = 0 \quad \forall\ i' > j \qquad (25)$$

$$V^{\varepsilon} w^{\varepsilon} = \left[\left(Q^{-1} - Q^{-1} A \left(A' Q^{-1} A \right)^{-1} A' Q^{-1} \right) \odot \left[\frac{gm^{o}}{x^{0}} \right]' \right] \qquad (2$$

$$\sum_{s=1}^{S} w_{j,l,s} = 1 \qquad (27)$$

$$\sum_{s=1}^{S} \mathbf{w}_{j,i,s}^{\varepsilon} = 1 \qquad (28)$$

where (23) and (24) are the first order conditions for the activities observed and not in the specific sub-areas l. The matrix $\boldsymbol{A}$ refers to the coefficients of all considered constraints (land, water and political).

In addition to the exogenous values on supply elasticities (Jansson, 2007), other exogenous information has been used for the estimation of various parameters. In particular, the average rent value of the area has been used for the estimation of the land dual value. Furthermore, according to

[9] For further details see Annex.

information obtained from the technicians of the Irrigation Board, it was considered that the total annual water availability is not binding in the base year and thus, that the relative shadow price is equal to zero.

This approach seems particularly suitable for analyses of a territorial type where, given the relatively small size of the study area, they are characterized by a relative homogeneity of environmental and economic conditions and it is possible to assume the existence of a homogeneous quadratic cost function for all farms in the study area. However, explicit consideration of the differences that may exist between sub-areas are explicitly considered by the error terms (Vw_l) that become linear parameters of the cost function. These parameters are defined in this way so as to enable the calibration of the model in all sub-areas that, because of specific local conditions, show a different allocation of the crop (Blanco et al, 2008).

Unlike the two approaches described above, the proposed approach also takes into account some aspects of the water policies. In particular, the constraints that connect the water demand of crops irrigated with its availability are accounted for. Moreover, the level of water price is considered in the objective function. In this way, the model is suitable to perform simulations on the level of water availability and water price.

4. Empirical analysis

a. Study Area

The empirical model has been estimated by using data from the agricultural area served by the Irrigation Board (IB) “Maremma Etrusca” located in Central Italy, about 80 kms north of Rome. There are approximately 1,000 farms in this area covering about 8,000 ha of land, more than one-third of which are irrigated (Table 1). Water is obtained from a river that originates from Lake Bolsena where considerable recreational activities occur during the summer (e.g. swimming, boating and fishing). The water outflow is reduced in the summer in those years characterised by limited rain fall to ensure that the water level of the lake is kept high enough to allow for these activities. When this occurs, water availability for downstream farmers becomes limited during the summer. Water availability for the farming sector is expected to decrease in the future due to a decline in the importance of farming and the growing demand for water in the tourism sector.

Table 1. Cropping patterns, prices, yields and variable costs of the more important crops; main characteristics of the whole study area and of sub-areas L1, L2 and L3^ (2007).

	Observed activity levels (ha)				Prices	Yields	Variable costs
Cropping activity	**L1**	**L2**	**L3**	**Total**	**€/ton**	**ton/ha**	**€/ha**
Durum Wheat	1,289	1,113	1,700	4,102	430	5	601
Maize	42	43	48	133	25	11	1,132
Asparagus	9	11	11	31	3,300	2	3,057
Artichoke	12	35	41	88	979	5	2,862
Cabbage	36	61	104	201	300	12	1,253
Sugar Beet	20	1	-	21	36	60	1,315
Tomato	89	339	311	739	55	80	3,000
Melon	69	85	77	231	260	25	3,500
Watermelon	86	105	76	267	140	30	1,670
Fennel	27	92	115	234	350	16	2,900
Other Crops	552	485	823	1,860	-	-	-
Utilised Agricultural Area (ha)	2,231	2,370	3,306	7,907			
Irrigated land (ha)	405	783	810	1,998			
Annual water use (1000 m^3)	1,057	2,024	1,992	5,074			
Average water cost (€/m^3)	0.07	0.13	0.13				

^ The Irrigation Board delivers water using three non-fully connected irrigation systems, which can be distinguished as sub-areas L1, L2 and L3. Each sub-area is represented in the model as a separate entity mades up of the sum of all farms located in that section of the study area.

The farmers are charged for the water by multiplying water use by an average unitary water distribution cost coefficient (€ m^{-3}) (Table 1). The IB calculates this at the end of the irrigation season by dividing water distribution cost by the amount of water distributed in each sub-area. This value is very low because it accounts only for the operational variable cost of water distribution incurred by the IB. It does not account for the financial cost of the infrastructures managed by the IB, nor for the opportunity and environmental costs of this resource. The implementation of the principle of cost recovery of water services introduced by the EU Water Framework Directive is thus expected to cause a relevant increase in the charge per unit of water.

The IB delivers water using three non-fully connected irrigation systems which we have distinguished as sub-areas L1, L2 and L3. These sub-areas are similar in terms of soil quality, farm size and production technologies. Data on cropped area, input use, variable costs per activity, product prices and yields by crop, water charges, irrigated area, water availability and agricultural policy subsidies and constraints were collected and used in previous researches (Lezoche and Severini, 2007; Blanco, Cortignani and Severini, 2008; Cortignani and Severini, 2009). Each sub-area is represented in the model as a separate entity made up of the sum of all farms located in that section of the study area.

We have calibrated the model to the pre-reform situation using 2007 cropland allocation data for 23 crops. Specifically, most of the land was used to grow durum wheat, but horticultural crops account for a non-negligible share of the rest of the land, especially for tomato for processing, while livestock activities are negligible. Furthermore, since the land was allocated by the agricultural reform after the war, there is a certain homogeneity among farm size[10]. This implies a relatively high production and structural homogeneity of the farms operating in the study area..

b. Simulation model

The simulation model has the following structure:

$$Z = \sum_l \sum_j (Pr_j * Y_j + CA_j) * x_{j,l} - \sum_l \sum_j d_{j,l} * x_{j,l} - \frac{1}{2} * \sum_l \sum_j \sum_i x_{i,l} * Q_{j,i} * x_{j,l} +$$

$$- \sum_l \sum_j u_{j,l} * x_{j,l} - \sum_l \sum_j Pw_l * Rw_j * x_{j,l} + \sum_l VUE_l * hel_l - \sum_l mdl_l \qquad (29)$$

s. to

$$\sum_j x_{j,l} \leq Land_l \qquad [\lambda land_l] \qquad \forall l \qquad (30)$$

$$x_{jfix,l} = x^0_{jfix,l} \qquad [\lambda fix_{jfix,l}] \qquad \forall l \qquad (31)$$

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[10] Approximately 90% of farms have a Utilized Agricultural Area (UAA) less than 20 hectares (Source: Land Registry of the Irrigation Board).

$$\sum_j facq_j * x_{j,l} \leq Wat_l \qquad [\lambda wat_l] \qquad \forall\ l \qquad (32)$$

$$ham_l \leq Ent_l \qquad [\lambda ent_l] \qquad \forall\ l \qquad (33)$$

$$hel_l \leq \sum_j x_{j,l} * eleg_j \qquad [\lambda hel_l] \qquad \forall\ l \qquad (34)$$

$$\frac{TotA}{NFr} = UNA \qquad (35)$$

$$AA \leq Thr \qquad (37)$$

$$[(AA * 0) + (BA * mdl_{\%})] * NFr = mdl \qquad (38)$$

where Pr_j are product prices (€/100 kg); Y_j are crop yields (100 Kg/ha); CA_j are the coupled aids (€/ha); $d_{j,l}$ and $Q_{j,l}$ are respectively the estimated parameters of the cost function; $u_{j,l}$ are the error terms that consider the differences of the linear parameters of the cost functions of the sub-areas; Pw_l are the average water cost charged by the Irrigation Board in each *l* (€/m^3); Rw_j are the unitary crop water requirements (m^3/ha); VUE_l is the unitary value of the entitlements (€/ha) and mdl is the amount of modulated direct payments (€).

Regarding the constraints, $Land_l$ is the land availability (ha), $x^0_{jfix,l}$ are the amount of permanent

Wat_l

crops observed in the base year (ha), is the water availability (m^3), Ent_l are the number of available entitlements (ha), $eleg_j$ is a vector with 0 and 1 that identifies the eligible crops[11]. Equations(35), (36), (37) and (38) refer to the modulation mechanism in each sub-area. In

[11] In the base line (2007) the horticultural crops are not eligible while in the simulation scenarios all the crops become eligible.

$mdl_{\%}$

particular Thr is the threshold modulation (5.000 €), is the modulation rate and NFr is the number farms belonging to each sub-area.

Three sustainability indicators are calculated on the basis of simulation model results: total gross margins, labour requirements, water and chemical input use.

The total gross margin is the difference between revenues and costs and can be considered as a valid estimate of the private profitability of the farming activity.

The demand for labour from farming is closely related to the crop production timetable which at certain times requires a concentration of labour. Thus this indicator may be regarded as a suitable estimator to measure the contribution of farming in maintaining the rural population.

The chemical input use is directly derived from the combination of activities multiplied by the respective use of chemical input such as fertilizer, herbicides and pesticides.

Table 2 reports the requirements of the more important crops in terms of total water, of total labour and of chemical input use.

Table 2. Water, labour and chemical input requirements for the main cropping activity.

	Water	Labour	Nitrogen	Phosphorus	Potassium	Herbicides	Pesticide
Cropping activity	**m^3/ha**	**hrs/ha**	**Kg/ha^**				
Durum Wheat	110	6	123	115	0	0.5	0.0
Maize	3,537	26.5	256	184	0	1.4	8.7
Asparagus	2,465	1132	226	176	128	1.7	5.9
Artichoke	2,660	227	65	156	156	0.6	0.1
Cabbage	1,734	123	155	154	216	0.3	0.8
Sugar Beet	990	20	98	184	196	4.7	2.9
Tomato	2,515	131	88.5	120	248	0.9	5.7
Melon	158	392	18	162.3	249	0.0	6.1
Watermelon	813	118	107	147	249	0.0	2.2
Fennel	112	642	94.5	138	104	2.3	3.1

^ Nitrogen (N); Phosphorus (P_2O_5); Potassium (K_2O); Herbicides (commercial product); Pesticide (commercial product).

c. *Simulated scenario*

The post-reform scenario takes into account the three main changes that were brought about due to the reform of the sugar and fruit and vegetable CMOs: the decoupling of the aid for the production of tomato for processing; the reduction in the price of sugar beet and the introduction of compensatory decoupled payments; the abrogation of Article 51 of Regulation 1782/2003 that has prohibited the cultivation of fruit and vegetable crops on land eligible for SPS and the abrogation of the quality premium of the durum wheat.

5. Results

The application of the simulation scenario causes a considerable reduction in tomato production from baseline conditions. Conversely, the sugar beet production, which had already undergone a substantial downsizing in the first year after the reform, shows a smaller percentage of reduction.

Table 3. Impact of the application of decoupling scenario on cropping patterns, water and labour use in the sub-areas and in the whole area.

	Base line				Decoupling			
	L1	L2	L3	Total	L1	L2	L3	Total
	ha				*% change with respect to Base line*			
Cereal and other field crops (COP)	1,404	1,251	1,898	4,553	3.3	6.5	4.5	4.7
of which:								
Oats	55	63	47	165	45.0	58.4	82.0	60.6
Barley	14	43	98	155	68.5	33.2	15.2	25.0
Durum Wheat	1,289	1,113	1,700	4,102	0.6	2.1	1.4	1.4
Maize	42	23	48	113	4.7	12.7	6.4	7.0
Vegetable crops	332	739	745	1,816	-21.4	-18.1	-18.9	-19.0
of which:								
Watermelon	86	105	76	267	3.0	3.6	5.2	3.9
Fennel	27	92	115	234	11.0	4.8	4.0	5.2
Melon	69	85	77	231	4.4	5.3	6.1	5.3
Tomato	89	339	311	739	-100.0	-47.3	-54.3	-56.6
Fodder crops	311	218	441	970	11.5	24.4	12.6	14.9
of which:								
clover	273	197	418	888	12.0	24.7	12.2	14.9
alfalfa	38	21	23	82	7.9	21.4	20.4	14.9
Other crops	184	162	222	568	-6.2	-0.6	-	-2.2
of which:								
Sugar Beet	20	1	-	21	-54.5	-100.0	-	-54.7
Total irrigated land	398	772	798	1,968	-19.5	-16.5	-16.7	-17.2
Water use (000 m^3)	1,107	1,945	2,022	5,074	-19.3	-19.5	-19.6	-19.5
Labour use (000 h)	99	197	212	508	-3.9	-4.7	-4.6	-4.5

The Irrigation Board delivers water using three non-fully connected irrigation systems that are named sub-areas L1, L2 and L3.

The land vacated by the tomato is replaced by fodder crops and COP crops but, to a much lesser extent, by other irrigated crops. The difficulty in switching to other horticultural crops (e.g. watermelon and melon) is due to the fact that this requires farmers to make structural changes to their farms, to acquire specific knowledge on cropping techniques and to find marketing channels in which to sell the products. Therefore, the changes in cropping patterns generate a substantial reduction of irrigated land and water consumption (Table 3) and the cultivation of more extensive crops such as fodder and durum wheat.

The extensification of cropping patterns also leads to a reduction of labour use. In particular, it reduces the demand for work and sub-contracting which is required for tomato cultivation, especially in transplanting and harvesting operations. This may affect hired labour more directly than family labour.

It is interesting to analyze the results for each sub-area. Considering that in sub-area L1 the water is distributed by open canals and the cropping patterns are more extensive, there is a different pattern than in the other two sub-areas where there is a more efficient water distribution system (pipelines). In fact, the reduction of tomato production in L1 is larger than in the other two because the cultivation of irrigated crops in L1 is less convenient. In this case, farmers have to increase the water pressure and, consequently, the water cost.

The application of the reform scenario generates a significant increase in farm gross margins. This is mainly due to the fact that the increase of decoupled payments more than compensate for the withdrawal of coupled support. This result is also caused by the fact that the reduction of the product value revenues comes together with reduction of the variable costs, including costs.

Table 4. Impact of the application of decoupling scenario on economic results in the sub-areas and in the whole area.

	Base line				Decoupling			
	L1	**L2**	**L3**	**Total**	**L1**	**L2**	**L3**	**Total**
	000 euro				*% change with respect to Base line*			
Total Revenues	6,120	8,131	9,932	24,183	-3.7	-4.8	-4.1	-4.2
- product values	4,988	6,472	8,031	19,491	-4.5	-6.1	-5.2	-5.3
- aids	1,132	1,659	1,900	4,692	0.0	0.4	0.5	0.4
of which								
decoupled	757	620	886	2,263	39.9	158.7	105.3	98.1
coupled	375	1,039	1,015	2,429	-80.6	-94.0	-90.9	-90.6
Specific variable costs	3,501	5,025	5,585	14,111	-13.1	-13.5	-13.6	-13.4
of which								
accounting costs	2,014	3,237	3,700	8,951	-13.6	-15.0	-14.0	-14.3
water costs	80	245	254	579	-19.3	-19.5	-19.6	-19.5
Gross margin	2,619	3,106	4,347	10,072	5.6	7.0	4.1	5.3
Gross margin without aids	1,487	1,447	2,446	5,380	10.3	14.8	7.4	10.2

The Irrigation Board delivers water using three non-fully connected irrigation systems that are named sub-areas L1, L2 and L3.

There are also differences between the various sub-areas of the study areas far as the economic results of farms are concerned. In particular, the L1 sub-area shows an extensification process that is lower than in the other two sub-areas in terms of revenues and total costs.

Regarding chemical input use, there is a reduction in the use of all considered inputs. However, there are differences that should be discussed. The reduction of nitrogen use is rather limited (around 0.5 %), because the COP crops and vegetables that take the place of tomato require higher nitrogen doses. The same is true for phosphorus.

Table 5. Impact of the application of decoupling scenario on chemical input use in the sub-areas and in the whole area.

	Base line				Decoupling			
	L1	L2	L3	Total	L1	L2	L3	Total
	*100 Kg^*				*% change with respect to Base line*			
Nitrogen	2,128	2,256	3,121	7,506	-0.7	-0.5	-0.4	-0.5
Phosphorus	2,246	2,522	3,312	8,081	-1.9	-2.3	-1.8	-2.0
Potassium	778	1,646	1,610	4,034	-25.3	-21.2	-22.7	-22.6
Herbicides	11	13	17	40	-9.5	-6.6	-5.0	-6.7
Pesticide	18	34	34	86	-26.4	-23.8	-24.6	-24.7

The Irrigation Board delivers water using three non-fully connected irrigation systems that are named sub-areas L1, L2 and L3. ^Nitrogen (N); Phosphorus (P_2O_5); Potassium (K_2O); Herbicides (commercial product); Pesticide (commercial product)

The situation is different for other inputs because the crops that replace the tomato are less demanding in terms of potassium and require fewer interventions to control weeds and diseases. However, the main result is that the considered reforms result in an overall lower chemical input use and this may lead to a lower pressure on the environment by the farm sector.

6. Conclusions

This work has assessed the impact of the full decoupling of the support provided by the CAP in an irrigated area of Central Italy. This was carried out in terms of land use changes, economic results and environmental pressures. The analysis was conducted with a PMP model that directly estimates the cost function parameters by imposing the first-order conditions of the farm model under consideration. The approach has been extended and adapted to conduct the analysis in irrigated areas served by Local Irrigation Boards.

The homogeneous cost function throughout the territory and the linear parameters that capture differences in preferences and local conditions seem to capture the structural differences between the different sub-areas. The sub-area that is less efficient in terms of irrigation distribution and the most extensive in terms of cropping patterns (L1) indeed responds differently to the simulation scenario than the other sub-areas.

The analysis has evaluated the impact of reforming the CAP measures for sugar, fruit and vegetable crops and durum wheat (quality premium) on the basis of a set indicators. These indicators have been used to provide insights into the economic, social and environmental dimensions of sustainability.

The results show that the considered change in policy generate a decline in the land devoted to the tomato and that this crop is not fully replaced by other irrigated crops. This determines a substantial reduction of total water and chemical input use.

These results seem in line with the new objectives of the CAP that, apart from moving to less distorting support, aims at lowering the pressure on the farm sector on the environment. However, these policy changes are going to decrease demand for labour on farms. This may have negative social consequences in the overall economy of the area. Of course, it is important to consider that in the medium-long term, the sector could adjust and find a new equilibrium.

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Annex.

In the annex we briefly illustrate the details of the calibration model:

$$max_{w,Q,L,\lambda}\, H(w_{j,l,s}) = -\sum_{j,l,s} w_{j,l,s} * \ln w_{j,l,s} - \sum_{j,s} we_{j,i,s} * \ln we_{j,i,s} \qquad (A1)$$

s. to

$$P_j * Y_j + CA_j - d_{j,l} - Pw_l * Rw_j - mdl_l - \lambda land_l - \lambda fix_{j,l} - Rw_j * \lambda wat_l - \sum_i Q_{j,i} * x^0_{i,l} - \sum_s V_{j,s} * w_{j,l,s} =$$

$$P_j * Y_j + CA_j - d_{j,l} - Pw_l * Rw_j - mdl_l - \lambda land_l - \lambda fix_{j,l} - Rw_j * \lambda wat_l - \sum_i Q_{j,i} * x^0_{i,l} - \sum_s V_{j,s} * w_{j,l,s} \leq$$

$$Q_{j,i} = \sum_{jj} L_{j,jj} * L_{i,jj} \qquad \forall\, j,i \qquad with\ jj = j \qquad (A4)$$

$$\sum_s Ve_{j,i,s} * we_{j,i,s} = \left[\frac{1}{Q_{j,i}} - \left(\frac{1}{\sum_{j,i} Q_{j,i}} * \sum_i \frac{1}{Q_{j,i}} * \sum_j \left[\frac{1}{Q_{j,i}} \right) \right] \right] * \frac{gm_{i,l}}{x^0_{j,l}} \qquad \forall\, j,i \qquad (A5)$$

$$\sum_s w_{j,l,s} = 1 \qquad \forall\, j,l \qquad (A6)$$

$$\sum_{s} we_{j,i,s} = 1 \qquad \forall\, j, i \qquad (A7)$$