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THE COMMON AGRICULTURAL POLICY IN ECONOMETRIC MODELS

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The CAP in econometric models

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Abstract

The paper reviews the econometric models used in the past 10 years to analyse the most widely used agricultural policy instruments. The main aim of the paper is to provide the reader with an overview of these models, analysing the technical solutions adopted, the type of results that can be obtained, as well as their potential for simulation exercises. The conclusion reached is that the contribution of econometric models to the analysis of the CAP has been significant, especially from the point of view of modelling the main policy instruments according to their theoretical impact on farmers' behaviour. However, many problems have still to be overcome. For this reason, in the concluding section, the paper tries to identify a number of priorities for further research.

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1. Introduction

The analysis developed in this chapter is concentrated on that segment of the agricultural economics literature that uses econometric techniques to analyse, either directly or indirectly, the impact of agricultural policy instruments. As regards this literature it has been decided to privilege, in terms of time frame, the studies published in the 1990s, referring to previous studies only when these offer a fundamental methodological contribution. From the point of view of content, we have limited ourselves to examining the studies in which agricultural policy instruments are considered as exogenous variables. In fact, an important area of the agricultural economics literature, in which econometric models play an important role, considers them as endogenous variables, in the sense that they are the outcome of the interaction of the various factors influencing political decisions; however, this type of study was deliberately excluded from our review.

Econometric analyses on agricultural policy instruments have always constituted one of the most important fields of inquiry for agricultural economists, even if the reliability of the results obtained in the first studies was inevitably influenced by the limitations of the analytical tools available. However, attention paid to this area of research has grown apace in the last few years, essentially for two reasons. The first is connected with the advances in economic theory on the modelling of agricultural production and its econometric translation. In fact, as will be seen later, the fundamental contribution of econometric models in this area lies precisely in having set up models that faithfully reproduce the impact of agricultural policy instruments on the decisions of agricultural producers, and this has been possible thanks to the progress in analyses applied to the theory of production. The second reason, on the other hand, is connected with the recent developments in agricultural policy and, in particular, the Common Agricultural Policy (CAP). Over the last few years we have seen the introduction of instruments which have had a complex impact on production decisions (consider, for example, transferable production quotas or partially decoupled subsidies), all these have encouraged those researchers who set themselves the task of appraising their impact in quantitative terms. In addition, the discretionary nature of decisions in agricultural policy has increased: in fact many of the new instruments are differentiated according to area or farm type , leading to the need to increase the accuracy of analyses, an objective that can be more easily achieved with the potential of present-day econometric techniques.

Thus, the objective of this chapter is to highlight the specific contribution of the econometric models in quantitative agricultural policy analyses, with particular reference to the CAP, analysing the modelling solutions adopted and the quality of the results obtainable, both when the models' main purpose is *interpreting* the relationships among economic variables and, above all, when they are used for *simulation* and/or *forecasting*.

In the light of this general objective, the chapter is organised as follows. Before entering into details of the analysis of the literature, the second section attempts, in a synthetic way, to introduce the reader to the general logic and the characteristics of the main econometric techniques utilised in studies of agricultural policy, the types of data on which the analyses themselves are based, as well as the results which can be obtained and their possible use. In the third section, the agricultural economics literature is analysed from a general point of view; inevitably, in the light of what has just been said, considerable space is devoted to the evolution of the theory of production and its econometric applications. In the fourth section, on the other hand, we enter into the details of the solutions proposed for the econometric modelling of different agricultural policy instruments, focussing on the ones which have made an important contribution; in view of this, we consider in detail all the most important studies on the CAP that use econometric models, analysing the technical solutions adopted, the type of results that can be obtained, as well as their potential for simulation exercises. Finally, in the concluding section, some remarks are made on the use of econometric models for agricultural policy analyses, highlighting areas for possible further research.

2. Econometric methods in agricultural policy analyses

2.1 Econometric techniques

If we were to give a general definition of an econometric model, we would have to refer to the attempt to organise quantitative instruments in order first to construct, and then to verify statistically, a given mathematical representation of the real world. The general nature of this definition immediately illustrates how the art of building econometric models draws heavily on the intuition and personal judgement of researchers as they try to build such models. Accordingly, a judgement on the quality of the econometric models, such as we hope to provide in this chapter, will not only be an appraisal of the formal theoretical coherence of the model in question, but also inevitably end up by being a judgement on the choices of the researchers on the representation of the economic problem that they are going to deal with.

Coming to the specific point of econometric techniques, if all the types of models illustrated in this volume attempt, using different approaches, to build a simplified formal representation of certain economic phenomena, the fundamental contribution of the econometric techniques lies in the possibility of validating the models and their results through statistical testing. In fact, all econometric models, from the simplest to the most complex, use basic economic data to estimate the parameters of equations that relate economic variables. Once the estimate has been made using the most appropriate techniques, the model can be submitted to statistical tests that, in general, make it possible to judge both its overall specification and the statistical significance of the individual parameters, or groups of parameters; moreover, if the model is used for simulation and/or forecasting, any one of its performances may likewise be validated on the basis of specific tests[1].

The central role of statistical validation in econometric work deserves to be emphasised in a particular way. In fact, statistical tests should be the main instrument for guiding the quality of econometric models in all phases of the modelling work: specification of the model, estimation, hypotheses testing, and simulation. It should, however, be emphasised that, in many of the econometric studies applied to agricultural policies, statistical verification of the models and interpretation of the results in the light of the tests becomes less important than the attempt to build a model which is coherent with the problem concerned. This approach may to some extent be justified by the fact that the phase of model specification expresses most clearly the creative effort of the researcher who, at the time of the empirical application, tends to attribute a merely illustrative value to the results, without worrying too much about their statistical reliability. It is also true that any statistical poverty of the results is not necessarily connected with an erroneous specification of the model, but may depend, for example, on the poor quality of the available data, a significant problem in many studies. Although these limitations may have some justification, they tend to impoverish the contribution of econometric models to agricultural policy analyses, since their specific merit lies precisely in the possibility of statistical validation.

2.2 Types of models, estimation methods and statistical tests

The aim of this section is to give an idea of the econometric techniques most frequently used in studies of agricultural policy. For reasons of space, it is obviously not possible to go into all the details concerning each estimation method (theoretical hypotheses, problems of application, limitations, etc…), but, more simply, we shall attempt to provide a minimum of technical terminology that will enable the reader to grasp the methodological references made in the following sections. In fact, it is important to note that all the methods described constitute a

1 Even in the case of non-parametric techniques for the study of certain economic relationships, statistical validation of the models is always possible (See, for example, Varian, 1984 and 1985).

standard set of instruments and for further information reference may be made to any modern text on econometrics.

If we had to classify the various classes of econometric models used for agricultural policy analyses from a technical viewpoint, this would almost inevitably lead to the classic distinction between structural models based on single equations, structural models based on multiple equations and non structural models. This is, of course, an arbitrary and in some ways incomplete classification, yet it does provide a preliminary grid for interpretation.

In *structural models based on single equations*, a single variable under study is analysed by means of a relationship (linear or non-linear) with a certain number of explanatory variables; the statistical formulation implies the addition of a term of error (also known as a "residual"), that represents the differences between the estimated values of the dependent variable and those observed in the sample. The specification of the model, and thus choice of the explanatory variables and their relationships, generally refers to what is foreseen by economic theory regarding such a relationship. A similar procedure defines whether, and if so in what way, the model should have a *static* structure (the explanatory variables explain the level of the dependent variable only in the same time interval) or a *dynamic one* (the dependent variable may be influenced by the level of the explanatory variables in different time intervals, as well as by the lagged values of the same dependent variable)[2]. In certain cases, however, the link between the specification of the model and economic theory may not be limited to the choice of the explanatory variables alone, but even for a simple model based on a single equation, it may be the result of a formal derivation, that refers to a precise hypothesis on the behaviour of the economic agents: this is the case, for example, with the dynamic models on the supply of agricultural products, described briefly in the next section.

As far as estimation methods and relative tests are concerned, the single equation models in agricultural policy analyses make use of the instruments of classic econometrics, starting from the *ordinary least squares* method and the associated statistics (the R^2 for evaluating the goodness of fit, the t test for the significance of the parameters, and the F test for the tests on groups of parameters), a method which may be generalised in the presence of serial correlation of the residuals (a typical problem of the use of time series) or heteroskedasticity (typical of the use of cross-sectional data). In the case of non-linear estimates, the estimation methods and tests become more complex: those most widely used are the *non-linear least squares* and the *maximum likelihood*, that require iterative procedures to reach a solution[3].

The *structural models based on multiple equations* are by far the most common econometric instruments for agricultural policy analyses. In this case, the evolution of a group of endogenous variables is studied on the basis of the evolution of a certain number of explanatory variables, that may be interrelated in various ways, through more than one equation. The reasons for the success of these models are due to various factors: the first, and most obvious, is their ability to study several variables of interest for a given problem in agricultural policy at the same time (supply of several agricultural products, demand for several factors of production, demand and supply of one or more products…), with the aim of studying the cross effects of a given policy. But probably the most important factor is the fact that recent developments in the theory of the firm has made it possible to specify certain fundamental relationships among economic variables in the form of systems of simultaneous equations, so becoming the most natural econometric model for an empirical analysis. The classic example is the specification of systems of equations of supply of agricultural outputs and of demand for inputs, starting from the hypothesis of optimising behaviour of the firm (profit

[2] In this context, the definition of dynamic model refers exclusively to its stochastic structure (Davidson and MacKinnon, page 146). The dynamic economic models applied to agricultural policy analyses, in which a process of intertemporal optimisation is hypothesised, are instead briefly discussed in section 3.3.

[3] For an introduction to single-equation econometric models, see, for example, Pindyck and Rubinfeld (1992, chaps. 4-6); for a more in-depth explanation, reference can be made to Davidson and MacKinnon (1993), for analysis of the method of linear and non-linear least squares (chaps. 1-5), for analysis of the maximum likelihood (chaps. 8 and 9) and for analysis of the problems of serial correlation and heteroskedasticity (chaps. 10 and 16), respectively.

maximisation, cost minimisation,…), that represent by far the most widely used model in the literature in question, which will be discussed in the next section.

From the point of view of the estimation methods, the models based on several equations present a wide range of possibilities. Under very special conditions (equations linear in parameters; absence of cross equation restrictions; absence of correlation among residuals of different equations) it is possible to estimate each equation of the system separately using the method of ordinary least squares, then referring to the same tests and the same possible generalisations as those used for the single-equation methods. In practice, in a large part of the studies on agricultural policy, this solution is only rarely applicable, so that the systems of equations are normally estimated simultaneously using ad hoc methods. If the model is linear in its parameters and non-simultaneous (with each dependent variable specified only on the basis of exogenous variables, which may or may not be common to one or more equations) the method of estimation most used is the so-called SUR method (*Seemingly Unrelated Regressions*), that is a generalisation of the method of least squares, taking explicitly into account the correlation among the residuals of the estimated equations. If the system is linear and simultaneous (the level of one or more endogenous variable may depend on the level of another endogenous variable), it is necessary to resort to the so-called 3SLS method (*Three-stage Least Squares).* This method is an application of the more general one known as the "*instrumental variable technique*", that deals, both at the level of single equations and of systems, with one of the cases in which the fundamental assumptions of least squares, and their generalisations, does not hold: when one or more explanatory variables is correlated with the error term. This problem is particularly important in the case of simultaneous systems, where the endogenous explanatory variable is, by definition, correlated with the error term.

Both of these methods may be considered instruments which refer to the fundamental criterion of least squares, with the appropriate generalisations and/or corrections. However, it is also possible to adopt estimation methods that refer to other principles, the best known and most used of these is *maximum likelihood*. The maximum likelihood estimator carries a whole series of properties (especially asymptotic properties, i.e. referring to sufficiently large samples) that enable it to work on a much wider range of models than the least squares method, even if it becomes necessary to assume a specific distribution for the error term. In the case of systems of linear equations, the maximum likelihood estimates are indicated as FIML (*Full Information Maximum Likelihood*).

If, finally, the model is not linear in its parameters, it is possible to estimate it by using the non-linear generalisations of the three methods referred to earlier (SUR, 3SLS and FIML), of course applied in the same conditions, and under the same hypotheses, for which it is possible to use the corresponding linear versions; in these cases, as in the non-linear single-equation models, the models require iterative procedures in order to get a solution.

The application of these methods implies a whole series of statistical hypotheses with relative tests. Besides the typical statistics of the single equations (R^2, t test), the specification of the model, and, in particular, any parametric restrictions, can be tested through the so-called *classic tests* (Likelihood ratio test; Lagrange multiplier test; Wald test), that can be applied both in a context of least squares and of maximum likelihood. Finally, to test the specific problem of the endogeneity/exogeneity of the variables, and thus the simultaneity of the system of equations, one can use the “Hausman test”[5].

The third and last type may be classified under the general term of *non-structural models*. This group comprises widely diverse models, but all characterised by the absence of any prior hypothesis on the economic relationship linking the variable being studied, which is instead the basis for the two previous classes of models. The usefulness of these models is based first of all on

[5] For a study of the structural models of simultaneous equations reference can be made, for an introduction to the subject, to the volume by Pindyck and Rubinfeld (1992, chaps. 11-12); while for a more in-depth explanation, see instead the manual by Davidson and Mackinnon (1993), both for an explanation of the methods of estimation (chap. 18) and for a description and interpretation of the associated statistical tests (chaps. 11-13).

the fact that their development is closely related to research on simulation and forecasting, which is very important also for agricultural policy studies.

The general hypothesis underlying these models is that, when the specification suggested by economic theory is too complex, or uncertain, it is possible to reverse the conventional approach and, instead of imposing a structure on the data, allow the data to suggest an interpretative structure itself. As regards non-structural models we can refer to the vast literature on the analysis of time series, where the evolution in time of a variable is classically interpreted on the basis of the past behaviour of that same variable, and possibly other connected variables; the information obtained is used for simulation and/or forecasting.

In this branch of the literature too, models may be based on one or more equation. Among the simplest ones, we could mention the univariate ARIMA models that are still being widely used for the forecasting of a large number of economic variables, such as the prices of many agricultural and food products[6]. In these models the time series of the variable studied, once it has been made stationary by differentiation of an appropriate degree, is interpreted in the light of its autoregressive and/or moving average components. The literature on time series has grown dramatically following the first studies on the so-called "cointegration" between time series, an instrument that, through the study of the characteristics of two or more time series, and, in particular, the possibility of combining them to obtain stationary series, permits verification of the existence of long-term relationships between the economic variables in question, and has therefore become very important, not only for forecasting, but also for dealing with theoretical problems.

Among the multi-equational models, we could mention the VARs (*Vector Autoregressions)*, given their success in recent years in terms of empirical applications. The VARs are systems of equations in which the value of each variable is explained by a linear relationship with the lagged values of that same variable and of all the other variables belonging to the same system; this approach makes it possible to estimate the dynamic relationship between the variables without imposing a priori restrictions. In fact, the researcher has only to choose the variables to be included in the system, without even specifying which ones are exogenous and which endogenous, and the maximum number of lags that can be taken into consideration. This choice is decisive, since it determines the number of parameters to be estimated; this increases considerably as the number of lags increases, which is one of the biggest problems with this type of model. The popularity of the VARs is due to their simplicity (the most elementary systems may be estimated equation by equation, using the method of least squares) and to their possible extension to the study of co-integrated variables in a context of maximum likelihood estimation.

Despite the great success enjoyed by this class of models in empirical applications in dealing with many economic problems, their use in agricultural policy analyses, and, more generally, in econometric studies applied to the agricultural sector, has been very limited. As far as studies in agricultural policies are concerned, one possible explanation may be that, as will be seen later, the nature of the agricultural policy instruments is such as to produce quite precise distortions in the market mechanisms, thus making an approach of structural type more natural. Time series models are not, however, completely absent from this literature: they are most frequently used to support structural econometric models. For example, it is fairly common to use the ARIMA models to simulate the formation of price expectations by agricultural producers, incorporating the estimated values, instead of those observed, as explanatory variables of the behaviour of these economic agents[7].

Concluding this brief and rather incomplete overview of the classes of models used in agricultural policy analyses, it should be underlined that, in the majority of the econometric studies which will be considered in the subsequent sections, the estimation methods and relative tests do

[6] For a review of the Italian works that have used these techniques, see the paper by Zezza (1993).
[7] The literature on analysis of time series is vast. For a short introduction to the ARIMA models, the reader is referred to the volume by Pindyck and Rubinfeld (1992, chaps. 19-20). An excellent guide text for empirical applications is that of Enders (1995).

not depend on the choices made for analysing agricultural policy instruments. For this reason, in the following discussion, the strictly econometric aspects will tend to be neglected, except in those cases where the choice of the estimation technique depends directly on the agricultural policy problem being addressed.

2.3 Basic data

In order to carry out estimations all the econometric models employed in agricultural policy analyses use a data base that is normally constructed ad hoc for that specific exercise and is usually the result of the assembling of information from various statistical sources. Generally the data used relates to agricultural production, the factors of production employed (fixed and variable), the prices of outputs and inputs and in addition, in the case of studies that also consider the international trade dimension, to the volumes of imports/exports and their relative prices. The data base is normally completed by a series of different kinds of information on the exogenous variables of agricultural and trade policy (minimum guaranteed prices, production subsidies, direct payments, measures of supply control, import tariffs, export subsidies, environmental policies and so on).

Despite the specificity characterising the data bases used in the various studies, it is nevertheless possible to distinguish at least two main types of information: aggregate information and that referring to the single decision-taking units.

The *aggregate* data usually comes from official statistical sources and consist of time series, normally annual, referring to large territorial aggregates (the European Union, an individual member country, one or more regions within a given country), for which the total values for flow and/or stock variables are recorded (productions, volume of exchanges, variable inputs, endowment in fixed inputs, etc…) and some form of average values (or indices) as regards prices. A large part of the econometric studies on agricultural policy, and more generally those applied to the agricultural sector, were initially developed on this type of data, for essentially practical reasons, in particular because of their availability and because of the limited number of observations, guaranteeing reasonable computing times even for complex econometric treatment. However, this data, that is still being used, has an evident defect in its level of aggregation, especially when the econometric treatment is based on theoretical hypotheses on the behaviour of individual economic agents. It is clear, for example, that use of this type of data for the estimation of equations deriving from the hypothesis of optimising behaviour of farmers obliges the researcher to assume that the information referring, for example, to an entire country may be assimilated to that from a single enterprise. This type of assumption imposes severe restrictions on the basic economic hypotheses (Chambers, 1988), making the results less reliable.

The data referring to *individual* units come from sample surveys that, for the agricultural sector, typically focus on agricultural firms. The most typical example of these surveys, at least for the European experience, is the FADN (Farm Accounting Data Network), an inquiry that, as is known, is carried out using similar procedures, even if still not perfectly standardised, in all the EU countries, by means of which information is collected regarding farms, their structures and economic results. There are also some examples of ad hoc surveys, carried out on farms, treating different specific aspects in depth (characteristics of the family, consumption, labour, etc…).

In the econometric literature dealing with the problems of agricultural policy we find a growing use of this second type of data, for a number of reasons. First of all, the data deriving from these surveys has become increasingly reliable and available in a form that is easy to handle for econometric purposes, even if a certain amount of re-organisation is required[8]. Secondly, the main

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[8] The transformations required for the econometric use of FADN data are different. First of all, it is normal that, starting off from the extremely disaggregated level of information, the researcher is forcedto aggregate the elementary data, for example to establish categories of input and output, in order to get an estimate; the criteria which guide this operation usually depend on the objectives of the study and on the number of available observations. This operation of

technical problems connected with the use of this data, and, in particular, the need to work with a very large number of observations, can now be overcome thanks to the impressive increase in the calculating power of the personal computers. Further, from a theoretical point of view, this data is preferable to aggregate data, especially for the estimation of models based on the theory of the firm that, as mentioned earlier, are widely used. A final reason is closely connected with the evolution of agricultural policy instruments that, as is known, are becoming more and more diversified, or at least differentiated in different parts of the same country and/or different groups of farms (think for example to the differentiated direct subsidies introduced with the reform of the CAP in 1992 for arable crops and for beef). Thus, the econometric use of aggregate data is not very meaningful, since the fact that the agricultural policy instruments are differentiated in the way just described, obviously implies differentiated answers by different decision-taking units.

However that is not the only problem with the use of this data. One problem is the way the FADN survey, which is by far the most widely used for studies on the CAP, is set up, since the sample of enterprises is neither random nor statistically representative, so that the estimates obtained are skewed. In addition, the FADN sample is "unbalanced", that is it does not consist of the same farms every year. These problems of sample composition are well known to all those involved in this work, but in general there is a tendency to underestimate their importance. Moreover, the increasing use of FADN data for forecasting studies related to the agricultural sector, should enhance the debate on the methodology of sample design.

Also with reference to the information collected from each firm, the FADN data base suffers from serious shortcomings when used for econometric studies; the most important is the lack of information on variable input prices, a key element for studying production relationships within the firm (output supply and/or input demand).

In addition, the use of this data poses new problems for their econometric treatment. The first problem is that of using techniques which take farm heterogeneity into account. In the framework of the traditional methods of estimation (least squares or maximum likelihood), this problem has been usually dealt with by means of what is called the *fixed effects* approach or by means of the parallel *random effects* approach. In both these cases, the basic hypothesis is that, in the equations of the model, farm heterogeneity is represented by a single parameter, that in the first case modifies simply the intercept of the equations of the model, while in the second it is the outcome of a given probability distribution. In the agricultural policy literature, this is the most common approach, in particular the *fixed effect* version, which has the advantage of simplicity, even though it is clear that the hypothesis that the other parameters are common to all the farms in the sample remains quite strong. Recently, a class of estimation methods was proposed that makes it possible to fully account for farm heterogeneity, through estimating the expected value of all the parameters of the model and their probability distribution, even with a very limited number of observations; these methodologies belong to the class of *Generalised Maximum Entropy* estimates, the principles of which are illustrated in the work by Oude Lansink (1999b).

The second important problem connected with the use of farm data relates to the treatment of so-called "corner solutions", that is those cases in which the equilibrium solution concerning certain endogenous variables is nil, and does not change even when we register significant variations in the explanatory variables. This problem, that in theory may occur with any type of data, is particularly important with data collected from individual decision-taking units. A typical example is that in which farmers choose not to produce a given good or not to use a given input, even though relative prices change significantly. The econometric treatment of this type of corner solutions was debated very recently (Arias and Perali, 1999; Shonkwiler and Yen, 1999), but the complexity of this issue is outside the scope of this review. In general, in agricultural policy studies published to date, the problem has been dealt with by using traditional technical solutions aimed at minimising distortions.

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aggregation takes the form of calculation of special indices, both for prices and for quantities, in which particular attention should be paid to the homogeneity of the unit of measurement and of the base period.

Despite these problems, there is clearly a general tendency towards the increasing use of data on individual decision-taking units, since it ensures greater adherence to the reality of the economic mechanisms connected with the use of agricultural policy instruments.

2.4 Use of the results

Bearing in mind that agricultural policy analyses aim to simulate scenarios of change in the level of the instruments and/or in their type, we can distinguish two types of approach for the use of the results of econometric models. The first, and in some ways the most natural one, is that of using the estimated model itself for making ad hoc simulations. In this case, the simulation exercise generally requires the formulation of hypotheses on the evolution of the whole series of independent variables, that will consist not only of the instruments of agricultural and/or trade policy, but also, in almost all models, of the price levels[7].

This approach has the obvious advantage of reproducing, in the simulated scenarios, the same structure as the model, and thus the same hypotheses on the behaviour of the variables involved, as well as that of using parameters which have been statistically validated within that same structure. Often, however, the complexity of building a model of this type obliges the researcher to concentrate exclusively on certain aspects of the functioning of the agricultural policy instruments, considering as exogenous a whole series of variables that, in reality, are likewise conditional on changes in agricultural policy or changes in the general economic scenario. Think, for example, of agricultural prices that in many econometric models are considered as exogenous, even though their evolution is obviously the result of a market equilibrium affected by a very large number of variables. The results of economic simulations may accordingly suffer from oversimplification, so that their reliability depends too much on the hypotheses concerning the exogenous variables.

For this reason, the results of the models, and in particular the estimated parameters (for example elasticity values), are often used as inputs for other models, with a different structure. In fact, we have only to glance through the other chapters in this volume to realise that the other classes of models used in agricultural policy analyses, having a minimum or even no econometric component, utilise values derived from the econometric literature as exogenous parameters that describe the fundamental relationships of the model. This way of using the results has serious shortcomings since, by definition, any estimated value of a given parameter depends both on the structure of the model that generated it, and thus on the underlying hypotheses on the behaviour of the economic agents, and on the data the estimate was based on. These shortcomings become particularly significant when the model using the results of the econometric work is based on hypotheses not consistent with those of the model which generated the parameters (for example, when short run elasticities are used in models referring to the long run). For these reasons, we should be extremely cautious when using the results of econometric literature as input for other models and, in general, should contribute to providing an interval of "reasonable" values for the parameter in question, based on one or more available estimate. This interval may be used both for sensitivity analysis of the results of the model with respect to the value of the parameter, and as a rough indication for deriving the numerical value to be imposed exogenously.

3. Classification of models analysed

3.1 Economic modelling of agricultural production: the Nerlovian models

[7] This approach, while widely used, is vulnerable to the well known “Lucas critique” (1976), that raises doubts on the reliability of the structural parameters estimated on the basis of the past evolution of the variables for simulating future changes in economic policy.

Any analysis of the econometric models used for agricultural policy can be reduced to analysing the evolution of the modelling of agricultural production. In fact, the majority of econometric models that, either directly or indirectly, have analysed the impact of agricultural policy, aim to answer a basic question, that is to evaluate the impact of these instruments on farmers' production decisions, a question which leads to others (effects on prices and on social welfare, impact on government spending, on employment, on the environment, etc…). The basic model must accordingly be referred to production decisions even if, clearly, researchers should be aware that, by focusing attention exclusively on the supply side, there is a danger of neglecting a whole class of extremely important effects of agricultural policies, that act on the demand side and that, as will be seen later, are taken into consideration only in a few very complex models.

Initially, the problem of modelling agricultural production was simplified to the specification of an econometric relationship (linear or non-linear regression) between a dependent variable under study (for example, the supply of a product or the demand for a factor of production) and a series of explanatory variables chosen by the researcher, which may have included agricultural policy instruments. However, after having observed certain peculiarities in farmers' production decisions, for example, the time lag between the moment when the fundamental production decisions are taken (land allocation, number of livestock) and the moment when productions are realised, the econometric models related to agricultural production became more sophisticated, being based on a more precise hypothesis on the behaviour of the economic agents.

A classic example in this field is the supply models. The original supply models of agricultural products were found in the studies of Nerlove (1956), the first author to formulate a dynamic hypothesis on the price expectations of farmers[10]. In particular, we owe to Nerlove the hypothesis of "adaptive" expectations in which the "naive" price forecast, where the expected price is equal to that observed in the previous period, is corrected from period to period to take account of the shifts between this forecast and the price actually observed in the subsequent period. A supply model consistent with this approach uses as key explanatory variables the normalised lagged prices and the supply level lagged one period, which can be shown to be the element that "captures" the above-mentioned process of adjustment. For example, the simplest model could be the following:

$$(1) \qquad y_{i,t} = \boldsymbol{a}_i + \boldsymbol{b}_i y_{i,t-1} + \boldsymbol{g}_i \frac{p_{i,t-1}}{p_{j,t-1}}$$

where p_i is the price of the product in question, y_i the quantity supplied, p_j the price used as deflator and t the time interval in which the variables are measured; the model may be further refined with the addition of other explanatory variables. From the point of view of econometric estimation, this type of model can be estimated using the method of least squares and does not give rise to any particular problems, apart from those connected with the presence of the lagged dependent variable; this calls for particular caution, especially as regards the tests for the serial correlation of the residuals (Pindyck and Rubinfeld, 1992, chap. 6).

The variants of Nerlovian models continue to be an important instrument for agricultural policy analyses, even if their potential is limited to the simulation of the effects of variations in institutional prices, assuming that these are transmitted perfectly to market prices. An example of this is found in the work of Moro (1991) on the Italian livestock sector, where the effects of a reduction in the market price of milk are simulated as a hypothetical alternative to the application of quotas[11]. Lianos and Katranidis (1993) use the version of the Nerlovian model that combines

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[10] In this case too the adjective 'dynamic' is used because the Nerlovian models are of dynamic-recursive type, since they account for a process of temporal adjustment. However, this does not imply intertemporal optimisation in the decisions taken by economic agents.

[11] The work of Moro (1991) is among the few, together with the MEISA model (Caiumi, 1997), to provide some statistics that, on the basis of estimates of the parameters obtained by using the first part of the available time series, compare the simulations on the last years of the sample with the data actually observed, thus making it possible to

"naive" expectations and partial adjustment of investments to model the beef sector in Greece[12], while Albiac and Garcia (1992) use a similar model to assess the impact of Spain's entry into the EU on the live pig market. The work of Cavailhès and Degoud (1995) uses a Nerlovian type of model to evaluate the elasticity of the price of land with respect to the prices of products and factors of production, before and after the MacSharry reform that, as is generally recognised, had important effects on the land market (Sorrentino, 1995)[13].

Finally Nerlovian models have had an important influence on the more complex ones, described in the following sections, in which, despite the more sophisticated level of the basic hypotheses and the structure of the models, it is still necessary to deal with the problem of the mechanisms of expectation formation concerning output prices. In the studies of the 1980s, the most frequent solution is that of introducing explicitly a hypothesis of *adaptive expectations*, which was translated by a more or less complex structure incorporating the information contained in past prices (see, for example, the literature quoted by Moschini, 1988). More recently, the hypothesis of *rational expectations* has become increasingly popular; this assumes that the expected price coincides with the expected value of the probability distribution that the economic agents are capable of constructing for that variable, given all the information available at the time the forecast is made. The reason for its popularity is due to the fact that its empirical application is relatively easy, since it is merely a question of replacing the observed prices with forecasts obtained from a time series model, selected on the basis of adherence to the specific data. According to the hypothesis of rational expectations, these results constitute the best forecast that agents can make in each time interval considered. For example, Moschini (1988) and Fulginiti and Perrin (1993) use an ARIMA model, while Oude Lansink and Peerlings (1996 and 1997) and Oude Lansink (1999b) use a simpler autoregressive AR model.

3.2 Modelling agricultural production: the dual approach

3.2.1 The profit function

If Nerlovian models have given rise to a rich literature on the supply of agricultural products, the econometric modelling of agricultural production has made impressive progress with the development of the "dual approach" to the theory of production[14]. The basic idea of this approach is that the characteristics of the production technology, represented, for example, by a "primal" production function, that relates outputs and inputs, can be analysed by means of its "dual" functions, which define the optimising behaviour of the economic agents (maximum profit, minimum cost of production,…), functions that, once specified by means of ad hoc functional forms, can be estimated econometrically.

It is obviously not possible here to review the theory underlying this type of models, so that the reader is referred to the text by Chambers (1988) and to the literature quoted in it. For the analysis developed here, it is, however, important to bear in mind the fundamental characteristics of

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measure the deviation of the simulation results from the real data and to evaluate the statistical quality of the model. The vast majority of the works analysed in this chapter do not take this aspect into account.

[12] Nerlove himself (1958) demonstrated that the model in (1) is consistent with the hypotheses of "naive" expectations and partial adjustment of investments, even if this affects the stochastic structure of the term of error.

[13] For a review of the Italian works that used this approach in the 1980s, see Zezza (1993).

[14] It is important to underline that, here, the adjective "dual" is used in a different way from the mathematical programming models, presented in another chapter of this volume, even if the basic concept is similar. In fact, in that context, the adjective ‘dual’ refers to the possibility of representing the same optimisation problem as a maximisation or minimisation, by modifying the objective function and the constraints.

the standard model of profit maximisation[15]. This theory hypothesises that, in the short term, agricultural producers aim to maximise profits from a convex set of production possibilities T:

$$(2) \qquad \pi(p, w, z) \equiv \max_{y,x}\left\{ py - wx \mid (x, y, z) \in T \right\}$$

where y and x are the vectors of the quantities of outputs and variable inputs, p and w are the corresponding price vectors (assumed to be exogenous) and z is the vector of the quantities of quasi-fixed inputs in the short run (family labour, land, capital,…). The profit function $\pi(.)$ carries some important properties: it is continuous, not negative, not decreasing in p and not increasing in w, homogenous of degree one and convex in (p,w). By applying the Hotelling lemma, it is possible to derive, by simple differentiation, the output supply and the input demand functions:

$$(3) \qquad \begin{aligned} y_i(p, w, z) &= \partial\pi(p, w, z)/\partial p_i \qquad i = 1,...,n \\ x_j(p, w, z) &= -\partial\pi(p, w, z)/\partial w_j \qquad j = 1,...,m \end{aligned}$$

while, by extending the assumption in question to the case of fixed inputs, it is possible to obtain the functions of the shadow prices v of these same inputs:

$$(4) \qquad v_h(p, w, z) = \partial\pi(p, w, z)/\partial z_h \qquad h = 1,...,l$$

This basic model was then modified in various ways to take account of a series of factors affecting the problem of profit maximisation. For example, in all the studies in which an econometric estimation is carried out on a sufficiently long time series (both on individual data and to aggregated data), it is necessary to take account of technological change over time, a phenomenon normally approximated by the introduction of a trend variable in the vector of fixed inputs z.

For the purposes of this work, however, the most important changes are those that deal with agricultural policy instruments. In fact, the standard model has been modified to account for production quotas (Moschini, 1988 and 1989, Fulginiti and Perrin, 1993), the quota market (Boots et al, 1997), land allocation choices (Chambers and Just, 1989; Ball et al, 1997) and their relationship with direct payments linked to land (Guyomard et al, 1996b; Oude Lansink and Peerlings, 1996), price and yield uncertainty (Coyle, 1992 and 1999) and expectation formation based on a minimum guaranteed price (Chavas and Holt, 1990), as well as the production of negative externalities due to agricultural activity (Oude Lansink and Peerlings, 1997). As will be discussed in greater detail in the next section it is precisely on the basis of these extensions that the main studies analysing the effects of the CAP have been developed.

3.2.2 The problem of functional forms

The econometric estimation of the model of profit maximisation requires the solution of a whole series of problems. The first is that of the choice of a functional form for the profit function, a decisive choice that will inevitably condition the results obtained, for which it is implicitly assumed that the functional form chosen is "correct". The class of functional forms within which this choice is made is called "flexible functional forms", that is those specifications that have a sufficient number of parameters to describe the number of independent effects foreseen by the theory[16]. In the case of the profit function

[15] The choice of presenting the profit function derives solely from the fact that this is the one most widely used in studies of agricultural policy; other functions describing the optimising behaviour of the enterprise, such as the cost function, may be defined in a similar way.

[16] The number of parameters of a given functional form must always be equal, at least, to the number of separate effects to be measured. For example, for estimating a long-term profit function (without fixed inputs) with a total of n outputs

illustrated before, these requirements are met by those functional forms that constitute a second order differential approximation (second order Taylor expansion) of an arbitrary function (Chambers, 1988).

An extremely rich literature has developed on the selection criteria of flexible functional forms, proposing various techniques. One is, for example, to specify a very general functional form, embodying a series of alternative functional forms as special cases; these are usually characterised by a smaller number of parameters, that can be tested more easily using the classic statistical tests. Other criteria imply the use of the so-called *non-nested* tests, that is tests not based, like the previous ones, on parametric restrictions imposed on the more general models, but on direct comparison between the functional forms considered (Davidson and MacKinnon, 1993), or simple comparison of the statistical performances of the models, like the *likelihood dominance criterion* proposed by Pollak and Wales (1991). In addition to these more strictly statistical procedures, ad hoc approaches are of course possible; these may range from simply noting the plausibility of results, to verifying the restrictions imposed by the theory.

It is important to underline the fact that in the studies applied to problems of agricultural policy even such a decisive choice as that concerning the functional form is hardly ever made by following one of the statistical procedures indicated above: the choice is generally made, instead, from ad hoc considerations, in particular those on the plausibility of results, and very often it is not even justified. However, among the criteria taken into consideration, an important role is played by the possibility of imposing in an easy and coherent way the standard restrictions of production theory (homogeneity of prices, symmetry, additivity,…), and, in particular, convexity in prices, that implies inequality restrictions[17]. In addition, it is important to take account of the type of data utilised for the estimates, especially the presence of nil or negative values in the variables employed.

Among the flexible functional forms most used in studies of agricultural policy it is important to mention the translogarithmic and the normalised quadratic ones[18]. Both these meet the requirements mentioned earlier and, from their specification, it is possible to derive a system of equations of output supply and input demand which is linear in its explanatory variables (logarithms of prices and fixed inputs for the former, and normalised prices and fixed inputs for the latter, respectively), in line with the relationships in (3). However, there are important differences between the two. For example, in the translogarithmic form it is not possible to impose convexity in prices at all points of the sample, but only locally, at a given point of interest for the researcher; moreover, working on the logarithms of the variables, it is not possible to treat negative or nil values. For these reasons, use of the translogarithmic form is mainly limited to those applications where it is not necessary to impose convexity on prices, since it is naturally verified by the data available, and where negative or nil values are not relevant. As discussed in the previous section, the latter condition generally occurs in aggregate data, not in individual data, where it is normal, for example, for a farm not to produce a certain good or not to utilise a given input (either fixed or variable).

In the normalised quadratic functional form, on the other hand, these two problems can be dealt with easily; accordingly, this has become the most natural reference for studies on farm data. The problem of the normalised quadratic form is the dependence of the estimates on the choice of the "numeraire", that is to say the price that is used to normalise all the others and to impose the

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and inputs, we will need, as a first approximation, 1 parameter defining the level of profit, n parameters defining the level of n functions of supply/demand and n^2 parameters defining the direct and cross effects related to their respective prices, for a total of $(1+n+n^2)$ parameters. If, however, the function is continuous and differentiable, the matrix of the cross effect will be symmetrical, so that one has to consider only the n elements of the diagonal and the $n(n-1)/2$ elements of the low or high triangle, bringing the total of the necessary parameters to $(n+1)(n+2)/2$. Further restrictions imposed by this theory (for example, homogeneity in prices) may further reduce the number of parameters.

[17] The solution of the problem concerning the imposition of the property of convexity in prices in the flexible functional forms is from the works of Lau (1978) and Diewert and Wales (1987 and 1988), even if, in the last few years, many specific papers have appeared.

[18] The properties of the different functional forms are discussed at length in the specific literature; as far as the two aforementioned ones are concerned, reference should be made to the work of Diewert and Wales (1987).

property of homogeneity. To overcome this problem, a "symmetric" version of the normalised quadratic form was recently proposed (Kohli, 1993), in which the normalisation of prices is imposed using a price index rather than a single price, thus reducing the distortion produced by the arbitrary choice of the "numeraire".

3.2.3 Estimates and results

In terms of estimation methods, any system of equations derived from the relationships in (3) can be easily estimated, using any functional form, with the variants of the SUR method, since, in the standard version, no endogenous variable appears on the right hand side. However, as will be clearly seen in the next section, it is true that in certain variants of the problems and with certain functional forms, estimation of the system of supply/demand functions does not permit recovery of all the parameters of the profit function, so it becomes necessary to estimate the latter together with the system of supply/demand. Moreover, other variants of the problem require the use of methods that include instrumental variables (for example 3SLS), because the system to be estimated includes certain endogenous variables among the explanatory variables.

However, the most important problem to be overcome is not the estimation method, but rather the level of disaggregation which the analysis has to be carried out at and its level of generality in terms of the agricultural products under study. In fact, agricultural policy instruments are extremely specific and, in order for the empirical analysis to produce reliable results, one always needs to have a considerable amount of detail. There is no point in limiting the analysis to a generic "cereals" aggregate if, for example, the level of institutional prices, or that of direct payments, is different for soft wheat, durum wheat, maize and the other cereals. From a theoretical point of view, this would not constitute a problem, since it is possible to estimate a system with an arbitrarily large number of equations of supply/demand. However, in practice the number of parameters to be estimated would increase enormously, making the estimation almost impossible in those cases in which the number of available observations is limited (for example, in estimates on aggregate data), making it in any case extremely complex and/or inefficient also in those cases in which the number of observations does not constitute a problem (for example, in applications utilising farm data).

There are two possible approaches to this problem. The first, and the one applied most frequently, is to concentrate the analysis on the few outputs/inputs of interest, aggregating the others in large residual categories; this may imply a very limited error, especially when working on selected data, for example a sample of specialised farms. What this obviously lacks is the generality of the analysis, which is reduced by the unrepresentative nature of the sample or, alternatively, by the underestimation of the cross effects which, being referred to large aggregates of "other" outputs or inputs, are not very meaningful.

A second approach, typical of those models providing a description of the entire agricultural sector, is to impose restrictions on technology, possibly after testing them statistically, restrictions that make it possible to reduce the number of parameters to be estimated. Among the hypotheses most utilised we could mention both "nonjointness" and "separability"[19]. This, for example, is the basic hypothesis of the MEISA.2 model (Caiumi, 1997) and of ESMERALDA (Jensen, 1996), where the hypothesis of separability makes it possible to estimate the model of profit maximisation in two stages: a first stage in which the equations on large aggregates of outputs/inputs are estimated in relation to the corresponding aggregate price indexes, as well as the level of fixed inputs, and a second stage where the details of the supply/demand of the individual components for each aggregate are considered.

Finally, it would be useful to discuss the type of results obtainable from these estimates and their utilisation in agricultural policy analyses. The most typical output of these models consists of the values of elasticity of output supply and input demand, that is referred not only to their

[19] For an analysis of the possible restrictions on production technology, in the various definitions and implications including econometric ones, refer to the text by Chambers (1988) and to the relative bibliography.

respective prices, but also to the prices of all the other outputs/inputs considered, to the fixed inputs (including the technological trend) and, once the model has been modified to take them into account, to the level of certain agricultural policy instruments (quotas, direct subsidies, etc.). The great advantage of these models is their ability to assess all the possible cross effects of the different production sectors, for example, from variations in the level of the agricultural policy instruments of a single sector, as well as the possibility of referring the values of elasticity to different points of the sample considered - groups of different farms (in the case of longitudinal data) or different time intervals (in the case of aggregate time series).

Problems may arise, however, when one tries to use the model of profit maximisation for simulation exercises. As is clear from the structure presented before, besides the exogenous hypotheses on any agricultural policy instruments modelled, each simulation exercise implies the imposition of exogenous values for the other explanatory variables as well: fixed inputs and the prices of inputs and outputs. This is the approach utilised in the vast majority of the studies discussed in this work, but it has the evident limitation of considering one of the key aspects of agricultural policy as exogenous: the impact on the equilibrium output and input prices.

A coherent extension of the model of profit maximisation that permits the endogenous determination of prices requires an equally careful modelling of the demand side and a reliable hypotheses on the mechanisms of price transmission. Moreover, if one works on farm data, this would be further complicated by the operations needed to extend the sample data to the corresponding population (Oude Lansink, 1999c; Oude Lansink and Peerlings, 2000) [21]. Among the examples of models that have attempted this complex extension, mention should be made of the MEISA, in its different versions (Rossi, 1988, Caiumi, 1997), even if, as will be seen in the next section, this model is based on extremely simplified hypotheses concerning the modelling of agricultural policy instruments, highlighting the *trade-off* between the different characteristics of the model.

3.3 Extensions of the dual approach to the theory of production

In the 1990s a number of important extensions of the dual approach to the theory of production were proposed, that have had (or are likely to have) important spillovers for the analysis of the effects of agricultural policy instruments.

The most important extension is the one which accounts explicitly for the risk aversion by producers (the standard model in (2) implicitly assumes risk neutrality); this extension, with reference to agricultural production, is from Coyle (1992). In the model in question, agricultural producers maximise an expected utility function of the *"mean variance"* type, where, compared to the more general case, it is assumed that the coefficient of risk aversion of producers is constant *(CARA = Constant Absolute Risk Aversion)* and that profits are distributed normally. In this case, the expected utility function takes the form:

$$(5) \qquad U(p^e, w, z, V_p) \equiv \max_{y,x} \left\{ p^e y - w x - (\alpha/2) y^T V_p y \;\middle|\; (x, y, z) \in T \right\}$$

where, compared to the standard notation, p^e are the expected output prices (the only stochastic variable) α is the risk aversion coefficient and V_p is the variance-covariance matrix of output prices. Coyle (1992), starting with the classic studies concerning the extensions of duality under uncertainty

[21] When working on farm data, another evident limitation of this type of model is the hypothesis that the number of farms in the sector does not change. Econometric models dealing with this type of structural aspect connected with the evolution of agricultural policies are somewhat rare; one example may be the study by Allanson (1993) that, on the occasion of the debate preceding approval of the MacSharry reform, estimated the proportion of farms potentially subject to the obligatory set-aside, on the basis of the estimate of a log-normal distribution of probabilities on the dimension of farms and their evolution.

(Epstein, 1981), shows that function $U(.)$ is not decreasing in p^e, not increasing in w, not increasing in the elements of V_p, linearly homogenous and convex in (p^e, w, V_p), as well as dual to the production technology. Thus, the properties of this function are similar to those of the standard profit function, such that it is possible, by means of differentiation with respect to the expected output prices and the input prices, to obtain an extended system of equations of output supply/input demands, since it includes the elements of the variance-covariance matrix among its arguments:

$$(6) \qquad \begin{aligned} y_i(p^e, w, z, V_p) &= \partial U(p^e, w, z, V_p) / \partial p_i^e \qquad i = 1, \dots, n \\ x_j(p^e, w, z, V_p) &= -\partial U(p^e, w, z, V_p) / \partial w_j \qquad j = 1, \dots, m \end{aligned}$$

Estimation of this system, besides the choice of an adequate functional form, requires the solution of two further problems. First, it is necessary to specify the variance-covariance matrix of output prices. A simple method is proposed by Chavas and Holt (1990) and used also by Coyle (1992) and Oude Lansink (1999a); here the elements of the matrix are calculated on the basis of the expected value of the discrepancies between the expected price and the observed price in the three previous periods, by applying decreasing weights as the lag increases[22].However more sophisticated techniques are also available, such as the multivariate ARCH models (Davidson and MacKinnon, 1993, chap. 16). It should be noted that, once the matrix is specified, it is possible to test the existence of risk aversion, where the null hypothesis is that all coefficients of the elements of the variance-covariance matrix are zero, and the model may accordingly be reduced to its standard version. The second problem concerns the estimation of the risk aversion coefficient that, as illustrated in Coyle (1992) and Oude Lansink (1999a), can be solved easily by re-specifying the supply equations appropriately[23].

Another interesting extension of the dual approach is the "household production models" that, in the case of the agricultural sector, have usually been applied to the problem of the supply of family labour on farm and off-farm. In this context, it is assumed that the agricultural household maximises a utility function of the type (Elhorst, 1994):

$$(7) \qquad U \equiv \max\{U(X, -L_a, -L_b) \mid qX = \pi(p, w, z) + w_b L_b + E\}$$

where X is the consumption vector, which obviously has a positive effect on utility, while the time spent on farm work L_a and that off-farm L_b have a negative impact. The profit function defined earlier thus enters into the budget constraint as a component of income, where q is the vector of consumer prices, w_b is the wage for off-farm work and E is the initial endowment of income. In this model, the solution of the problem in (7) makes it possible to specify a system of demands for consumer goods and the corresponding supply of on-farm and off-farm labour, that are added to the functions of output supply and input demand deriving from the profit function. The problem of the supply of off-farm labour can also be analysed in a specific way using ad hoc models to evaluate the variables influencing the choice of whether or not to enter the labour market (see, for example, Woldehanna et al., 2000).

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[22] The expected price may be calculated in various ways; in Chavas and Holt (1990) and Coyle (1992) it is obtained as the price in the previous period plus the sample average of discrepancies between this "naive" forecast and the price observed thereafter; thus it is a hypothesis of adaptive expectations. In Oude Lansink (1999a), on the other hand, the expected prices are approximated by an autoregressive model AR on the corresponding time series, according to the hypothesis of rational expectations.

[23] Recently Coyle (1999) has proposed a further extension of this model, introducing, besides the hypothesis of stochastic prices, also that of stochastic yields, and in addition he allows the risk aversion coefficient to vary with producers income. In this way the model becomes much more complex, but unfortunately for reasons of space, it is not possible to present it fully here. However, it is extremely interesting, since it makes it possible to study in a more accurate way not only the dynamics of agricultural production, but also the effects of agricultural policy instruments. For the moment, however, the applications available in the literature are limited to the more simplified version, where only prices are considered stochastic.

Estimation of these models calls for the choice of an appropriate functional form not only for the profit function, but also for the consumption/supply of labour components. Moreover, if the model analyses the choice of participation in the off-farm labour market specifically, the dependent variable becomes a dichotomic variable (participation/non participation), which entails the use of appropriate econometric techniques (see, for example, Davidson and MacKinnon, 1993, chap. 15).

The third important extension of the dual approach is the dynamic version of the basic model, where it is assumed that the farmer's objective is to maximise an intertemporal flow of profits discounted at the present time (or to minimise a corresponding flow of costs). Without entering into the technical details, it is worth stressing that with this version of the model one can derive not only the output supplies and/or the input demands, but also the flow of investments in fixed inputs (Stefanou et al, 1992; Oude Lansink and Stefanou, 1997).

Finally, another extension of the dual model considers the negative externalities of the agricultural production process[24]. In this case, it is a simple application of the standard approach to the idea of an "undesired" output, represented by the externality. The work of Oude Lansink and Peerlings (1997), referring to a specific provision of Dutch agricultural policy (a tax on the use of nitrogen-based fertilisers), presents an interesting application, since it incorporates information on nitrogen-based fertilisation that all farms are obliged to record, in the profit function. In this case, the externality is considered as a function of the level of a certain sub-vector of input and profit is obviously reduced by the amount of the tax multiplied by this function. In this problem, it is necessary to divide the process of maximisation into two stages (the optimal level of the sub-vector of input being chosen at the second stage) and to derive the equation on the externality. This shows that, when the necessary information is available (the data on nitrogen-based fertilisation in Dutch farms is recorded by the FADN), it is possible to extend the standard model considerably to take on quite complex problems of agricultural policy.

4. Econometric modelling of agricultural policy instruments

In this section we deal with the econometric modelling of the most important agricultural policy instruments, with special attention on studies analysing the CAP. As mentioned earlier, the analysis of specific agricultural policy instruments has implied, in almost all cases, the adoption of ad hoc extensions of the dual approach to the modelling of agricultural production, with the consequent estimation of specific functional forms tailored to the problem at hand. However, it is important to underline that a large part of the studies considered emphasise the theoretical set-up of the model, while giving the empirical part a mainly illustrative value. Thus, the validity of the approaches presented does not derive so much from the results of their initial applications, but from the fact that, after having been proposed in the literature, they have been applied in different contexts using different data bases.

4.1 Direct price support

As far as the CAP is concerned, one of the most important agricultural policy instruments is the minimum guaranteed price, the so-called "intervention price", which has been in force for all the most important products. The standard model of profit maximisation presented in the previous section is, however, a static model, based on effective market prices, and accordingly takes no account of the support mechanisms for these prices, such as government purchases at guaranteed minimum prices, which clearly have a very significant effect on price expectations.

These aspects of price formation, while universally known, have often been neglected in econometric applications, where the model of profit maximisation is estimated in its static version,

[24] A large body of literature where the econometric models play an important role analyses the environmental impact of agricultural policies. , However, we have chosen not to discuss it here, since it is outside of the scope of the present volume.

on the basis of the prices observed, without providing any particular justification for this choice. Several studies have introduced important changes in an attempt to overcome this by explicitly introducing a hypothesis on price expectation formation, following either the adaptive expectation or the rational expectation approach (see for example Moschini, 1988, Oude Lansink and Peerlings, 1996 and 1997, and Oude Lansink, 1999b)[25].

However, these modifications of the standard model deal with only one of the aspects involved (the formation of price expectations), leaving untouched the second aspect, that of the impact of a guaranteed minimum price. An attempt in this direction has been proposed in the MEISA model (Rossi, 1988; Cagliesi and Rosati, 1989; and Caiumi, 1997): in the latest version (Caiumi, 1997), the mechanism of price formation for the main aggregates of agricultural products is estimated through the relationship:

(8) $$\log p_i = a_1 \log t_i + a_2 \log m_i + a_3 \log c_i \qquad a_1 + a_2 + a_3 = 1$$

where t_i is the EU target price of the product in question, that represents the proxy of the minimum guaranteed price, m_i is the import price and c_i is a measurement of production costs. The relationship in (8) is estimated using an *"error correction model"*, that makes it possible to test whether there is a long-term equilibrium between institutional prices and internal prices, or whether, on the contrary, the dynamics of import prices and of production costs generates a situation of disequilibrium in the long run (Davidson and MacKinnon, 1993, chaps. 19-20). The econometric estimation of the relationship in (8), appropriately modified, makes it possible to use the estimated values as an input for the model of profit maximisation, thus incorporating institutional prices explicitly as a variable influencing production choices.

The most brilliant solution to the two problems (formation of price expectations and role of institutional prices) is, however, that in which the standard model is extended to take account explicitly of the risk aversion of producers, along the lines proposed by Coyle (1992) and illustrated earlier. The significance of this variant of the model, besides the fact that the assumption of choice under uncertainty hasa sounder theoretical basis, lies in the fact that it now becomes easy to model the existence of a minimum guaranteed price, through a modification of the specification of the variance-covariance matrix. In these applications, the distribution of prices is truncated at the level of the minimum price, using the methodology proposed by Chavas and Holt (1990) and used by Oude Lansink (1999a) to model the CAP for arable crops. In this way the estimated elasticities take account of the mechanism of formation of price expectations, the risk attitude of producers and the presence of a guaranteed price; their use in simulation exercises ensures the contemporaneous control of all of these aspects.

4.2. Trade policies

If the contribution of the econometric models to the analysis of the effects of agricultural policy has certainly been important, the same cannot be said as regards the econometric modelling of trade policies. The introductory chapter to the volume of Francois and Reinert (1997) analyses very clearly the difficulties embodied in building a model that attempts to deal fully with the problem of the commercial exchanges of one or more products in the presence of trade barriers, with the consequent formation of different equilibrium prices, internally and at the world level. According to these authors, this complexity implies a sort of trade-off between taking into account the details on trade and trade policies, requiring the collection and management of an enormous amount of data, and the estimation of the parameters of its fundamental relationships, those describing the behaviour

[25] By introducing explicitly a hypothesis on the formation of price expectations, it is also possible to deal with more specific problems: for example, in the work of Peters (1995), a model incorporating adaptive expectations is used to analyse the problem of technical progress induced by policies supporting cerealprices , that influence the mix of feeds used in livestock farming.

of economic agents in terms of technologies and preferences. This second aspect, where generally econometric modelling can make its contribution, has frequently been relegated to a secondary position by applied trade economists. Indeed, it is sufficient to take a look at the analyses carried out in other chapters of this volume to note that the models of largest dimensions, both of general equilibrium and of partial equilibrium, where the representation of trade plays a central role, have minimal or even no econometric component, and the fundamental parameters are alternatively obtained from the econometric literature on the individual countries and/or specific agricultural policy instruments, or from ad hoc procedures (calibration, exogenous fixing, etc…).

The result of this situation is that, apart from the econometric component of certain models of large dimensions (AGLINK, FAPRI) discussed in other chapters, there are very few studies of this type concerning agricultural trade in general, and, in particular, the effects of CAP policies on trade. This does not mean, however, that there is no debate on the econometric components of trade models in the literature. Beginning with the well known work by Armington (1969), who proposes the hypothesis of imperfect substitutability between domestic and foreign products as an instrument for estimating the functions of import demand, quite a rich literature has developed. In certain cases this consists of simple applications of the model in question and, among those on the CAP, we might mention the work of Haniotis (1990), who uses a model of this type to assess the impact of Spain's entry into the EU on the US exports of maize and soya; while other studies concentrated on proposing variants to the Armington model, to take account, for example, of the impact on world prices of variations in the exports of a “large” exporting country (Duffy et al., 1990). The Armington approach has nevertheless been subject to a certain amount of criticism: for example, in order to overcome the restrictions deriving from the hypothesis of homothetic separability implicit in the Armington model, several authors have proposed the use of flexible functional forms, similar to those described in the earlier sections (Alston et al, 1990; Seale et al, 1990; Wilson, 1994), while others, although remaining bound to the traditional Armington hypothesis (imperfect substitutability among import sources), have found certain errors in its standard econometric specification (Davis and Kruse, 1993)[26].

Other studies that emphasise the econometric part and refer to the Armington approach, though using simpler functional forms, are those of Kim (1990), on the wheat market, and Sparks and Ward (1992), on the trade in fruit and vegetables. In both these studies, the modelling of trade policies is highly simplified, referring to the unitary values of PSE (*Producer Subsidy Equivalent*) and CSE (*Consumer Subsidy Equivalent*) in the first case, and to an equivalent percentage tariff in the second case. The work of Heien and Sims (2000) tests the hypothesis of a structural change in demand for U.S. wine imports in Canada as a result of the free trade agreement between the two countries; in this case, therefore, the impact of commercial policies is analysed indirectly, in the form of changing parameters of the import demand function.

As a general rule, the studies mentioned before reproduce on a small scale, that is with a very small number of products and of geographical areas, the structure of the partial equilibrium models discussed in other chapters of this volume, where the size of the model makes it possible, in certain cases, to achieve a slightly more sophisticated modelling. This is the case, for example, with the work of Wahl et al. (1991) on the meat market in Japan, where domestic demand is estimated using an AIDS model and trade policies are modelled in a very specific way for all types of meat (for example, while the prices of products subject to a tariff are modelled using a classic "price transmission equation", for products subject to variable levies they are determined endogenously). The work of Williams and Shumway (2000) may also be included in this group, since simulation of the effects of the NAFTA agreement on the use of chemical products in agriculture is based on the estimate of two restricted profit functions on the United States and Mexican agricultural sectors.

[26] Even if it cannot be classified as an application of the Armington approach, the work of Wu (1992b) may also be included in this field of literature, since a comparison is made between alternative methods of estimation for a single equation of import demand in the presence of import quotas, showing how a Tobit model can lead to better results.

In these papers, as in those mentioned earlier, the EU is included as one of the main players in world trade, however none of them deals specifically with the problems connected with the impact of the instruments of the CAP on the most important markets[27]. Only recently, has the debate following the application of the 1992 MacSharry reform and the modifications introduced with Agenda 2000, produced a number of specific contributions. Immediately after the approval of the reform of 1992, the work of Guyomard et al. (1993) aimed at simulating the impact of the new policy on the European and world cereal market, utilising a variant of the MISS model (discussed in another chapter), where flexible functional forms are used to estimate the supply elasticity in the European Union and in the United States. The problem of this work, however, lies in the fact that it fails to allow explicitly for the partially decoupled nature of direct payments, since it only simulates two radically different scenarios, in which full coupling or full decoupling of the per hectare aid are hypothesised.

More recently, using very similar models, Thompson et al (2000) and Thompson and Gohout (2000) dealt with the theme of the possible increased instability in the internal prices of wheat, due to the reduction of guaranteed prices and to the process of tariffication and the reduction of import protection as a result of the application of the GATT agreement. As regards the econometric treatment, their model remains extremely simplified (with linear functional forms in one case and log-linear in the other), but the interesting element is that the equation of price transmission, that constitutes the core of this analysis, is estimated within the system of equilibrium between EU market and world market, distinguishing, by means of a dummy variable, the two periods: pre- and post-reform[28].

Among the contributions dealing with the CAP, the work of Gray et al. (1994), while extremely simple from the methodological point of view, deserves to be mentioned since it is one of the very few that analyses a particular market such as that of durum wheat. Both the work of Devadoss and Kropf (1996), and that of Poonyth et al. (2000), on the other hand, deal with the impact of the GATT agreement of 1994 on the sugar market, by means of somewhat simple models, structured on single equations estimated using the method of least squares. In particular, in the second work the supply equations take account of the different price levels that influence the choices of producers on the three types of sugar (A, B and C) defined in the framework of the CAP, while the commercial component is derived from the FAPRI model. Finally, the work of Ames et al. (1996) analyses the oilseed market, especially the impact of the various agreements characterising trade between the United States and the European Union; once more this study offers no particular methodological innovations, simply limiting itself to proposing a variant of the SWOPSIM model (also discussed in this volume) in order to allow for the evolution of world price formation for oilseeds as a result of the policies applied, at different times, by the two commercial partners.

Despite the small number of specific contributions in this area, the most interesting econometric studies are those that attempt to answer extremely specific questions on trade policies.

[27] Among the works dealing specifically with the CAP, besides those quoted in the text, mention could be made of Wu (1992a), who examines the impact of the enlargement from 6 to 10 members of the EU on the import demand of oilseed products; however, the dynamic model based on a single equation is of slight interest. As far as Italy is concerned, a partial exception is still that of the MEISA.2 model (Caiumi, 1997), where a simple modelling of import demand is proposed according to the Armington approach: in fact, it considers the hypothesis of imperfect substitutability between domestic and foreign goods, estimated as an *error correction model*. A similar pattern is also proposed for exports, which are modelled as the demand for products by foreign purchasers.

[28] Concerning the modelling of commercial policies of the EU, it may be worthwhile underlining that the agricultural economics literature contains very few contributions that analyse quantitatively the impact of the preferential policies granted to the ACP countries through the various versions of the Lomé convention. It is well known that this is an overall trade agreement, covering a large number of goods and services and that, conventionally, it does not belong to the CAP. In the Italian literature the works of Aiello and Anania (1990) and Aiello (1999) are a partial exception to this. In the former work the authors, though using an extremely simplified model, attempt to estimate the importance of preferential policies on the penetration of agricultural products from ACP countries on the EU market; while, instead, the second work tries to estimate the contribution of the same policies to the economic growth of the recipient countries.

This is the case, for example, of the work of Moschini and Meilke (1992), on the application of countervailing duties aimed at re-establishing the equilibrium preceding the application of production subsidies in the case of pork meat trade between Canada and the United States; its originality lies in taking into consideration the vertical relationships characterising this production sector; in this case, the econometric model has mainly an illustrative purpose, and refers back to Nerlovian models. With reference to the European situation, on the other hand, the study by Bourgeon and Le Roux (1996) is of great interest: they analyse the mechanisms of awarding by auction export refunds for wheat in the EU, on the basis of the theory of the behaviour of the traders and of the auctioneering authority; this time, the econometric model takes the form of an estimate of probability distributions on the offers of those taking part in the auction. In this same area of research we find the work of McCorriston (1996), who proposes a procedure for testing the effects of the oligopsony power possessed by the holders of import quota licences statistically; however, the work refers to the United States only and, in particular, to import quotas of milk and dairy products.

4.3 The quantitative constraints on production

This section will discuss the econometric methodologies that enable us to assess the impact of production quotas, distinguishing between the specific modelling of the impact of the instrument in question on producers behaviour and the related problem of the quota market. Modelling of the set-aside, the other typical supply control instrument, will be discussed in the next section since, given its application in the CAP framework, it is closely linked to the delivery of per hectare subsidies.

4.3.1 Production quotas: modelling of the instrument

Of all the agricultural policy instruments, production quotas are the ones that have received most attention in the empirical literature; the applications on the CAP refer generally to milk quotas.

As far as the first aspect is concerned, the extension of the standard model of profit maximisation to the case in which one or more products are subject to quotas is due to Moschini (1988 and 1989) and Fulginiti and Perrin (1993), who base their works on the definition of the restricted profit function proposed by McFadden (1978). In this case, the vector y of outputs is subdivided into two parts, the products subject to quota y^0 and those not constrained y^1; by modifying the price vector in a similar way, the maximum profit obtainable may be rewritten as

(9) $$\pi \equiv p^0 y^0 + G(p^1, w, y^0, z)$$

where *G(.)* is a restricted profit function defined as:

(10) $$G(p^1, w, y^0, z) \equiv \max_{y^1, x} \left\{ p^1 y^1 - wx \,\middle|\, (x, y, z) \in T \right\}$$

Function *G(.)* maintains most of the standard properties of the profit function (not decreasing in p, not increasing in w, homogeneous of degree one and convex in (p,w)), even if it does not satisfy the property of non-negativity. In addition, it is important to underline that the production of constrained outputs is always considered to coincide with the respective quota, since it is assumed that market conditions are such as to make the constraint on production always binding.

By differentiating function *G(.)* we obtain a system of equations of output supply and input demand functions where the arguments also include the vector of production quotas:

$$(11)\qquad \begin{aligned} y_i(p^1,w,y^0,z) &= \partial G(p^1,w,y^0,z)/\partial p_i \qquad i=1,...,n^1 \\ x_j(p^1,w,y^0,z) &= -\partial G(p^1,w,y^0,z)/\partial w_j \qquad j=1,...,m \end{aligned}$$

It should immediately be noted that, in this version of the model, the vector of quotas has similar effects to that of the vector of fixed inputs; this means that it is possible to define a vector of "shadow prices" of the products subject to quotas, that play an important role in this context:

$$(12)\qquad v_k^0(p^1,w,y^0,z) = -\partial G(p^1,w,y^0,z)/\partial y_k^0 \qquad k=1,...,n^0$$

It is possible to demonstrate that the vector of shadow prices v^0 coincides with the marginal cost vector of the products subject to quota, and accordingly the rent associated with the quotas may be defined as the difference between the price of the products and the corresponding shadow prices:

$$(13)\qquad r_k^0 = p_k^0 - v_k^0 \qquad k=1,....,n^0$$

From the econometric perspective, if the data refers to a period when the system of quotas has always been operative, the estimation of the system in (11) presents no particular problems and, depending on the functional form chosen, may be achieved by means of the variants of the SUR method (linear or non-linear). If, on the other hand, the data also refers to the period before the introduction of quotas, the system may still be estimated in the previous form. However, the method of estimation should allow for the fact that, in the first period, the production of the products subject to quota is determined endogenously, so that one needs to resort to variants of the method of instrumental variables, such as 3SLS (Helming et al., 1993). A further econometric problem may arise in the case in which, instead of using farm data, that is the most suitable for this type of analysis, one should decide to estimate the system on aggregate data; in this case, the variability in time of the national quotas is generally very limited and the results in terms of elasticity are often not very significant. For example, in the case of the CAP, milk production quotas have been in force since 1984 only, so from time series of annual data, the number of observations on the period of application of the quotas is very limited; in addition, the national milk quotas have undergone only slight variations from the initial level (with the exception of certain countries, including Italy, for which errors in the initial process of fixing the quota have been recognised), so that it is extremely difficult to obtain statistically significant results by working on aggregate data.

Assuming we have solved the econometric problems, by estimation of the system in (11) it is possible to obtain direct measurements of the elasticities of non-constrained output supplies and of input demands with respect to quotas. These results may be used for simulating the adjustments induced by variations in the production quotas on decisions on related sectors (for example, the effects of reducing milk quotas on the supply of beef).

It is clear however that the questions on the application of quotas do not end here, but move in at least two other directions. The first is the estimation of shadow prices (marginal costs) of the products subject to quotas, and accordingly of the rents associated with the right to produce; while the second, and in some ways the more important one, is the estimation of an "implicit" elasticity of the output supply subject to quota, a key parameter for simulating scenarios of liberalisation of the sector, and, in particular, the removal of quotas.

Problems of estimatingshadow prices arise in those cases where the quotas are only transferable together with the farm, and therefore it is not possible to obtain a market evaluation of the right to produce[29]. If, in fact, this data were available, one could estimate a system including the

[29] In any case, even when quotas are freely marketable, it is difficult to obtain precise data on what should be an annual rent for the right to produce. In fact, the majority of exchanges take place in the form of a final sale; in order to

equations in (12), thus making the estimation more accurate, whereas, in the absence of data, the equations in (12) are used to calculate the shadow prices, on the basis of the estimated parameters. For certain functional forms, however, such as the translogarithmic or the normalised quadratic in its standard version, in order to use the equations in (12) it is necessary to estimate the profit function together with the equations of output supply and input demand, an operation that, in certain cases, may involve problems of convergence in the estimation algorithm (Moschini, 1988). This is, however, the approach utilised in the work of Helming et al (1993), who calculate the shadow prices for different groups of Dutch farms following the introduction of milk quotas where, by comparing the data with the previous period, a very marked increase in rents can be noted. An interesting extension of this approach is found in the work of Gardebroek et al. (1999), in which the calculation of the shadow prices allows for any under-utilisation of the fixed inputs due to the introduction of quotas and/or their reduction. To complete the analysis on the distortions induced by quotas, it is possible to measure overall support guaranteed to agricultural producers, according to the method proposed by Guyomard and Mahé (1994) who, starting from the results of a similar model to the one just illustrated (elasticity of the output supply not subject to quotas and shadow prices of the products subject to quotas), take into account the effects of quotas and the contemporaneous presence of a mechanism of guaranteed minimum prices.

Moschini (1989) has dedicated a full review to the problem of the "implicit" estimation of the output supply subject to quota, a problem that has been solved thanks to the contributions of Moschini (1988) and of Fulginiti and Perrin (1993). Basically, if we define the profit function in the absence of quotas as:

$$\text{(14)} \qquad \pi(p^1, p^0, w, z) \equiv \max_{y^0} \left\{ p^0 y^0 + G(p^1, w, y^0, z) \right\}$$

it is possible to demonstrate that the matrix of elasticity of the shadow prices with respect to quotas, deriving from function *G(.)*, is equal to the reverse of the matrix of the corresponding elasticities of supply with respect to prices, deriving from function *π(.)*:

$$\text{(15)} \qquad E^{\pi}_{y^0 p^0} = \left| E^{G}_{v^0 y^0} \right|^{-1}$$

In order to determine these elasticities it is necessary to estimate all the parameters of the restricted profit function *G(.)*, an operation that, as mentioned earlier, requires for certain functional forms, the combined estimation of the system in (11) with the profit function. However, it is clear that, if any problems of estimation are solved, the parameters deriving from relationship (15) are of enormous importance for the simulation exercises.

The literature on analysis of the production quotas also includes a group of studies based on some of the possible extensions of the standard model of profit maximisation. Among the studies utilising the dynamic version of the model, it is possible to quote that of Stefanou et al. (1992), on the milk sector in Germany. The case presented in this work is extremely interesting, since it analyses the changes that have occurred in the flow of investments to specialised German farms before and after the introduction of milk quotas, thus highlighting another extremely important effect of quota policy. The work of Elhorst (1994), on the other hand, uses the approach of the "household production models" to analyse the behaviour of Dutch milk farms before and after the application of quotas, even if the results are not conclusive, since the introduction of the consumption/supply of labour component seems to have a minimum impact.

4.3.2 Production quotas: the market of rights to produce

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transform this data into the corresponding annual rents, it is necessary to hypothesise a certain rate of interest and the expected time horizon of the quota system, an operation that is always difficult and arbitrary (Moschini, 1989).

It is widely recognised that, when production quotas are in place, the tradability of the rights to produce separately from the farm contributes to increasing the efficiency of the system and to reducing the rigidities connected with the attribution of individual production quotas. In this context, the effects of the transferability of quotas have been given great attention by researchers.

From the modelling point of view, this group of studies is concerned with defining the functioning of the quota market theoretically, while the econometric applications normally serve to derive parameters that are used as inputs in simple partial equilibrium models. This is the case, for example, of the studies of Babcock and Foster (1992) and of Guyomard et al. (1995 and 1996a), where the starting point is always the definition of the profit function in the presence of tradable quotas that, in the simplified hypothesis of a single output y subject to quota, is defined as:

$$
\begin{aligned}
\pi(p,w,z,r,y^0) &\equiv \max_{y} \left[py - C(y,w,z) - r(y-y^0)\right] \\
&= \max_{y} \left[(p-r)y - C(y,w,z) + ry^0\right] \qquad (16) \\
&= \pi(p-r,w,z) + ry^0
\end{aligned}
$$

where y^0 is the initial quota endowment and r is the market price of the quotas. On the basis of a series of hypotheses, it is possible to define the condition of maximum profit for the individual producer, the curve of individual excess demand for quotas and, finally, the equilibrium condition in the quota market, with the final determination of the quota price[30].

The empirical part of the model estimates a cost function on farm data, for which a functional form is postulated (quadratic in the two studies of Guyomard et al., 1995 and 1996a, that refer specifically to milk quotas) and, when the redistribution problems are analysed, account is taken of the behaviour of different groups of farms, generally classified by area, size, age of the farmer, etc… From the estimated cost function, it is easy to derive a marginal cost function, that is the key element for simulating the functioning of the quota market in a context of partial equilibrium. In Guyomard et al. (1995), these results are used to analyse the impact of various hypotheses on the application of a tax in kind on quotas traded without land (that in the EU legislation takes the form of obliging producers to transfer part of the quota exchanged to the national reserve), while in Guyomard et al. (1996a) the effects of the regional redistribution of milk production in France are analysed using the hypothesis of a liberalisation in the quota trade.

The work of Boots et al. (1997), related to the Dutch market, extends the model presented in the previous section. The use of a normalised quadratic functional form in the symmetric version makes it possible to estimate the necessary parameters for calculating the shadow prices without resorting to joint estimation of the profit function. The shadow prices and the revenues associated with the quotas are thus calculated for the farms in the sample and, by means of a model of mathematical programming[31], the equilibrium price of the market of quotas is calculated on the basis of the model in (16), according to various hypotheses on the functioning of the national quota market (free trade, minimum and maximum threshold in exchangeable quantities, presence of geographic constraints to the circulation of quotas, brokerage costs). This makes it possible to highlight the effects of any constraints on quota marketing on the overall amount traded and final distribution across different areas and/or farm types. A similar approach is developed in the work of Bureau et al. (1997), related to the hypothesis of marketing of sugar quotas, in which, however, the complexity of the details on the functioning of the CAP sugar regime made any econometric

[30] Moro and Sckokai (1997 and 1999) have developed this model to analyse, from a theoretical point of view, the possible scenarios of CAP reform for milk, up to the proposals contained in Agenda 2000.

[31] This work is a typical example in which the econometric estimates serve as input for a different model (in this case a mathematical programming model).

estimation of the model extremely difficult, and accordingly the scenarios are simulated thanks to the equilibrium solution derived from a mathematical programming model.

In conclusion, it is important to underline that, despite the evident limitations of these empirical models on the market of quotas (where, for example, the cross effects with other unrestricted products are often neglected), the theoretical development of the model makes it possible to answer effectively very important questions connected with the management of production quotas, such as the geographical redistribution of production under conditions of free trade, or the distortions produced by the imposition of constraints on the quota market.

4.4. The partially decoupled policies of support

The problem of modelling compulsory set-aside and direct payment policies effectively has become extremely important following the reform of the CAP in 1992. The two problems, while conceptually separate (the set-aside is a supply control tool, while direct subsidies are income support tools), have a common root from the point of view of the modelling approach, that originates from their joint application in the CAP. In both cases, in fact, it is a question of extending the standard model of profit maximisation to allow for the allocation of land for different uses, since the new arable crop regime establishes per hectare aids linked to land allocated to program crops and to the obligation of setting aside a fixed percentage of this land. The problem, defined specifically on the basis of the new structure of the CAP, may, however, be generalised to cover all of those cases where direct subsidies are linked to allocatable fixed inputs (Chambers and Just, 1989; Coyle, 1993).

The extension of the standard model to the problem of land allocation comes from the studies of Ball et al. (1997), Oude Lansink and Peerlings (1996) and Guyomard et al. (1996b). The first work merely formulates the problem, in order to make a simple comparison between the values of elasticities in the standard model and in the one which considers the allocation of land explicitly, while the other two use the model in order to simulate the effects of the MacSharry reform. The general model, common to all three studies, is based on the hypothesis of profit maximisation in two stages: in the first stage, the optimal levels of output and input are chosen for a given allocation of land:

(17) $$\pi(p, w, z, s, s_1, \ldots\ldots, s_n) \equiv \max_{y,x} \left\{ py - wx \,\middle|\, (y, x, z, s, s_1, \ldots\ldots, s_n) \in T \right\}$$

where z is the vector of the non-allocatable fixed inputs, s is the overall endowment of land, while $(s_1, \ldots\ldots, s_n)$ are the land allocations to the various outputs. From this restricted profit function it is clearly possible to derive a system of equations of output supply and input demand functions conditional on land allocations:

(18) $$\begin{aligned} y_i(p, w, z, s, s_1, \ldots\ldots, s_n) &= \partial\pi(p, w, z, s, s_1, \ldots\ldots, s_n) / \partial p_i \qquad i = 1, \ldots, n \\ x_j(p, w, z, s, s_1, \ldots\ldots, s_n) &= -\partial\pi(p, w, z, s, s_1, \ldots\ldots, s_n) / \partial w_j \qquad j = 1, \ldots, m \end{aligned}$$

In the second stage, the optimal land allocations are chosen, on the basis of the parameters of the problem (prices, other fixed inputs, and total availability of land):

(19) $$\pi(p, w, z, s) \equiv \max_{s_1, \ldots, s_n} \left\{ \pi(p, w, z, s, s_1, \ldots\ldots, s_n) \,\middle|\, \sum_{k=1}^{n} s_k = s \right\}$$

The first order conditions for the problem in (19) establish the equality of the shadow prices of land:

$$(20) \qquad \partial \pi(p,w,z,s)/\partial s_1 = \partial \pi(p,w,z,s)/\partial s_h \qquad h = 2,...,n$$

and from these relationships we can implicitly obtain *(n-1)* land allocation functions. Thus, this approach allows us to estimate a single system that includes both the equations in (18) and the land allocation functions derived from the conditions in (20), a system which should obviously be estimated using instrumental variable techniques (typically 3SLS, linear or non-linear according to the chosen functional form), since the land allocations are arguments of the functions of output supply and input demand, but determined endogenously, through their respective equations.

In all the studies previously mentioned, the model is estimated in the form just illustrated, without incorporating explicitly the structure of the arable crop regime (crop-specific per hectare aids, set-aside obligation,…), because the data available refer to the pre-reform period. In carrying out the respective simulations, the authors use the parameters estimated in the pre-reform period; this constitutes an obvious drawback (which is recognised by the authors themselves) since it assumes that the structure of agricultural production is not modified by such an important reform.

In the work by Oude Lansink and Peerlings (1996), that is estimated on farm data, account is taken of the variations in the profit function in (19) in three different hypotheses of producer participation (the simplified scheme; the simplified scheme up to the maximum limit allowed before the set-aside obligation; the standard scheme, or "professional producer" scheme), deriving the corresponding modified versions of the equations. For example, in the case of the "professional producer" scheme, the profit function should take into account the percentage of compulsory set-aside *c*, the premium *b* guaranteed for the set-aside area and the vector *a* of crop-specific per hectare aids, so that (19) could be rewritten as:

$$(21) \qquad \pi(p,w,z,s,a,b,c) \equiv \max_{s_1,\dots,s_n} \left\{ \pi(p,w,z,s,s_1,......,s_n) + \sum_{i=1}^{n_a} \left(a_i + b\frac{c}{1-c} \right) s_i \;\middle|\; \sum_{k=1}^{n} s_k = s \right\}$$

where the term in brackets identifies the actual per hectare premium guaranteed to each of the n_a program crops (that also includes the premium for the set-aside). The first order conditions for this problem are thereby modified, and include the value of the subsidies:

$$(22) \qquad \begin{aligned} &\partial \pi(p,w,z,s,a,b,c)/\partial s_1 + a_1 = \partial \pi(p,w,z,s,a,b,c)/\partial s_h + a_h \qquad h = 2,...,n_a \\ &\partial \pi(p,w,z,s,a,b,c)/\partial s_1 + \left(a_1 + b\frac{c}{1-c} \right) = \partial \pi(p,w,z,s,a,b,c)/\partial s_h \qquad h = n_a + 1,...,n \end{aligned}$$

The corresponding land allocation equations enter into all the functions of output supply and input demand; this shows clearly why the per hectare aids are not fully decoupled, since output supply depends on the level of aid guaranteed to each crop, through the mechanism of land allocations (Sckokai and Moschini, 1993).

As highlighted earlier, the new versions of the equations cannot be estimated directly, since the data refers to the pre-reform period, but on the basis of the estimated parameters, it is possible to recalculate some important variables (land allocation, production, profits) for all the farms in the sample in the three scenarios considered by Oude Lansink and Peerlings (1996), hypothesising that each of them chooses the option that guarantees maximum profit. This makes it possible to build up a picture of the effects of the reform for different groups of farms.

In the work by Guyomard et al. (1996b), on the other hand, estimated on aggregate data, all the comparative static relationships concerning the system in its two versions (with or without the instruments introduced by the MacSharry reform) are calculated, thus we can arrive at a value of "implicit" elasticity for the supply/demand equations with respect to financial aid per hectare, on the basis of the elasticities of the shadow prices of land[32]. This is necessary because, in this case too, the estimates refer to the pre-reform period[33].

If the data on the period of application of the reform is available, it is possible to simplify the problem and to lay down the process of profit maximisation in a single stage, as proposed in the work by Moro and Sckokai (1998), where, in the case of the "professional producer" scheme, the problem may be written as:

$$(23) \qquad \pi(p,w,z,s,a,b,c) \equiv \max_{y,x,s_1,\ldots,s_n} \left\{ py - wx + \sum_{i=1}^{n_a} \left(a_i + b\frac{c}{1-c} \right) s_i \;\middle|\; \sum_{k=1}^{n} s_k = s \quad (y,x,z,s) \in T \right\}$$

and where the system of equations becomes:

$$(24) \qquad \begin{aligned} y_i(p,w,z,s,a,b,c) &= \partial\pi(p,w,z,s,a,b,c)/\partial p_i & i &= 1,\ldots,n \\ x_j(p,w,z,s,a,b,c) &= -\partial\pi(p,w,z,s,a,b,c)/\partial w_j & j &= 1,\ldots,m \\ s_i(p,w,z,s,a,b,c) &= \partial\pi(p,w,z,s,a,b,c)/\partial a_i & i &= 1,\ldots,n_a \end{aligned}$$

thus obtaining a system that can be estimated using the variants of the SUR method[34].

For all of these applications, the key result in terms of simulation of the impact of agricultural policy is the elasticity of output supply and/or input demand functions with respect to direct subsidies, an instrument that, as shown earlier, has an important impact on production decisions, an impact that is, however, "separate" from price effects.

Finally, as regards the impact of compensation payments, studies have appeared in the literature based on extensions of the standard model of profit maximisation. For example, Woldehanna et al. (2000), using the "household production model", have analysed the problem of participation in the off-farm labour market for specialised Dutch arable crop farms; the model is estimated on data preceding the MacSharry reform, but is used to simulate the impact of the 1992 reform and of the Agenda 2000 further reform.

5. Conclusions

In the light of the analysis developed, it is possible to make some concluding remarks on the use of the econometric models in agricultural policy analyses. These concern at least three important aspects: the strictly methodological ones, those connected with the capacity of modelling the

[32] Guyomard et al. (1996b) claim that, in order to derive relationships of comparative statics that are easily "manageable" from a mathematical point of view, it is necessary to resort to the hypothesis of nonjointness in production (total profit equal to the sum of profits obtainable by the individual crops), but this does not exclude the possibility, when overcoming the difficulties of calculation, of working with a more general version of the model.

[33] To assess the impact of the reform of the CAP and the proposals of Agenda 2000 on Italian agriculture, on the basis of the reform parameters, use was also made of the MEISA 2 model (Caiumi, 1997), the results of which are reported in ISMEA(1998). Although this is a complex exercise, which has the merit of taking into consideration at the same time all the sectors of a model displaying a fair level of disaggregation, the structure of MEISA, which does not include the land allocation mechanism, has forced the researchers to consider the per hectare aids as price integrations, assuming implicitly that they are fully"coupled". This obviously reduces the validity of the results obtained, since the only instrument that permits modelling of the partial decoupling of the compensatory payments is precisely the mechanism of allocation of fixed inputs.

[34] The model concentrates attention exclusively on land allocation of program crops, leaving as residual the land allocated to other crops. If the latter is also taken into consideration , the land allocation equations should be obtained by the first order conditions in (22), in a similar way to the models of Oude Lansink and Peerlings (1996) and Guyomard et al. (1996b). In this case, the land allocations to non-program crops would also enter as arguments of the output supply, input demand and program-crop land allocation functions, so that the system would be estimated by using the 3SLS method.

agricultural policy instruments and, finally, the "institutional" context in which these studies are carried out.

Before entering into these considerations, we wish to clarify how to approach this branch of the literature correctly and what one can expect in terms of results. As emerges clearly from the analysis of the previous sections, this literature is very large and extremely diversified. If we were to seek a common aspect, the most significant would probably be the fact that it consists almost exclusively of articles published in scientific journals, where the researcher's primary goal is to propose an analytical methodology for studying one or more agricultural policy instruments. Thus, in this sense the accent is more on the scientific content of the papers rather than on immediately useful results for policy makers. However, one can expect that the methodologies proposed will gradually become part of the models managed by national and international institutions, those most often used to answer the needs of the policy makers. In fact, this is exactly what has happened with some of the methodologies proposed in the past (the use of flexible functional forms, the modelling of price expectations, the structure of import demand following the Armington hypothesis,…) so that, bearing this in mind, one can expect that even the most recent methodologies may well be transformed, over the next few years, into standard approaches, targeted at meeting more sophisticated demands for the assessment of agricultural policies.

Coming to the methodological aspects, it is important to underline the fact that the peculiar characteristic of the econometric techniques, compared to other types of quantitative models, is their ability to produce results that can be verified statistically. This constitutes a great methodological advantage for the researcher, even if, in the literature taken into consideration, the effective use of the statistical instruments potentially available is fairly limited. This may be understandable, especially if the researchers' efforts are aimed first and foremost at setting up a new analytical approach; in general, however, the studies that prove most rewarding are those where the methodological proposal is supported by a rigorous econometric analysis. In this sense, it is certainly desirable that, in the future, the use of the statistical instruments available to the researcher will become more regular. This means, for example, that the choice of the functional form should be based on one of the techniques made available by the econometric literature, or, if it is decided to impose restrictions on technology, these should be formally tested. Moreover, it is desirable that, for the estimated parameters and elasticities, the relative significance tests are always carried out and, when the models are used for simulation exercises, the forecasts are subject to specific reliability tests.

Again from the methodological point of view, the points of strength of econometric models also include the relative simplicity of the techniques required for estimating them. The researchers who proposed these models have succeeded in making satisfactory use of the potential of modern econometric techniques, at least as regards the "structural" models (with one or more equations), so that, thanks also to the enormous increase in the power of the personal computers, estimation does not entail particular problems.

Finally, as regards the methodological aspects, it is important to point out that econometric analyses on agricultural policy have almost completely ignored "non-structural" models, those proposed in the vast literature on the analysis of time series, which, on the other hand, have become very popular in other areas of applied economics. This phenomenon is usually attributed to the nature of the agricultural policy instruments that, by producing rather precise distortions in the market mechanisms, make a structural approach more natural. However, it is likewise true that the economic literature on time series analysis has recently proposed modelling solutions that can incorporate these aspects, so that it has become important that agricultural economists as well should try to use them more often.

Considering now the issues related to the capacity of modelling agricultural policy instruments, it may be claimed that this area constitutes the most important strong point of econometric approaches. The models considered in the previous sections are, in fact, capable of incorporating instruments which have a very complex impact on farmers' production decisions in a way that is coherent with economic theory . Just think, for example, that, by means of the ad hoc extensions of the dual model of profit maximisation, it is possible to evaluate, in terms of the elasticity of the output supply and/or input demand functions (and, in some cases, land allocation functions), the impact of instruments such as production quotas or crop-specific per-hectare aids. These key parameters may also be obtained in a model that takes into account output price uncertainty and the risk reducing impact of guaranteed minimum prices. Thus, the literature provides the researcher with extremely sophisticated instruments, capable of meeting at least potentially, all of the most important acquisitions of theory.

A second very important strength lies in the possibility of estimating parameters that, because of their coherence with economic theory, make it possible to simulate scenarios of radical change in agricultural policy. This is the case, for example, with the estimation of the implicit elasticity of output supply subject to quotas, through which we can simulate scenarios of increase and/or removal of the production quotas, or that of the implicit elasticity of output supply with respect to direct subsidies, which makes it possible to simulate the introduction/modification of partially decoupled direct subsidies. These are the scenarios that, in other models, often oblige the researcher to resort to oversimplifications, so the contribution of econometric models becomes particularly promising.

Along with these positive considerations, it is necessary to underline certain important limitations of the econometric approaches in modelling agricultural policy instruments. First of all, it has been clearly shown that the available models cover such an important area of research as the modelling of commercial policies in a very limited way. The scarcity of original contributions in this field seems to be due to the extreme complexity of the models dealing with international trade in agricultural products. In fact, the enormous mass of information and the level of disaggregation needed force the researcher to adopt an extremely simplified approach in terms of functional forms and estimation of the behavioural parameters, the area in which the contribution of econometric models may be most qualified.

Another area in which econometric applications have not yet succeeded in producing significant results is that of the effects of agricultural policies on the structure of the agricultural sector (evolution of the number and dimension of farms). In this case too, the shortcomings seem to be due to the complexity of modelling farm decisions of entering/exiting the sector and the difficulty of obtaining reliable data on which to formulate the estimation. Despite these objective problems, the centrality that both the trade themes and those on the structure of the sector assume for agricultural policy makes it necessary for further research in these areas to improve its performance so far.

Even if, as mentioned earlier, it is not correct to expect immediately useful results for policy makers from these models, it must be pointed out that one of the limitations of the available analyses stems from the fact that the majority of studies deal with modelling a single problem and/or a single instrument of agricultural policy. Since these are recent or even extremely recent contributions, this is not surprising, since the main objective of the authors is precisely to extend a standard model in such a way as to incorporate new agricultural policy instruments. Once such extensions have become a common practice, the natural development is the setting up of models that take into consideration several aspects at the same time (price uncertainty, production quotas, direct subsidies, set-aside…) and, since the instruments generally concern different products, the models should have a higher level of disaggregation, which would also make it possible to highlight all the important "cross" effects. A prospect of this type of course implies a number of technical difficulties, and it is likely that one would have to postulate some simplifying hypotheses in other parts of the modelling work (for example, by imposing restrictions on production technology). In any case, as regrds simulations, in order to have more reliable models at our disposal this seems to be the only way forward.

A further problem emerging from the analysis comes from the fact that, on key variables for agricultural policy, such as market prices, one is almost always forced to formulate exogenous hypotheses, when these are actually the outcome of a complex market equilibrium. In this case too, the way to improve the models is already laid down, and implies an equally careful modelling of the demand side and of the mechanisms of price transmission. However, the lack of experience available shows just how complex it is to modulate complete models of this type, while maintaining the characteristics of flexibility and the necessary accuracy in modelling policies. Thus, this is another area where it is necessary to intensify research efforts, to obtain even more reliable models for representing the impact of policies.

And finally, coming to the "institutional" context in which the econometric analyses are developed, it is important to highlight the finding emerging from many studies, that the central problem is that of the quality of the data on which estimates are based. In view of the general tendency to use ever more frequently information on the individual decision-taking units (farms), the problem boils down to the need for a revision of the methodologies of data sampling and collection by the FADN. For example, it is necessary to pose the problem of an effective representativeness of the sample, so that the econometric results obtained are valid for the reference population too, and the quantitative results can be referred to the regional situations and/or relevant farm groups . Furthermore, it is necessary for the FADN findings to be complemented with key information that is not yet available, such as, for example, the prices of the variable inputs utilised on the farm.

Again on the theme of the "institutional" context, it should be reported that researchers working on other types of models of agricultural policies address increasingly look to econometric studies for reliable parameters to be used as inputs for their simulations, where these parameters are imposed exogenously. As underlined in the previous sections, this way of using econometric results has serious shortcomings, and should, therefore, be carried out with extreme caution, verifying that the basic hypotheses underlying the model used for simulations are compatible with those of the model that generated the elasticity values. However, seeing that, at least at the present time, the use of parameters is still somewhat "casual", closer collaboration is clearly desirable between those who construct and manage the big simulation models (and in particular the national and international institutions) and the researchers dealing with the econometric estimates, for example, by building a sort of "bank of parameters" where, besides numbers, detailed information is available on how they have been estimated and how they could reasonably be used in other simulation models.

In conclusion, it is possible to state that the contribution of econometric models to quantitative agricultural policy analyses has been important. Moreover, if until the end of the 1980s the studies of highest quality were to be found essentially in the North American literature, in the 1990s European researchers produced extremely useful contributions, both in terms of modelling solutions of the agricultural policy instruments of the CAP in particular, and in terms of making the best possible use of the information available, for example, through the FADN European data bank. Nevertheless, it is equally true that, precisely on the basis of the results obtained in the last few years, new demands for research have emerged that, if met, could lead to considerable improvements in the quality of this class of models, in terms of their capacity to represent the reality of agricultural policies, of the quality and scope of the results obtained and of their statistical reliability.

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