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# An integer programming dynamic farm-household model to evaluate the impact of agricultural policy reforms on farm investment behaviour

Davide Viaggi [a,*], Meri Raggi [b], Sergio Gomez y Paloma [c]

[a] *Department of Agricultural Economics and Engineering, University of Bologna, Viale Fanin, 50, 40127 Bologna, Italy*
[b] *Department of Statistics, University of Bologna, Via Belle Arti, 41, 40126 Bologna, Italy*
[c] *European Commission, Joint Research Centre (JRC), Institute for Prospective Technological Studies (IPTS), Edificio Expo, C/Inca Garcilaso 3, 41092 Seville, Spain*

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ABSTRACT

We develop a multi-objective farm-household dynamic integer programming model to simulate investment behaviour in different policy and price scenarios, with a particular focus on the decoupling of the Common Agricultural Policy (CAP). The model takes into account the characteristics of individual assets, including ageing and fixity through the explicit consideration of transaction costs. A case study application in the context of arable farming in Northern Italy is provided as an example. The results emphasise different patterns of reaction of different farm-household types over time, as an effect of the varying opportunity costs of resources and initial asset endowments. Overall, this application highlights the potentialities and limits of the methodology. In particular, the approach proved to be effective in providing a variety of results depending on the individual features of each farm-household, such as the differences between: (a) a 'no reaction' attitude; (b) an adaptation of farm activity and assets; and (c) a radical reaction pattern guided by high-income alternatives to farming. This highlights the potential of this tool as a generator of ideas and working hypotheses. We argue that, in view of the further developments of the CAP, the use of instruments able to account for multiple objectives, dynamics and investment choices will become even more relevant in the analysis of EU agricultural policy.
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## 1. Introduction and objectives

Mathematical programming models have found extensive use in agricultural economics applications. Broadly speaking, two main areas of application can be distinguished: (a) support to farm-level decision making; and (b) support to policy decision making, e.g. through the simulation of farm reactions to policy effects. Both areas of application now include several tangible examples, and indeed a large body of literature.

A wide literature review of the tools used to support firm (farm) decision makers (point (a) above) is provided by Ahumada and Villalobos (2009), who focus their attention on the different components of the supply chain related to crop production. The review emphasises the variety of different approaches and applications. In fact, examples of the uses of mathematical programming for farm planning purposes range from crop harvesting schedules (Prestwidge et al., 2009; Bohle et al., 2010) to whole farm models (e.g. Pannell, 1996; Annetts and Audsley, 2002; Recio et al., 2003). When included in operational tools, mathematical programming may be complemented by a user-friendly interface (e.g. Prestwidge et al., 2009) or act as the basis for proper decision support systems (Recio et al., 2003).

The area of policy support (point (b) above) has attracted comparable attention in recent years. This includes a variety of applications at different scales and with differing scopes, including interaction with physical and biological processes (Janssen and van Ittersum, 2007; Buysse et al., 2007), and stimulating innovation in modelling designs and calibration techniques. The use of mathematical programming farm models for policy support is also the subject of this paper. In this field of research, a special area of interest in Europe has been the study of the Common Agricultural Policy (CAP) of the European Union (EU). The CAP is the largest component of the EU budget and a major driver of farmers' choices. A number of different models are used to assess its impact on farm behaviour. Individual farm or territorial programming models are widely used in this context. However, in most cases models are characterised by a comparative statics approach that does not take into account investment behaviour. This is most properly addressed through a multi-period decision structure, taking into account expectations and dynamic effects (see Gardebroek and Oude Lansink (2004) for a general model).

Relevant exceptions exist, most frequently concerning territorial models such as AgriPoliS and RegMAS, which deal with structural changes and land transactions and hence include some

* Corresponding author. Tel.: +39 051 2096114; fax: +39 051 2096105.
*E-mail addresses:* davide.viaggi@unibo.it (D. Viaggi), meri.raggi@unibo.it (M. Raggi), sergio.gomez-y-paloma@ec.europa.eu (S. Gomez y Paloma).

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investment mechanisms. Yet results are often not provided in terms of investment behaviour (e.g. Happe, 2004; Lobianco and Esposti, 2008). In addition, these models maintain a rather simplified approach to the investment decision making process, generally based on gross margin maximisation by farm units.

Another stream of research develops a refinement of the basic profit-maximising model in the direction of accounting for uncertainty. Examples are provided by the Real Option Approach (Pyndick, 1991), or by Stochastic programming (Heikkinen and Pietola, 2009).

A few papers have attempted to refine the choice of investment by taking into account the wider perspective of the multiple objectives of the whole decision making unit, mostly represented by the farm-household. An example is provided by Wallace and Moss (2002), who present a recursive strategic weighted goal-programming model, including adaptive expectation formation, where household consumption objectives are mediated with farm expansion and other farm-related objectives. Contrary to most of the literature using a multi-objective approach, they also cast the problem in a dynamic framework and include investment concepts among the objectives.

Along the same line, Gallerani et al. (2008) adopt a multi-objective dynamic programming household model to assess the impact of CAP and market scenarios on a selected sample of 80 farm-households in eight EU countries.

This paper aims to present the methodology developed in the context of this study, and to discuss the design and calibration problems associated with a multi-objective dynamic programming model of farm-household behaviour the objective of which is to simulate farm-household reactions to policy and market scenarios. The paper develops the discussion of the theoretical and empirical models, as well as implementation, and provides a case study concerning six arable farms in Northern Italy.

The term “farm-household model” in this context refers to a well established category of models in agricultural economics in which the household is the unit of analysis (embedding the farm) and which treats the allocation of household and external resources (labour, land, capital) on- and off-farm, as well as the production and consumption decisions, driven by the maximisation of farm-household utility, as endogenous and inseparable (Chayanov, 1966; Singh et al., 1986; Taylor and Adelman, 2003).

Following the prevailing perspective of this literature, the paper focuses mainly on the use of such a model for policy simulation purposes aimed at providing support for the public decision maker.

The paper is organised as follows. In Section 2 we illustrate the model. In Section 3 we discuss its implementation, calibration and validation, while in Section 4 we provide the illustration of a case study. The paper continues with a discussion in Section 5 and closes with some final remarks.

## 2. The model

### 2.1. Theoretical model

Taking into account the large body of literature on farm investment behaviour (for a review, see Gallerani et al., 2008) and the number of determinants highlighted in the literature, we focus on a model which is able to provide: (a) a detailed technical representation of investment assets (age, value, non-divisibility); (b) an accurate representation of the decision making unit, identified as the farm-household (multiple objectives, on-farm vs. off-farm use of capital and labour, liquidity constraints); and (c) a sufficiently good representation of exogenous variables affecting household decisions (prices, policy payments).

The chosen approach is a multi-objective dynamic model of the farm-household. This approach is implemented by way of a dynamic integer programming model, which is particularly suitable to represent inter-temporal decisions with non-divisible assets (Hillier and Lieberman, 2005, for an example see van Asseldonk et al., 1999).

The theoretical model for household-level decision making, based on the multi-objective approach, follows the following maximisation approach:

$$\text{Max } Z(x_t) = F[z_{1,t}(x_t), z_{2,t}(x_t), \ldots z_{q,t}(x_t), z_{Q,t}(x_t)] \quad (1)$$

$$\text{s.t.} \quad x_t \in X, \quad (2)$$

$$x_t \geqslant 0, \quad (3)$$

where $Z(x_t)$ = farm-household utility expressed as a function of the value of the vector of decision variables $x_t$; $X$ = feasible set; $x_t$ = vector of the values of decision variables for each time $t$; $z_{qt}$ = value of objective $q$ in time $t$ as a function of the vector of decision variables $x_t$; $q = 1,2,\ldots,\ Q$ = farm-household objectives; $t = 1,2,\ldots,\ T$ = time (years) in the planning period, with $T$ = time horizon.

The objective function is a representation of farm-household utility. The farm-household is expected to maximise a function defined as a combination of multiple objectives, each defined as a function of the set of decision variables. By maximising the value of total utility, the model quantifies farm reactions to prices and policies in terms of a set of decision variables ($x_t$), including crop mix, labour allocation (on-farm vs. off-farm), capital allocation (on-farm vs. off-farm) and investment/disinvestment. Most of these variables, in particular crop mix, are extensively used in the mathematical programming models applied to agriculture and their previous applications can be found in the literature cited in Section 1. The main peculiarity of this model, together with the investment variables, concern on- and off-farm resource allocation, in order to represent the household rather than farm decision process, and dynamic liquidity management, which is needed to guarantee a realistic inter-temporal representation of liquidity-constrained investment decisions.

The maximisation is subject to limitations to the range of values of decision variables, represented by constraints to the feasible set, and by non-negativity constraints.

We describe this in detail in the empirical model by illustrating first the objective function, and then the constraints to the feasible set.

### 2.2. Empirical model: objective function

The use of multi-objective programming is proposed when attempting to interpret household behaviour (instead of simple farm optimisation) as an alternative to the Net Present Value (NPV) approach in order to take into account multiple objectives (e.g. consumption, leisure, household worth) that may be relevant in household choices. However, whether farm-households make investment choices in a way that is better represented through multi-objective decision making is an empirical issue. In practice, and in the long run, the objective function may often be relaxed to a unique objective represented by the maximisation of the net household cash flow. This may be a debatable issue in theoretical terms, but it is acceptable to think that there could be cases in which criteria other than profit maximisation add little to the fitness of the model, and cases where they may be among the determinants of the results. In all cases, the NPV model can be taken as a benchmark. Following these arguments, multi-objective thinking can be seen as consistent with the household having a shorter vision with respect to the full time horizon usually adopted in the NPV maximising models. Consequently, the choice of this study is to run models in two forms:

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