Farm level modelling of CAP: a methodological overview

Authors (in alphabetical order): Pavel Ciaian, Maria Espinosa, Sergio Gomez y Paloma, Thomas Heckelei, Stephen Langrell, Kamel Louhichi, Paolo Sckokai, Alban Thomas and Thierry Vard

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Joint Research Centre
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List of Acronyms

ABM Agent based model
ACRE Average Crop Revenue Election
AEM Agri-environmental measures
AGLINK-COSIMO Worldwide Agribusiness Linkage Program + Commodity Simulation Model
AGMEMOD Agricultural Member States Modelling
AGRIPOLIS Agricultural Policy Simulator
AGRISIP Agricultural Regional Integrated Simulation Package
APES Agricultural Production and Externalities Simulator
AROPAJ Agriculture, Recomposition de l’Offre et Politique Agricole
CAP Common Agricultural Policy
CAPRI Common Agricultural Policy Impact Modelling System
CAPRI-FT Farm type module within CAPRI
CIRAD Centre de coopération Internationale en Recherche Agronomique pour le Développement
CC Climate Change
CORMAS Common Resources Management Agent-based System
DARA Decreasing Absolute Risk Aversion
EMP Econometric-mathematical programming
EPIC-PHASE Erosion Productivity Impact Calculator (French version)
ESIM European Simulation Model
ETS Emission trading scheme
EU European Union
EU-FADN European Farm Accountancy Data Network
EU-FASOM European Forest and Agricultural Optimisation Model
EUROSTAT European Statistics
EXPAMOD Tool for linking farm level and market level models
FADNTOOL Integrating Econometric and Mathematical Programming Models into an Amendable Policy and Market Analysis Tool using FADN Database
FAMOS Forest and Agricultural Optimisation Model
FAO-Aquastat FAO’s global information system on water and agriculture
FAPRI Food and Agricultural Policy Research Institute
FARMIS Farm Modelling Information System
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>FES</td>
<td>Financial Economic Simulation Model</td>
</tr>
<tr>
<td>FLIPSIM</td>
<td>Farm Level Income and Policy Simulation Model</td>
</tr>
<tr>
<td>FSS</td>
<td>Farm Structure Survey</td>
</tr>
<tr>
<td>FSSIM</td>
<td>Farming System Simulator</td>
</tr>
<tr>
<td>GAMS</td>
<td>General Algebraic Modelling System</td>
</tr>
<tr>
<td>GHG</td>
<td>Greenhouse gases</td>
</tr>
<tr>
<td>GME</td>
<td>Generalized Maximum Entropy</td>
</tr>
<tr>
<td>GTAP</td>
<td>Global Trade Analysis Project</td>
</tr>
<tr>
<td>IACS</td>
<td>Integrated Administration and Control System</td>
</tr>
<tr>
<td>IES-FADN</td>
<td>Integrated Estimation and Simulation FADN model</td>
</tr>
<tr>
<td>IIASA</td>
<td>International Institute for Applied Systems Analysis</td>
</tr>
<tr>
<td>INRA</td>
<td>Institut National de la Recherche Agronomique</td>
</tr>
<tr>
<td>IPTS</td>
<td>Institute for Prospective Technological Studies</td>
</tr>
<tr>
<td>LCA</td>
<td>Life-Cycle Analysis</td>
</tr>
<tr>
<td>LEI</td>
<td>Agricultural Economics Research Institute (LEI-Wageningen UR)</td>
</tr>
<tr>
<td>LEITAP</td>
<td>Extended GTAP version (implemented by LEI)</td>
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<tr>
<td>LFA</td>
<td>Less Favoured Areas</td>
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<tr>
<td>LP</td>
<td>Linear programming</td>
</tr>
<tr>
<td>MAS/LUCC</td>
<td>Multi-Agent System models of Land-Use and land-Cover Change</td>
</tr>
<tr>
<td>MIDAS</td>
<td>Model of an Integrated Dryland Agricultural System</td>
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<tr>
<td>MIP</td>
<td>Mixed integer programming</td>
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<tr>
<td>MIRAGE</td>
<td>Modelling International Relationships in Applied General Equilibrium</td>
</tr>
<tr>
<td>MP</td>
<td>Mathematical programming</td>
</tr>
<tr>
<td>MS</td>
<td>Member State</td>
</tr>
<tr>
<td>NLP</td>
<td>Non-linear programming</td>
</tr>
<tr>
<td>NUTS</td>
<td>Nomenclature of Territorial Units for Statistics</td>
</tr>
<tr>
<td>PASMA-FAMOS</td>
<td>Positive Agricultural Sector Model Austria</td>
</tr>
<tr>
<td>PMP</td>
<td>Positive mathematical programming</td>
</tr>
<tr>
<td>SAPIM</td>
<td>Stylised Agri-Environmental Policy Impact Model</td>
</tr>
<tr>
<td>SEAMLESS</td>
<td>Integrated assessment of agricultural systems. A component-based framework for the European Union, FP7 project</td>
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<tr>
<td>SFP</td>
<td>Single Farm Payment</td>
</tr>
<tr>
<td>STICS</td>
<td>Simulateur multIdisciplinaire pour les Cultures Standard</td>
</tr>
<tr>
<td>UAA</td>
<td>Utilised Agricultural Area</td>
</tr>
<tr>
<td>USDA</td>
<td>United States Department of Agriculture</td>
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Preface

This report constitutes a comprehensive compilation and synthesis of the principal issues and outcomes of the joint Institute for Prospective Technological Studies/Directorate-General for Agriculture and Rural Development workshop on “Developments and Prospects of Farm Level Modelling for post 2013 CAP impact analysis” held in Brussels between 6-7 June 2012.

Gathering a range of international experts and specialists in the field of agricultural and farm level modelling development and implementation, from those applied within the EU to a range of policy applications to those developed and applied in other areas of the world, and different policy regimes (e.g. Australia and USA), the workshop ultimately focused on the assessment of the feasibility of developing an EU wide farm level model able to analyse the various future CAP scenario impacts, with particular attention to the effective capitalisation from the two principle EU wide farm level data sources: the Farm Accountancy Data Network (FADN) and the Farm Structure Survey (FSS). Based on participant deliberations and discussions, a number of empirically based policy recommendations towards achieving such methodological capabilities were highlighted.

The production of this report, following completion of the workshop, has been the responsibility of the IPTS. This task has been facilitated through collaboration with three internationally recognised experts (Thomas Heckelei, University of Bonn, Germany (Chapter 3 and 4), Paolo Sckokai, Università Cattolica del Sacro Cuore, Italy (Chapters 5 and 6), and Alban Thomas, INRA/Toulouse School of Economics, France (Chapter 7) acting as rapporteurs for each of the workshop’s five technical sessions, whose efforts in capturing the principle issues and outcomes of their respective sessions has been instrumental towards realisation of this report. Stephen Langrell, Maria Espinosa, Kamel Louhichi, Pavel Ciaian and Sergio Gomez y Paloma compiled Chapters 8 (conclusions and recommendations). Stephen Langrell and Thierry Yard (DG-AGRI, Directorate L) compiled Chapter 1, whilst Kamel Louhichi, Maria Espinosa, Pavel Ciaian and Sergio Gomez y Paloma compiled Chapter 2. Stephen Langrell further acted as editor.

As such, this report constitutes a particular and comprehensive technical overview of the state of farm-level modelling in the EU and in two other principle western agricultural regions, with a consideration of the prospects for further development of more policy specific orientated methodologies and platforms towards CAP scenario assessment. It reviews a wide range of methodologies currently applied for policy impact assessment at farm level, from the general perspective to specific impact of policy reforms, not least structural change and risk/uncertainty as well as financial and dynamic investment behaviour and technological choice, to market and biophysical inter-linkages.

The report closes with expert opined policy-relevant conclusions as a basis for policy suggestions and recommendations. It is envisaged that this report will provide a valuable source of technical and conceptual information for the further development of impact assessment methodology(ies), and ultimately effective policy implementation, post CAP 2013.

John Bensted-Smith
Director – IPTS
Executive Summary

This report constitutes a comprehensive overview of the state of approaches and modelling platforms currently employed for micro-level policy analysis at farm-level, representing a specific response to, and consideration of, recent policy developments within the evolving CAP context. Taking into consideration the increasing need for more targeted impact analysis of new policy instruments, and subsequent scenario assessments, the JRC/IPTS, in collaboration with DG-Agriculture and Rural Development organized a technical workshop on "Developments and Prospects of Farm Level Modelling for post 2013 CAP impact analysis", held between the 6th and 7th June 2012 in Brussels. Produced in conjunction with eminent (EU and international) experts, this report constitutes a comprehensive synthesis of that workshop. Within the overall primary aim of the workshop, to assess the modelling tools at farm level in the context of using the two EU wide farm level data sources, the Farm Accountancy Data Network (FADN) and the Farm Structure Survey (FSS), the main objectives of the report are to:

- Highlight the most relevant farm-level models applied for policy impact analysis.
- Assess the possibility for farm level models to capture policy relevant impacts and inter-linkages such as modelling CAP instruments at farm level, investments and technological choice, management practices, farm structural change, market inter-linkages and biophysical inter-linkages.
- Compare the methodological differences and identify the key modelling challenges for EU applicability.
- Assess the feasibility of implementing farm model/s at the EU-27 scale using FADN and FSS databases.
- Assess data constraints and issues related to model maintenance and update.

The report is organised in eight Chapters. Chapter 1 provides an introductory discussion and rationale for this challenging initiative, with focus on the spectrum of farm-level modelling platforms currently employed. Highlighting limitations to the ever increasing requirements and more detailed focus for the latest, more targeted, (CAP) policy instruments, this chapter lays down the initiatives principle objectives, with the ultimate aim of assessing various technical scenarios towards more tailored model development.

Chapter 2 reviews and discusses the recent state of applied farm-level models in the European and non-European context, then compares them in terms of methodology, and their ability to capture key features of policy impacts and applicability at EU level.

Chapters 3 provides conceptual insights on farm-level modelling and discusses general methodological issues related to representing heterogeneity, market inter-linkages and dynamic adjustment as well as some additional challenges considered of importance in the development of an EU wide farm-level modelling platform.

Chapter 4 moves from such general challenges associated with farm modelling to more policy specific methodological aspects, in particular those covering four modelling systems (CAPRI-FT, AGRISP, IES-FADN, and AROPAj) that have already been applied to specific CAP impact analysis.

Chapter 5 reviews a set of models that depart from perfect market assumptions and considers and explores the methodological issue related to inclusion of risk and uncertainty of farm decision making into a micro level modelling framework.

Chapter 6 further extends the methodological discussions by reviewing the implications of financial and dynamic investment behaviour for farm-level modelling, while Chapter 7 addresses the specific challenges derived from linking farm-level models with environmental impact models, and how they have been addressed from a methodological point of view.

Finally, Chapter 8 summarises the main findings of Chapters 1 to 7 and attempts to formulate recommendations towards developing an appropriate platform for farm-level policy analysis. Three different strategies for analysing CAP impact at farm level emerge from the report: (i) a “single” model, (ii) multiple models/approaches and (iii) an intermediate approach. Each of the three proposed strategies of assessing the CAP impact at farm level can be developed and maintained either within one institution or a closed set of cooperating institutions, or within a functional network of institutions. Experience often supports the “network approach” in developing and maintaining farm modelling activities, as it reduces cost, whilst permitting a wider and more effective exploitation of human resources and expertise available in the specific area.
The choice of the methodology used in a farm-level modelling framework is a key element as it should allow flexibility in terms of capturing farm behaviour as well as for allowing the possibility for inclusion of various policy instruments in the model. As identified in the report, there are different methodological approaches for farm level modelling. However, the most prominent, and most extensively tested/applied, in literature in the area of agricultural policy modelling is mathematical programming.

An additional important aspect of farm model development relates to the level of disaggregation. It has been highlighted from the review of models that a key issue associated to modelling future CAP developments is related to the problem of aggregation and incorporation of sufficient farm heterogeneity within the farm model.

There are two distinct approaches that differentially influence the degree of heterogeneity that can be assessed: individual (real) farm models and farm-type models. Both approaches have their advantages and disadvantages. Farm-type models are more frequently used and their application for CAP analysis at EU scale is relatively well developed in the scientific literature. However, this approach significantly reduces farm heterogeneity and thus is not fully able to model policies targeted at farm level without considering additional model adjustments or/and imposing additional behavioural assumptions. Individual farm models are, on the other hand, more suited to capture farm heterogeneity and to model farm specific policies. However, individual farm models are more demanding in terms of parameterization and calibration than farm-type models.

With such considerations, the actual choice of the modelling approach and adoption is also strongly influenced by financial and human resource availability as both approaches require differing effort in terms of model development, data preparation and maintenance.
Chapter 1. Introduction to farm level modelling

Stephen Langrell¹ and Thierry Vard²

¹ Institute for Prospective Technological Studies (IPTS)
Joint Research Centre (JRC)
European Commission

² Directorate General – Agriculture and Rural Development
European Commission

1.1. Introduction

Over the last decade, the CAP has been placing great emphasis on enhancing farm incomes and environmental performance while increasing market orientation for agriculture. This has been apparent with the shift from market support instruments toward the Single Payment Scheme and by enhancing support for environmental protection, public goods and rural development. The recent European Commission proposal on the CAP post-2013 goes further in this direction by proposing to introduce a mandatory “greening” component to direct payments with the aim of enhancing the environmental performance of agriculture. The proposal also introduces various instruments aiming to better target and rebalance the support between farmers. These CAP developments call for more disaggregated analysis of the economic and environmental impacts which is a central issue for both EU policymakers and researchers. Currently applied agricultural models, initially developed to model market intervention instruments, are unable to fully capture the impacts of new policy measures. As agricultural policies continue to be increasingly targeted and more farm specific, the need for more detailed description of their economic and environmental impacts at disaggregated level (regarding farms and products), and by geographical/spatial scale, becomes a central issue for both EU policymakers and researchers. In fact, this new policy orientation will affect farms differently according to their resource endowment and socio-economic contexts, but also localisation (i.e. agro-ecological conditions) leading to a new thinking in terms of modelling approach(es). Currently applied agricultural models (e.g. AGLINK-COSIMO, CAPRI, GTAP, AGMEMOD) which were initially developed to model early CAP instruments (e.g. price support), and to capture their impact on markets, prices and trade, are, in fact, inappropriate for such policy analysis. Such market models are unable to represent many of these new policy instruments, to capture farm heterogeneity and to address a finer geographical scale than the regional level (requiring model disaggregation at a level of policy implementation able to provide analysis relevant for policy-making support). Indeed, only sufficiently detailed farm level models are able to take into account these new policy specifications giving them an advantage over regionally aggregated models when modelling new CAP instruments. However, most of the existing farm level models in Europe are developed for specific purposes and locations and are not easily adaptable and reusable in wider generic contexts. They are either only applicable for a single purpose and location for which they were initially developed, or able to investigate different questions, but as they were fully integrated within a modelling framework, they cannot be used as standalone approaches for other applications and contexts (e.g. climate, soils and socio-economic conditions, etc.). Indeed, farm models that allow flexible impact assessment for a range of issues at very large scale are scarce. This seems to be due, on the one hand, to data limitation and, on the other hand, to the complexity and heterogeneity of policy schemes. Identification and understanding of the limitations of such approaches and challenges towards the development of more appropriate policy targeted analysis (from both a policy and technical perspective, not least the availability of quality data sources) are therefore key considerations towards the realisation of more specific policy targeted assessment capabilities.

Taking into consideration the recent policy developments and the increasing needs for models/tools for micro-level policy analysis, the JRC/IPTS together with DG-Agriculture organised a workshop on “Developments and Prospects of Farm Level Modelling for post 2013 CAP impact analysis”, between the 6th and 7th June 2012 in Brussels. The main aim of this workshop was to assess the modelling tools at farm level in the context of using the two EU wide farm level data sources: the Farm Accountancy Data Network (FADN) and the Farm Structure Survey (FSS). This report constitutes a comprehensive synthesis of that workshop.
1.2. EU wide farm level data sources and contribution towards CAP post 2013 assessment

Two key challenges when developing and using farm models for policy analysis at EU level are data availability and quality. Both the FADN and the FSS are two comprehensive and rich sources of EU wide farm level data. The FADN is an annual farm survey that gathers detailed EU wide accounting data from a sample of agricultural holdings (see Box 1.1). The FSS, although lacking in economic variables, provides harmonised data on the structure of agricultural holdings regarding land use and livestock, farm labour force, machinery and equipment, as well as participation in rural development programs. The basic unit underlying the FSS is the agricultural holding and a complete agricultural census is updated every 10 years (with intermediate sample surveys). Although extremely useful for determining farm structural change, FSS data is not designed nor orientated to assess the impact of new policy measures as accountancy data are not recorded, and therefore not part of its dataset.

As for previous policy reforms, the FADN is initially used for setting the scene of the situation of the farming sector as concerns the income of farms and the costs and margins for the main sectors, and secondly, to assess various ex-ante policy scenarios. In this domain, the EU-FADN is particularly well suited for analyses of income at farm level, e.g. to test the design of an ‘Income Stabilisation Tool’, or to evaluate the need of coupled payments in some sectors. However, its primary and main use is related to the assessment of numerous scenarios of direct payments.

The current CAP post 2013 proposal intends to improve the targeting of instruments in order to better take into account the specific situation of individual farmers. Indeed, in the current proposal, the European Commission foresees a system of layers of voluntary and compulsory aids combined with features to redistribute support with respect to enhancing environmental performance (e.g. basic flat rate, green payment, young farmers’ scheme, natural constraints support, coupled support, progressive reduction and capping of aids, and small farmers’ scheme).

In terms of policy assessment, clear methodological development is required to take into account farm heterogeneity, including in terms of farming practices, with the ability, capacity and level of resolution capable of clearly characterising and assessing different impacts. The FADN dataset is particularly powerful towards this type of assessment as the rich data source allows effective policy simulation and impact evaluation at individual farm level and, as such, forms the basis of a thorough assessment and presentation of distribution of individual results under different policy scenarios.

Currently, in terms of methodology, the assessment of the various policy scenarios has been performed by combining the assessment at FADN individual farm level with the results of the market simulations using a modified version of the AGLINK-COSIMO model. The main features of this static comparative approach method are:

- the static accounting calculation at farm level
- the market situation in 2020 (prices and yields) based on AGLINK-COSIMO simulations
- the policy implementation of direct payments in 2020 for the various scenarios
- the impact of the greening differentiated in terms of the direct effect (possible loss of income due to adaptation at farm level) and of indirect effect (change in market prices due to changes in land use and supply).

Although this accounting calculation at farm level approach is very flexible, allowing simulation of policy options, (even if more details would be needed in FADN in terms of farming practices), the approach is inherently limited to first order effects, and as such, this static comparative approach has clear limitations:

(i) there is no adaptation of individual farmers (within fixed structure) to market and policy changes within the short to medium term.

(ii) In the long term there is no structural adjustment in terms of size and production over time.

Subsequently, research efforts to consider and address such issues, and how they might be more comprehensively incorporated and assessed in various and differentiated policy simulations, through modified existing, or novel methodological approaches, are clearly required. Indeed, this can be considered complimentary to IPTS initiated research activities to investigate methods to incorporate structural adjustment in long term policy simulations (Gocht et al., 2012).

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Introduction to farm level modelling

1.3. Modelling approaches

Over the last decade, development and use of farm-level models for policy analysis have become major activities of agricultural economists. This growing interest can be attributed to the increasing demand for tools and methods for micro-level policy analysis, in addition to the better understanding of farm-level decision making. Various approaches are employed in the building and development of farm models reflecting a wide range of questions and purposes (research scope), required levels of resolution, data availability (sources and quality (all EU based models use FADN data)) and spatial, as well as temporal, distribution. They can be grouped according to two broad criteria;

(i) farm supply models that seek to describe the decision making process of one (individual or representative) farmer considered as a pure producer or ‘entrepreneur’, and
(ii) farm household models, which combine consumer and producer models into a single model (i.e. the consumer is also the producer and off-farm income is explicitly modelled), aiming to represent household behaviour.

Within each group, models can be classified as either mathematical programming (including linear programming, non-linear programming, mixed integer programming, positive mathematical programming and multi-criteria mathematical programming), econometric approach, or, a more advanced programming technique referred to as ‘econometric-mathematical programming’, with the choice of an approach, and model development focus, depending primarily on the research scope.

Chapter 2 provides a comprehensive and detailed overview of farm level models more recently applied in the EU and discusses their theoretical backgrounds and assumptions as well as their relevance in terms of policy representation and impacts. Moreover, chapter 2 compares the most relevant EU farm-level models in terms of methodology, ability to capture key features of policy impacts and applicability at EU level.

1.4. Objectives

Taking into consideration possible implications of the current EC legislative proposal, and consequently the increasing needs for disaggregated policy impact analysis, this report aims to assess the feasibility of developing an EU wide farm level model able to analyse the various CAP scenario impacts. In particular, an overall important consideration of this report is the assessment of modelling tools at farm level in the context of capitalising from the richness of the two EU wide farm level data sources: the Farm Accountancy Data Network (FADN) and the Farm Structure Survey (FSS).

Consequently, with this background in mind, the main objectives of the study are to:

- Highlight the most relevant farm-level models applied for policy impact analysis.
- Assess the possibility for farm level models to capture policy relevant impacts and inter-linkages such as modelling CAP instruments at farm level, investments and technological choice, management practices, farm structural change, market inter-linkages and biophysical inter-linkages.
- Compare the methodological differences and identify the key modelling challenges for EU applicability.
- Assess the feasibility of implementing farm model/s at the EU-27 scale using FADN and FSS databases.
- Assess data constraints and issues related to model maintenance and update.
- Based on the above, assess the potential for the development of a novel generic farm model for application across the various European farming systems.

These issues are explored and further elaborated on within the principal chapters of this report dealing with, and specifically addressing, general issues of farm level modelling, modelling reform impact(s) on markets and farm income, modelling structural change and risk/uncertainty in decision making, as well as financial and dynamic investment behaviour, and the interlinking of farm level with biophysical (environmental impact) models. Horizontal issues, where they occur, are dealt with within the scope of each specific topic (within the respective chapter).
In essence, a principal expected outcome of this report is the establishment of a comprehensive and integrative knowledge base to facilitate the EC-JRC-IPTS to assess the feasibility of either selecting an existing platform, or, develop a novel, robust and fit for purpose generic farm-level model towards the effective evaluation and assessment of possible CAP scenario impacts.
Chapter 2. Farm-level models for EU policy analysis: review of recent literature and comparison of most relevant models

Kamel Louhichi, Maria Espinosa, Pavel Ciaian and Sergio Gomez y Paloma

Institute for Prospective Technological Studies (IPTS)
Joint Research Centre (JRC)
European Commission

2.1. Introduction

Since 2005, the European Commission has clearly formalized, through a mandatory impact assessment, its need of an ex-ante impact assessment of its future agricultural policy and its environmental aspects. Science has largely contributed to such issues, and the body of literature and models for such purposes is increasingly dealing with different aspects and scales. They range from highly aggregated equilibrium models, like GTAP (Hertel, 1997) or MIRAGE (Bouët and Laborde, 2010), to partial equilibrium models such as CAPRI (Britz and Witzke, 2011) or AGLINK-COSIMO (OECD, 2006) and, to single behavioural models like FARMIS (Offermann et al., 2005), or FSSIM (Louhichi et al., 2010). Each of these models has its strengths and weaknesses and suitability for specific policy questions. Salvatici et al. (2000) and Britz and Heckelei (2008) have discussed the advantages and disadvantages of these different modelling approaches with respect to different types of policies and questions of interest. Accordingly, single behavioural models, such as farm-level models, are more suitable for microeconomic analysis as they provide detailed insights on the impacts of policy changes. If policy analysis aims at assessing the impacts of policy change on specific commodity market, or on the whole agricultural sector, partial (sector) equilibrium models can successfully be used. However, if system-wide effects and spill-over effects between different sectors are also of particular interest, Computable General Equilibrium models are then more appropriate.

This chapter however, only deals with farm-level models. The prime decision making unit in agriculture is the farm. It is also the unit where agro-economic innovations start and where agricultural and agri-environmental policies trigger changes in land use, production and externalities. Over recent years, there has been a growing interest in this kind of models as analytical tools to simulate the potential impact of European agricultural policies. One of these reasons is that as the CAP (Common Agricultural Policy) becomes more and more targeted to specific farmers, greater emphasis has been placed on enhancing farm incomes and environmental performance rather than market support policies. This has been apparent with the shift toward the Single Payment Scheme and by enhancing support for environmental protection, public goods and rural development. The recent European Commission proposal on the CAP post-2013 goes further in this direction by proposing to introduce a mandatory “greening” component to direct payments with the aim of enhancing the environmental performance of agriculture (European Commission, 2011a). These CAP developments call for a more disaggregated analysis of the economic and environmental impacts by farm type (e.g. specialization, size) and by geographical localisation. This can only be handled by models working at farm level which are able to provide very detailed results at individual/farm-type level and to capture heterogeneity across farms in terms of policy representation and impacts (i.e. policies impacts are highly differentiated according to behaviour, type and localisation of farms). As pointed out by Buyssse et al. (2007b), the more local and farm-specific interventions are, the more the modelling of farm-level elements becomes important. The other reasons of the increased attractiveness of farm level models are: (i) they can better model key issues such as climate change (impact, adaptation and mitigation), technological innovation, structural change, farm investment decision, risk management, etc., and, not least; (ii) they can be easily handled with standard computer packages, including spreadsheets and more sophisticated packages such as GAMS (General Algebraic Modelling System). The main limitation of farm models is the lack of interaction...
with the rest of the economy. That is, input-output prices cannot be generated within the model as they have to be set exogenously. However, this could be handled by linking them to partial or general-equilibrium models to have price feedback from the demand side.

This chapter first reviews and discusses the recent state of applied farm level models in the European context and then compares the set of farm models presented in the workshop (in terms of methodology, ability to capture key features of policy impacts and applicability at EU level).

2.2. Review of different types of farm level models

The literature review reveals a wide range of farm level models which investigate different questions at various locations. They can be grouped into two broad categories: (i) the farm supply models seeking to describe the decision making process of one (real or representative) farmer considered as a pure producer or “entrepreneur”, and (ii) the farm household model, which combines consumer and producer models into a single model (i.e., the consumer is also the producer), aims to represent household behaviour. Within each category, models can be classified into empirical vs. mechanistic, normative vs. positive, static vs. dynamic, deterministic vs. stochastic, discrete vs. continuous classes, etc. (Janssen and Van Ittersum, 2007; chapter 3).

This chapter focuses on farm supply models which are more relevant for the European context since farmers are predominantly commercial enterprises, dominated by profit motives and where production and consumption activities are independent.

Farm level models vary in terms of whether modelled farms are based on individual (real) farms (e.g. Evans et al. 2006; Buysse et al., 2007a) or on farm-type. Farm type refers to a predefined typology; it could be farm-group such as in CAPRI-FT (Gocht and Britz, 2011) or representative (i.e. average) farm such as in FSSIM (Louhichi et al., 2010) or in AROPAj (De Cara and Jayet, 2010). The modelling of individual farms presents some advantages, in comparison to farm-types: (i) it can better represent the heterogeneity among farms in terms of policy representation and impacts (e.g. CAP greening/distribution of direct payments); (ii) it provides the most possible disaggregation regarding farms and activities, and (iii) it reduces aggregation bias in response to policy and market signals. The main limitations are its heavy computational requirement as well as its parameterisation and calibration, which are challenging compared to farm-type models.

Five approaches are often used for building a farm level model: mathematical programming (MP) (including linear programming (LP), non-linear programming (NLP), mixed integer programming (MIP) and positive mathematical programming (PMP)), econometric approach, an advanced technique termed by Buysse et al., (2007b) as “econometric-mathematical programming” (EMP), simulation approach and agent based model (ABM). The type of farm modelling approach to choose depends often on data availability, model specification and research scope.

Farm mathematical programming models

Most of the developed EU farm level models are based on mathematical programming. This approach consists in solving at given prices and unit costs, a general maximisation problem in terms of input choice and land decisions, subject to a set of constraints representing production technology and policy restrictions. It can be used either in a normative way to determine how decision-making should take place, or in positive way to explain how actual decisions are made (Flichman and Jacquet, 2003). It can also be used as a tool for tactical planning, to emphasize the components of decision-making (i.e. comparative-static approach), or for strategic planning, to underlie the decision-making process (i.e. dynamic approach). Standard formulations of different types of mathematical programming models can be found in Hazell and Norton (1986).

Mathematical programming has several advantages justifying its increased use over recent years such as: (i) it allows, thanks to its primal based approach, the explicit representation of behaviour and technology. This specification facilitates interdisciplinary research on agri-environmental interaction and makes possible the modelling of technology changes and the environmental assessment of agricultural systems (e.g. the reliability of input coefficients such as fertiliser and pesticide application rates per activity is very important to account for environmental effects); (ii) it permits the modelling of complex policy constraints under which behavioural function cannot be derived easily, or not at all (Heckelei and Wolf, 2003); (iii) it is flexible in terms of incorporating policy, economic and environmental constraints (e.g. the conversion of technical measures into input costs can be very difficult or even impossible); (iv) it can easily capture elements of the basic economic theories such as the new institutional transactions cost theory (Buysse et al., 2007b); (v) contrary to an econometric approach, which is limited to policies/ technologies for which past observations are available (i.e. ex-post analysis), mathematical programming is suitable for both ex-post analysis as well as for the appraisal of new technological/policy options (ex-ante and ex-post analysis); (vi) contrary to simulation models which focus only on financial impact analysis (income effects, farm viability, cash flow), mathematical programming can deal

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3 For a review on farm household models see Taylor, 2002 and Louhichi et al., 2012.

4 For a review on PMP models see Heckelei and Britz (2005), Henry de Frahan et al. (2007) and Heckelei et al. (2012).
Several farm mathematical programming models have been applied during the last decade to address a multitude of questions in agricultural systems. Recently, Janssen and Van Ittersum (2007) reviewed studies using these kinds of models, focusing mainly on normative programming approaches. As an example of recently published farm programming models, we can cite those used (i) to assess the impact of EU Common Agricultural Policy (FARMIS (Offermann et al., 2005; Onate et al., 2006; Riesgo and Gomez-Limon, 2006; Semaan et al., 2007); FSSIM (Louhichi et al., 2010); AGRISP (Arfini and Donati, 2011); CAPRI-FT (Gocht and Britz, 2011)); (ii) to handle landscape and resource conservation problems (Bamière et al., 2011; Schuler and Kachele, 2003; FAMOS (Schönhart et al., 2011)); (iii) to analyze environmental issues (Ekasingh et al., 2005; Nousiainen et al., 2011); (iv) to anticipate farms responses to climate change (Butt et al., 2005; Dueri et al., 2007; AROPAj (De Cara and Jayet, 2011)); etc.

Econometrically estimated farm models

The second approach rests in econometrically estimated farm models. The use of an econometric approach for modelling farmer behaviour is less widespread compared to mathematical programming. Most of the econometrically estimated farm models are built for representative farms as modifications of the standard short run profit maximization model developed by Chambers (1998). In this framework, profit (or utility) maximization is assumed to derive behavioural functions representing first order conditions, where parameter restrictions and/or the choice of the functional form guarantee regularity. The biggest advantage of this dual approach is its full empirically based simulation behaviour as well as its ability to test for underlying behavioural assumptions (Gocht and Britz, 2011). It also offers a flexible and theoretically consistent specification of the technology and allows testing for the relevance of parameters given an adequate data set (Howitt, 2005). However, the often highly computational time of econometric models and their data-intensive nature limit their use. Moreover, additional constraints cannot be easily incorporated and the choice of a functional form is restricted because of analytical limitations in driving the behavioural function to be estimated (Heckelei and Wolff, 2003). Another drawback is that only changes in existing policies, accounted for in the estimation phase, can be simulated. As such, they are poorly suited to investigating the impact of policy reforms based on "new" instruments. The other serious disadvantage of these duality based models is the missing explicit technology description where input demands can typically not be allocated to activities. This renders it difficult to link their results to biophysical models, useful for assessing the environmental impacts of agricultural systems.

Among the econometrically estimated farm model reviewed, the following modelling targets included (i) price uncertainty and minimum prices (Chavas and Holt, 1990; Coyle, 1992; Oude Lansink, 1999), (ii) production quotas (Fulginiti and Perrin, 1993; Helming et al, 1993; Gardebroek et al, 1999; Boots and Peerlings, 1999), (iii) tradable output quotas (Guyomard et al, 1995 and 1996a; Boots et al, 1997), and (iv) land allocation and direct payments (Guyomard et al, 1996b; Oude Lansink and Peerlings, 1996; Ball et al, 1997; Moro and Sckokai, 1998). More recently, Sckokai and Moro (2006) developed an econometrically-estimated farm model for modelling the impact of the CAP single farm payment based on farm investment and output.

Econometric-mathematical programming farm models

The third category of farm level models is based on the so-called "Econometric-mathematical programming" approach. This approach was introduced by Heckelei and Wolff (2003) as an alternative to Positive Mathematical Programming. Based on multiple observations, this approach consists in estimating the parameters of the programming model using the optimal conditions as estimating equations, and, then, to employ estimated parameters in the programming model for running simulation scenarios. As stated by the authors, using EMP for agricultural models has two advantages. First, the limitations of the functional form, inherent to many PMP applications, are attenuated. Second, new activities can be introduced based on estimated functions (Buysse et al., 2007b). Despite its attractiveness, this approach is rarely applied to policy analysis, mainly because of data availability and numerical solving problems. The only application at farm level was done by Buysse et al. (2007a) to analyse the reform of the Common Market Organisation in the EU's sugar sector. Here, they used a sample of 117 Belgian sugar beet farms across 9 years to estimate parameters of a cost function quadratic in activity levels by employing GME on the following modelling targets included (i) price uncertainty and minimum prices (Chavas and Holt, 1990; Coyle, 1992; Oude Lansink, 1999), (ii) production quotas (Fulginiti and Perrin, 1993; Helming et al, 1993; Gardebroek et al, 1999; Boots and Peerlings, 1999), (iii) tradable output quotas (Guyomard et al, 1995 and 1996a; Boots et al, 1997), and (iv) land allocation and direct payments (Guyomard et al, 1996b; Oude Lansink and Peerlings, 1996; Ball et al, 1997; Moro and Sckokai, 1998). More recently, Sckokai and Moro (2006) developed an econometrically-estimated farm model for modelling the impact of the CAP single farm payment based on farm investment and output.
Farm simulation models

Farm simulation models are the fourth category of models that have been used for representing farmer behaviour. They consist of statistical relationships estimated from historical data as well as accounting identities used to simulate the behaviour of a real system. As in other modelling approaches, two types of simulation models exist namely deterministic and stochastic models, based on the type of agricultural systems being modelled (Strauss, 2005). Stochastic models incorporate risk by assigning probability distribution to specific exogenous and endogenous variables. Contrary to the mathematical programming approach, which could be used for both positive and normative purposes, the simulation approach is purely positive and only used for representing or imitating the real system as closely as possible. The main limitation of this kind of model is the impossible adjustment of farmer behaviour under different policy scenarios (i.e. no change on land allocation under different scenarios). Moreover, because there is no optimisation in such models (i.e. no single optimum solution is obtainable from a typical simulation model), the researcher/model developer has to decide on the number of alternative options to be simulated and on the best option. This implies that the simulation process is, in many instances, costly and time consuming. Another shortcoming is that a lot of time is spent on validating and verifying the model, and in many cases very little accurate historic data exist with which the model can be validated.

The well-known farm simulation models available from the literature are (i) the Farm Level Income and Policy Simulation Model (FLIPSIM) developed by Richardson and Nixon (1986) to simulate the impacts of alternative (agricultural, energy and environmental) policies, technology changes and income taxes for 99 representative crop and livestock farms across the USA; and (ii) the Financial Economic Simulation Model (FES) developed by LEI, Wageningen University, to answer questions regarding the financial-economic development of individual agricultural enterprises in the Netherlands.

Agent-based models

The last category of farm level models is the agent-based model (ABM) such as the AGRIPOLIS model (Kellermann et al., 2008). Agent-based modelling is a powerful simulation modelling technique that has seen a number of applications in the last few years in different scientific domains. In agent-based modelling, a system is modelled as a collection of autonomous decision-making entities called agents. Each agent individually assesses his or her own situation and makes decisions on the basis of a set of rules (Bonabeau, 2002). The main advantages of agent-based models of agricultural structure are the explicitly modelling of farm interaction (i.e. modelling the transfer of tradable factors among farms) and the consideration of spatial dimension of agricultural activities (Happe, 2004). These two aspects cannot be easily captured through standard mathematical programming and econometric models. Although very interesting for investigating issues such as structural change, these models are extremely time-consuming in terms of parameterisation and calibration and thus are not (yet) applicable for large-scale assessment. Bousquet and Le page (2004), as well as Matthews et al. (2007), provide a review of application of Agent Based Models in agriculture. Beside the AGRIPOLIS, the most frequently used ABM for Agricultural Landscape Analysis are (i) the Schreinemachers and Berger's (2011) model developed to simulate human-environment interactions in agricultural systems; (ii) the Parker et al.’s (2003) model used to analyse land use and land cover change (MAS/LUCC); (iii) the Heckbert's (2011) model applied for modelling emissions trading for coastal landscapes in transition; and (iv) the Common Resources Management Agent-based System (CORMAS) developed by CIRAD for application in the field of natural resource management (Bousquet et al. 1998).

The main finding from this short literature review is the highest number of publications on farm level models and its substantial increase over time (see Figure 2A in van Wijk et al., 2012). However, a large number of existing farm level models are developed for specific purposes and locations and are not easily adaptable and reusable. They are only usable for a single purpose and location for which they were initially developed; they cannot be used as stand-alone for other applications and contexts (e.g. climate, soils and socio-economic conditions). Except some particular models that will be detailed below, farm level models that allow for flexible impact assessment for a range of issues and functions at EU-wide scale are scarce. This seems to be due, on the one hand, to the limited data availability and the diversity of situations and policy schemes across EU-27 and, on the other hand, to the need of a considerable collaborative effort between scientists, programmers and software engineers to provide a user-friendly, easily-accessible modelling system.

Having in mind these limitations, the models presented in the workshop were selected according to four main criteria (i) scientific soundness; (ii) their potential for application at EU-wide scale; (iii) relevance for policy impact analysis; and (iv) reliance on FADN/FSS data. This implies that our sample covers only partially the literature on farm level modelling and there are a wide range of farm models based on specific data sources (other than FADN) or working at very local level which are not surveyed. Moreover, there are a set of other FADN based models which are not included in the sample simply because they do not correspond to our selection criteria.

A set of farm models for non-EU countries were also presented in order to gather experience of similar exercises in other world regions.
2.3. Comparison of most relevant farm level models

This section provides a brief description and comparison of the surveyed farm level models in terms of methodology, geographical and product coverage, data use, policy representation, and behavioral considerations. This comparison is based on information published in papers and websites and completed by input from model developers.

### 2.3.1. Global overview on the selected farm models

In total 13 models have been selected and presented at the workshop. 10 are EU based models and 3 are for non-EU countries. Table 1 provides the names of the selected

<table>
<thead>
<tr>
<th>Model name</th>
<th>Institution/s</th>
<th>Geographical coverage</th>
<th>Farm heterogeneity</th>
<th>Product coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAPRI-FT</td>
<td>Vti, U. Bonn (DE), IPTS</td>
<td>EU-25 (NUTS-2)</td>
<td>1900 Farm types* (size, spec., region)</td>
<td>Crop (37) &amp; livestock (16) activities</td>
</tr>
<tr>
<td>FES</td>
<td>LEI, Wageningen (NL)</td>
<td>EU-25</td>
<td>1500 individual farms</td>
<td>Field crops, horticultural, animal</td>
</tr>
<tr>
<td>Integrated estimation &amp; simulation model</td>
<td>U.C. Louvain (BE), Vti (DE)</td>
<td>EU (applied for selected EU MS/regions)</td>
<td>Individual farms</td>
<td>Dairy products, other animal products, wheat, other cereals, oilseeds, potatoes, sugar beet, other industrial crops</td>
</tr>
<tr>
<td>AROPAj</td>
<td>INRA-UMR-EP (FRA)</td>
<td>EU 24 (EU 25 – Malta)</td>
<td>1307 Farm types (size, spec, region, altitude)</td>
<td>Crops (24), grassland &amp; livestock activities</td>
</tr>
<tr>
<td>FARMIS</td>
<td>Vti (DE)</td>
<td>Germany, Switzerland &amp; selected EU MS</td>
<td>630 Farm type (size, spec, region, conventional/ organic)</td>
<td>Crop (31) &amp; livestock (22) activities</td>
</tr>
<tr>
<td>FSSIM</td>
<td>SEAMLESS Association</td>
<td>13 NUTS-2 in EU</td>
<td>Partial EU coverage</td>
<td>Arable crops, industrial crops, root tuber, livestock</td>
</tr>
<tr>
<td>AGRIPOLIS</td>
<td>IAMO (DE)</td>
<td>4 NUTS-2 &amp; 10 NUTS-3</td>
<td>Farm types</td>
<td>Arable, fodder, grassland, livestock activities</td>
</tr>
<tr>
<td>AGRISP</td>
<td>U. Parma (IT)</td>
<td>Italy</td>
<td>900 Farm types (size, spec, altitude, province, region)</td>
<td>Main arable, industrial &amp; livestock</td>
</tr>
<tr>
<td>FAMOS</td>
<td>BOKU (Austria)</td>
<td>Austria</td>
<td>Farm types (size, spec, part/full time, conventional/ organic, biophysical conditions)</td>
<td>All major crops (organic/ conventional) &amp; livestock, forestry products</td>
</tr>
<tr>
<td>Econometric farm model</td>
<td>U.C. Piacenza (IT)</td>
<td>Italy (extension to other MS under development)</td>
<td>Individual farms</td>
<td>Arable crops (3 subcategories)</td>
</tr>
<tr>
<td>SAPIM</td>
<td>OECD</td>
<td>Case studies (Finland, Switzerland, Japan, US)</td>
<td>Farm types (productivity, agri-environment)</td>
<td>Rice, cereals, oilseeds, pasture, milk</td>
</tr>
<tr>
<td>FLIPSIM</td>
<td>Texas A &amp; M University (USA)</td>
<td>USA, Kenya &amp; Mexico</td>
<td>Mixed &amp; Non-mixed EU models</td>
<td>Crops (20) &amp; livestock (8) activities</td>
</tr>
<tr>
<td>MIDAS</td>
<td>Dep. Agriculture &amp; Food, Cooperative Research Centre (Australia)</td>
<td>Southern Australia</td>
<td>Farm types</td>
<td>Arable crops, pastures, sheep, forestry</td>
</tr>
</tbody>
</table>

*Farm type could be farm-group or representative (i.e. average) farm.
models and the institutions in charge of their development and maintenance5.

Only 4 out of the 10 EU based models have a full EU coverage (CAPRI-FT, FES, AROPaj and Integrated estimation & simulation model). Although the integrated estimation & simulation model can be implemented at EU level, it was actually applied for only selected MS or regions and/or for specific agricultural sectors. An EU wide application was not yet developed. The rest of EU based models cover either a selected set of MS/regions (FARMIS, FSSIM, AGRIPOLIS and SAPIM) or a specific MS (FAMOS, AGRISP and Econometric farm model). The remaining three models (SAPIM, FLPSIM and MIDAS) cover non EU countries (Table 2.1).

Four out of the EU-based models are individual (real) farm models and the rest are farm-type (representative) models. The number of farm types (representative farms) differs strongly across models and depends on data availability and model focus. The most often used typology criteria for all farm type-based models are size and specialisation. The other used criteria are: biophysical condition (e.g. climate, altitude, soil type, etc.), intensity/productivity and farm orientation (conventional, organic, etc.). The key factors in choosing typology criteria are the research topic and the availability of data which often goes beyond FADN/FSS. Moreover, there appears to be a trade-off between model complexity and farm coverage. For example, individual farm models tend to have either simpler structure in terms of behavioral assumptions or smaller regional coverage. In contrast, farm-type models either cover larger regions or have higher level of complexity in representing environmental and economic behavioral structure.

In terms of product (commodity) coverage, all the selected models have a good representation of main agricultural sectors. The well covered sectors are arable crops and livestock. Fruits, vegetables, permanent crops and forest sectors are, in contrast, less represented (Table 1). The level of disaggregation of production activities varies across models and depends on the model's geographical coverage, the availability of data and the modelling approach. It seems that the production disaggregation is negatively correlated with the geographical coverage, except for CAPRI which has a high geographical coverage (1900 farm types) and a high disaggregation level of production activities (53 production activities). In general, farm mathematical programming models have a high disaggregation level, compared to others farm models. They provide greater product detail and include heterogeneous land endowments as well as different technology options. For example, the degree of disaggregation in MIDAS is very important, with about 50,000 matrix coefficients, including all major crops, more than 25 animal classes, 8 soil types and 20 to 50 possible rotation options per soil.

In terms of methodology, the selected farm level models present some similarity but also a lot of significant differences. The main resemblance is that most of the selected models are based on mathematical programming and, more specifically, on Positive Mathematical Programming (PMP). This is not unexpected since most of the recent applied programming models in the European arena rely on PMP. However, the PMP variant of use differs across models. In some models, PMP terms are estimated using multiple observations such as in AGRISP or CAPRI-FT, and in other models, such as in FSSIM or FARMIS, they are estimated using exogenous information. The main advantage of PMP programming models is their ability to exactly reproduce observed behaviours during a reference period, without requiring a series of observations such as with econometrics. The remaining three programming models are based on linear programming (MIDAS), non-linear programming (SAPIM) and Mixed Integer (Non-Linear) Programming (AROPaj). These three models rely on profit-

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5 More details about the surveyed models are given in the following chapters.

6 The FSS covers all the holdings of at least one hectare (ha) and also those holdings with a UAA of less than 1 ha where their market production exceeds certain natural thresholds.

7 The weighting factors are calculated based on the Farm Structure Survey already defined above (FSS) and reflect the number of farms a sample farm represents in the population.
maximising behaviour and attempt to find the optimal farm management practices from a set of production activities, derived from either engineering knowledge, agronomic models or statistical database, and taking into account resource, crop rotations, feeding, policy and other agro-economic constraints. Although the degree of disaggregation in these models is very important, they are more normative than descriptive, which is not fully in line with recent policy modelling needs.

Only one model was econometrically estimated (i.e. Econometric Farm model) (Table 2.2). Based on FADN data, this model was used to assess the long term impact of price support and direct payments on farmer behavior under uncertainty. This model was initially developed for Italy and is now extended to the main EU crop producing countries (Germany, France, United Kingdom and Spain). According to our literature review, this is the only large-scale econometric farm model that exists and which could be extended to the whole EU-MS. As explained above, econometric Farm models are less widespread compared to Mathematical Programming models although several programming models use econometric tools in different stages of model development and/or application (e.g. for calibration and/or parameterization).

As in macro-level models, the comparative static approach has certainly not gone out of fashion in farm modelling. In fact, the majority of selected models are static-comparative (i.e. they do not explicitly take account of time). Only two models (FES and econometric model) favour dynamic or dynamic-recursive approaches which permit them to generate time paths of variables and lagged adjustment patterns. The use of a dynamic approach depends on the issue at stake. It is not always suitable, as it can be a complicated task in terms of data requirements and model complexity. Moreover, several aspects which are time dependent can be easily captured in a static model such as crop rotations or herd dynamic. In agriculture, dynamic models are particularly used for modelling investment decisions (e.g. FES, the econometric model), or for making long-term predictions of the changes in farm structure and for assessing the sustainability of

| Table 2.2: Methodology and data sources of the selected models |
|---------------|---------------------|----------------|-----------------|
| Model name    | Data sources        | Model Type     | Time            | Risk & uncertainty |
| CAPRI-FT      | FADN, FSS, CAPRI data | PMP            | Comparative-Static | X             |
| FES           | FADN, Dutch BIN     | Simulation model | Recursive Dynamic | X             |
| Integrated estimation & simulation model | FADN, EUROSTAT, OECD, International Penn Tables | EMP | Comparative-Static | X             |
| AROPaj        | FADN, Land cover/use statistics (LUCAS), biophysical data | MIP | Comparative-Static | X             |
| FARMIS        | FADN, Farm management manuals | PMP | Comparative-Static | X             |
| FSSIM         | FADN, expert knowledge | PMP | Comparative-Static | √             |
| AGRIPOULIS    | FADN, FSS, Farm management pocket books | ABM | Comparative-Static | X             |
| AGRISP        | FADN, IACS-AGEA (land use) | PMP | Comparative-Static | √             |
| FAMOS         | FADN, FSS, SGM catalogue, IACS, EAA, Price statistics, bio-physical data | NLP | Comparative-Static | √             |
| Econometric farm model | FADN, EUROSTAT | Econometrically estimated model | Dynamic | √             |
| SAPIM         | Field experiment, crop budgets, literature review, etc | NLP | Comparative-Static | X             |
| FLIPSIM       | Interview farmers, FAPRI,USDA outlook, Congressional Budget | Simulation model | Comparative-Static | √             |
| MIDAS         | Expert knowledge, census, rural banks, biophysical data | LP | Comparative-Static | √             |

Notes: PMP: Positive Mathematical Programming; LP: Linear Programming; NLP: Non Linear Programming; MIP: Mixed Integer Programming; EMP: Econometric Mathematical programming; √: implemented (and tested); X: not implemented.
farming systems. A 5 years time-horizon was adopted in both surveyed dynamic models for conducting impact analysis. According to the model developers, longer term impacts are less relevant for policy makers due to the high uncertainty on macro-economic variables, structural change and other farm decision variables.

Only few EU based models take into account risk and uncertainty (AGRISP, FAMOS, FSSIM and Econometric model). All the models with a full EU coverage and most with partial EU coverage do not embed risk and uncertainty. This implies that the modelling of risk and uncertainty in a large-scale system is still a challenging task. The sources of risk taken into account and the used approach for modelling risk vary across models. For example, in FSSIM two sources of risk are accounted for, namely, market and climate risk, using a mean-standard deviation approach (Hazell and Norton, 1986). However, in FLIPSIM market and output risk (i.e. not only climate risk) are included, by assigning probability distribution to all stochastic exogenous variables (i.e. all prices and outputs) using the Monte Carlo method.

The other selected farm models are simulation models (FSS, FLIPSIM) and an agent based model (AGRIPOLIS).

2.3.3. Model specifications and assumptions

This section provides a quick overview of the main specifications and assumptions of the selected farm models and highlights their capability in modelling key aspects such as technological innovation, management choice, structural change, farm investment decision, and production factor allocation, etc.

As shown in Table 2.3, there is, on the one hand, a significant heterogeneity across models regarding the set of aspects that are able to model and, on the other hand, no model is able to address all of these aspects at the same time. For example, except the AGRIPOLIS model, none of the selected models can capture endogenous structural change. Most of models independently simulate the behaviour of each farm/farm-type under fixed size, so they cannot capture the interaction among farms for factor markets (such as land, labour and capital). This implies that the possibilities of simulating land market, off-farm labour, size change and farm entry/exit to the sector are not allowed. Some farm models, such as FARMIS or CAPRI-FT, attempt to capture some of these issues through projected trends estimated exogenously using Markov or econometric approaches. However, these two applications are still under test and not (yet) fully implemented. Other models, such as AGRISP, attempt to partially capture structural change by allowing only farm re-specialization (i.e. farm size is fixed).

All surveyed models allow for the transfer of land between production activities within farms. In contrast, the explicit consideration of capital and labour market is less represented and it is missing in most farm programming models. This is due to limited data availability and to the static nature of the majority of these models. In PMP models, such as CAPRI-FT and FSSIM, labour and capital costs are captured indirectly by the so-called PMP terms.

As shown above, most of the EU-based models use FADN. However, this database provides only total variable costs and total variable inputs per input category (e.g. seeds, fertiliser, pesticide, feed, etc.), without indicating the input use (and unit costs) of each (crop and animal) output which is needed to capture policy impacts and to represent technologies in an explicit way. To overcome this lack of information and predict input use per crop and animal, different approaches have been used. For example, AGRIPOLIS and FSSIM use engineering handbooks and expert knowledge to estimate input coefficients. FARMIS and FAMOS utilise farm management books and externally estimated yield-dependent input functions. AROPAj uses yield response functions generated from biophysical model to estimate nitrogen use per crop and for the remaining inputs it uses other Pan EU databases. CAPRI-FT estimates fertilizer input coefficients from national expert surveys and derives the remaining inputs from FADN using the Highest Posterior Density estimator. AGRISP allocates total variable cost to production activities simultaneously with the estimation of the non-linear cost function using a “Generalised PMP estimator”. Econometric and simulation models do not allocate variable inputs to production activities, which could be very constraining because the reliability of input coefficients such as fertiliser and pesticide application rates per activity is very important to account for environmental and climate change impacts.

The capacity of the selected models for modelling technological change and management practice variation is quite different. Mathematical programming models are defined as those with a more explicit representation of technology and which are more relevant for assessing the impacts of new technologies as well as for simulating the switching between management practices. This is entirely true but, firstly, other models are also able to capture such issues like Agent Based Model and Simulation models, Secondly, the level of detail provided by programming models varies across models. For example, in CAPRI-FT crop production activities are presented by a low and high yield variant, so in case of price/policy/climate change the model can only switch between these two variants. In other models, such as MIDAS or FSSIM, a wide range of production activities with different intensity levels are defined, which increases the solution space of the model and yields smooth responses to policy changes. AROPAj uses another approach based on the inclusion of yield functions as an alternative to discrete current and alternative management options. Apart from increasing the model's adjustment capacity, a detailed description of farm management practices facilitates the
link with biophysical models and the assessment of agri-environmental policies and climate change impacts. However, model calibration and validation become more complicate.

2.3.4. Modelling CAP Pillar I and II measures

All the selected EU farm level models are supposed to fulfil the criterion that they are relevant for current CAP issues. This involves the CAP first pillar measures such as; direct payments (coupled and decoupled), price support, set-aside, production quota and cross-compliance regulations as well as the CAP second pillar measures (e.g. agri-environmental measures) for providing relevant analysis related to rural development and agricultural public goods and externalities.

A short review of the main specification and application of the surveyed models shows that, firstly, no model is able to entirely fulfil policy requirement and, secondly, there is a significant difference in the present state of modelling of the first and second pillar measures (Table 2.4). In fact, in all selected EU models the modelling of the first pillar measures is noticeably more advanced than the modelling of the second Pillar 1. With the exception of cross-compliance measures which are complex and more farm-specific, all the other CAP first pillar measures are well represented in the selected farm models. In contrast, apart from LFA and AEM measures which are implemented in some farm models, all the CAP second pillar measures are not taken into account. This difference between first vs. second pillar state of modelling is due, on the one hand, to the fact that former policies (i.e. first pillar) were implemented much earlier than the latter ones, therefore more theoretical and empirical work was conducted. On the other hand, the intervention logic of first pillar measures is much simpler and their modelling is less complex requiring fewer data compared to second pillar measures. All experts agreed that the second pillar policies are so diverse across measures, regions and Member States and, thus, they cannot be easily captured through one EU-wide model. This will emerge as the key challenge in coming years, especially with more substantial budgetary shift from first to second pillar.

<table>
<thead>
<tr>
<th>Models additional features</th>
<th>Structural change</th>
<th>Allocation of variable inputs across activities</th>
<th>Technological progress</th>
<th>Changes in management practices</th>
<th>Public goods &amp; Externalities</th>
<th>Interaction with agri-outputfactor markets</th>
<th>Interaction with rest of the economy</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAPRI-FT</td>
<td>X</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>FES</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Integrated estimation &amp; simulation model</td>
<td>X</td>
<td>√</td>
<td>✓</td>
<td>X</td>
<td>/</td>
<td>/</td>
<td>X</td>
</tr>
<tr>
<td>AROPAj</td>
<td>X</td>
<td>√</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td>FARMIS</td>
<td>/</td>
<td>√</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td>FSSIM</td>
<td>X</td>
<td>√</td>
<td>✓</td>
<td>√</td>
<td>√</td>
<td>✓</td>
<td>X</td>
</tr>
<tr>
<td>AGRIPOLIS</td>
<td>✓</td>
<td>√</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>/</td>
</tr>
<tr>
<td>AGRISP</td>
<td>✓</td>
<td>√</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>FAMOS</td>
<td>X</td>
<td>√</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>X</td>
<td>✓</td>
</tr>
<tr>
<td>Econometric farm model</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>SAPIM</td>
<td>/</td>
<td>√</td>
<td>X</td>
<td>√</td>
<td>√</td>
<td>✓</td>
<td>X</td>
</tr>
<tr>
<td>FLIPSIM</td>
<td>✓</td>
<td>√</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>MIDAS</td>
<td>✓</td>
<td>√</td>
<td>✓</td>
<td>✓</td>
<td>X</td>
<td>✓</td>
<td>X</td>
</tr>
</tbody>
</table>

*Note: Evaluation criteria: ✓: implemented (and tested); X: not implemented; /: partially implemented (prototype, not fully implemented or a yes/no answer)*
This chapter has provided a short overview of the most applied farm-level models in the EU, investigating their specificities as well as their strengths and weaknesses in supporting EU policy makers. The review highlights, amongst other issues, the multiplicity of farm models across the EU and their wide heterogeneity with respect to methodology, modelling assumption, data sources, geographical coverage and risk consideration, etc. The main conclusions to be drawn from this review are:

- Five approaches are used for building a farm level model: mathematical programming, econometric approach, econometric-mathematical programming, simulation approach and agent based model. The type of farm modelling approach actually applied depends often on data availability, model specification and research scope. However most frequently used models are based on mathematical programming.

- In total 13 models have been selected and presented at the workshop. 10 are EU based models and 3 are from non-EU countries.

- Even though the surveyed 10 EU-based models fulfill the selection criteria (scientific soundness; application at large scale; relevance for policy impact analysis; reliance on FADN/FSS databases) no single model seems to suit all purposes. Each of the models has its own merits, given the goals addressed and the issues treated with the model.

- Most of the surveyed (EU and non-EU) models use heterogeneous data sources; however the applied procedure for ensuring consistency and compatibility between these data sources is not well developed (except CAPRI-FT).

- Data requirements are very heterogeneous depending on the model methodology and on the degree of detail covered in the model. Often, it is needed to go beyond FADN/FSS data to address all relevant issues related to farm modelling especially in the area of agronomic and environmental data.

- There is a trade off between the farm type approach and the individual farm approach (FLIPSIM vs. FSSIM), on the one hand, in terms of detail in behavioral assumptions and other policies.

### Table 2.4: State-of-the-art of modelling the CAP in the surveyed farm level models

<table>
<thead>
<tr>
<th>Market policies</th>
<th>Rural Development policies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coupled payments</td>
<td>Decoupled payments</td>
</tr>
<tr>
<td>CAPRI-FT</td>
<td>√</td>
</tr>
<tr>
<td>FES</td>
<td>√</td>
</tr>
<tr>
<td>Integrated estimation &amp; simulation model</td>
<td>√</td>
</tr>
<tr>
<td>AROPA</td>
<td>√</td>
</tr>
<tr>
<td>FARMIS</td>
<td>√</td>
</tr>
<tr>
<td>FSSIM</td>
<td>√</td>
</tr>
<tr>
<td>AGRIPOLIS</td>
<td>X</td>
</tr>
<tr>
<td>AGRISP</td>
<td>√</td>
</tr>
<tr>
<td>FAMOS</td>
<td>√</td>
</tr>
<tr>
<td>Econometric farm model</td>
<td>√</td>
</tr>
<tr>
<td>SAPIM</td>
<td>Coupled &amp; Decoupled payments, cross-compliance</td>
</tr>
<tr>
<td>FLIPSIM</td>
<td>Most US farm programs</td>
</tr>
<tr>
<td>MIDAS</td>
<td>Input &amp; output price changes</td>
</tr>
</tbody>
</table>

Note: Evaluation criteria: √: implemented (and tested); X: not implemented; LFA: Less Favoured Areas; AEM: Agri-Environmental Measures; R&D: Research and Development co-funding; RD: Rural Development
geographical coverage and, on the other hand, on capturing farm heterogeneity across the EU.

- The majority of selected models are comparative static. Only two models (FES and econometric model) apply dynamic approaches. The main reason behind this choice is that the use of the dynamic approach is not always suitable as it can be a complicated task in terms of data requirements and model complexity. Moreover, several aspects which are time dependent can be easily captured in a static model such as crop rotations or herd dynamics.

- In terms of product (commodity) coverage, all the selected models have a good representation of the main agricultural sectors, in particular the arable crops and livestock sectors.

- Only few EU based models take into account risk and uncertainty (AGRISP, FAMOS, FSSIM and Econometric model). All the models with a full EU coverage, and most models with only partial EU coverage, do not embed risk and uncertainty.
Chapter 3. General methodological issues on farm level modelling

Thomas Heckelei
Department of Food and Resource Economics, University of Bonn, Germany

3.1. Introduction

There are two objectives addressed in this chapter. First, this introduction discusses some general methodological characteristics by which farm level models can be distinguished. The basic characteristics of normative versus positive models, programming versus models based on behavioural functions, static versus dynamic and finally deterministic versus stochastic models are briefly introduced in view of different potential aims of analysis. Second, challenges associated with the objective of the workshop defined in chapter 1 are discussed. Specifically, we will look at issues of representing heterogeneity, market interlinkages and dynamic adjustment as well as some additional challenges considered of importance for developing a large scale, farm level modelling system. The final section of the chapter concludes and gives recommendations.

The term “farm level” is here understood in the broader sense, i.e. economic models considered reflect situations of choice relevant at farm level and a set of farm level models in a given region depicts some degree of heterogeneity across farms in the region. This definition does not restrict considerations to individual farm modelling exercises but also includes farm type/representative agent models. This way we follow the model (and participant) selection and delineation implicit in the program of the farm modelling workshop. Apart from reflecting heterogeneity across farms, the criterion of “representativity” in the sense of political relevance at national or EU level played an additional role in pre-selecting approaches discussed and evaluating their suitability for different aims. This is closely connected to interlinking issues between market- and farm-level models.

Modelling of policy impacts relevant for the policy process is expected to have ex-ante simulation capabilities. Policy makers need to know what the impact of debated policy options is in a likely future environment while separating policy from other driving factors. Impacts of implemented policies depend on behavioural adjustments to these policies and consequently farm models need to project farm behaviour in some realistic (validated) fashion. They should be “positive” models i.e. those that try to explain or predict farm level behaviour and are consequently generally capable of evaluating the impact of policy options compared to a reference situation. This can only be successfully done if models depict relevant observed behavioural responses and are based on theories that explain the reaction of farmers to changing conditions robustly over time. Normative models prescribing choices that are optimal with respect to a defined objective, for example those supporting farm management decisions in a dialogue with the farmer, are not considered here.

An almost philosophical issue often discussed is the methodological choice between the two main concepts for farm level modelling, programming models versus simulation models based on behavioural functions (such as supply, variable input demand, land demand, profit functions). These two approaches root in different strands of literature and modellers generally have competence in either one or the other. Programming models are defined as those with at least a partially explicit technology representation in terms of production activities defined by specific input-output combinations and an explicit implementation of optimizing behaviour choosing activity levels. Models based on behavioural functions typically have only an implicit technology representation (duality based models where technological relations are embedded in price-quantity relationships) with very few exceptions in the last two decades (primal models with explicit production technologies, see for example Chavas and Holt 1996). The behavioural functions are often econometrically estimated using time series or cross sectional data and therefore the term “econometric models” is repeatedly used to distinguish them from programming models. Econometric farm models using behavioural functions are generally seen as “positive” mainly because they specify the parameters based on past observations. Programming models have normative roots, i.e. they ask what should be under certain objectives of the agents considered. This is because they have their origin...
in logistical and farm planning contexts and were used as decision support tools. In today's reality this distinction between the two methodological worlds is not so clear anymore (Heckelei and Wolff, 2003). Programming models specified in the spirit of “Positive Mathematical Programming” (PMP) offer varying degrees of “positiveness”. Some even rely on econometric estimates of parameters (e.g. Buysse et al. 2007; Jansson and Heckelei 2011; for a recent survey see Heckelei et al. 2012). Consequently, the term “econometric models” does not seem useful anymore in distinguishing models with behavioural functions from programming or explicit optimization models.

Production details, i.e. differentiated multi-input and multi-output situations are often easier to handle in the context of programming models as the specification of activities and constraints is highly flexible allowing to depict any complex non-linear input-output relationships (to be distinguished from typically linear activity level definitions) for which information is available. The estimated or calibrated parameters of behavioural functions – if based on microeconomic theory – implicitly assume some optimizing behaviour and represent complex technologies at the same time. Any “structural change” in these underlying processes and relationships renders the estimated parameters less valid and often requires re-estimation. Consequently, programming models show advantages in situations where specific technology changes expected for the future are of relevance (adoption of new technologies following indicator based policy formulations, for example Lengers and Britz 2012) or where interactions with the biophysical sphere are at the core of the policies to be assessed (e.g. environmental impacts or climate change adaptation and mitigation interaction, for example Jayet 2012)). Input-output coefficients are often expert-based and specified with information from an engineering background and ease the interdisciplinary collaboration. However, the empirical basis of programming models is comparatively weak in models of traditional type with respect to explaining observed production activity choice. The newer strand of PMP type models do better in this respect but generally still lack the rigorous economic rationale embedded in most behavioural function models (Heckelei et al. 2012).

Another important distinction is given by static versus dynamic models of farm behaviour. Solutions of traditional type with respect to explaining the participation of the farmer in primary factor (land, labour, capital) markets.

Dynamic models can be defined as having a concrete temporal resolution (e.g. months, years) where the model behaviour at one point in time depends on the model results of the previous period. Such models can be of high interest in the case of imperfect input markets when the time path matters for the objective of analysis. For example, when inputs for the dairy herd development on a farm cannot be bought flexibly at desired quality and price at each point in time and the speed of development is relevant for the impact of policies changing milk prices. From a behavioural perspective, we can also distinguish between recursive dynamic and fully dynamic models. For the former, the farmer makes a choice on decision variables in one time period based on the conditions at the beginning of this period. The results of the decision determine the conditions at the beginning of the next period. A fully dynamic model assumes that the farmer takes all information on economic conditions in future periods and consequences of today’s decision on future time period into consideration when making a decision today. These models typically require complex expectation models and are often analytically solvable only for simple setups. However, feasible mixed integer farm programming models exist with detailed technological specifications that are fully dynamic (see for example Britz and Lengers 2012).

The final pair of terms describing contrasting model types is “deterministic” versus “stochastic”. Stochastic models are defined such that model outcomes depend on random variables in the mathematical structure of the simulation model. Consequently, model outcomes of a stochastic model for a specific farm and point in time are actually distributions of endogenous model variables. To avoid misunderstandings: econometrically estimated behavioural functions include a random error term at estimation step but for simulation, only the deterministic part is typically used by setting the error term to zero and consequently creating only one outcome per farm and point in time. Similarly, farm models reflecting uncertainty and risk behaviour are generally not stochastic. They only reflect the influence of stochastic properties of relevant variables on the (deterministic) decision.

In principle, however, estimated error distributions could serve as random elements simulating distributions of projected variables under the assumption that the stochastic properties do not change for the simulation year. Stochastic farm simulation models will likely become more relevant in the future as volatility issues on the climate (yield generation) and market side seem to increase in relevance. However, even larger scale policy impact assessment models have used stochastic versions in the past already motivated by the relevance of probabilities for crossing certain thresholds which in turn induce budgetary expenses (FAPRI 2006).
3.2. Modelling challenges

In this section we discuss general modelling challenges associated with the workshop’s objectives identified in chapter 1.

3.2.1. Heterogeneity

There is plenty of evidence that impacts of many agricultural policies depend on specific farm characteristics. Representing more heterogeneity in modelling the agricultural policies aims at

- better describing policies and
- better capturing impact of policies.

But representing an increased level of heterogeneity across farm characteristics in models is not better in all respects. Farm level data bases typically show various limitations. For example, the FADN database does not offer full coverage of the agricultural sector due to the exclusion of small farms and, due to its sampling approach, it is only representative with respect to a very limited set of variables (chosen size and specialisation classes). The Farm Structural Survey (FSS) is of the census type but here economic indicators or yields and input use are missing. Depicting more heterogeneity has also trade-offs with the quality of the parameter specification. We expect more from the data, but don’t necessarily have more data. We expect behaviour to change with farm characteristics, i.e. in econometric exercises we need to incorporate interaction terms between variables or estimate varying coefficient models. Moreover, there is little experience in analysing distributions of behaviour across farms (an exception is for example Wieck and Heckelei, 2007), let alone in validating models with respect to projecting such heterogeneity. Most econometric farm models in the literature estimate parameters of an aggregate of representative agent whose geographical extent or type is often defined by available data and based on the assumption that parameters do not differ between individual agents.

The objective of having modelling results at finer geographical scale needs to be distinguished from the one targeting farm heterogeneity. Unless spatial positioning and spatial farm interaction is specifically relevant for the analysis of a particular policy impact, representation of farm heterogeneity generally does not need to know where farms are located. Finer geographical scale could mean analysis at a lower level of regional classification or with geo-referenced individual farms. The former might imply missing representativity of existing data sets at the new geographical scale. Probably both, but at least the latter quickly runs into conflicts with the confidentiality of single farm data. This has already led to approaches artifically distributing single farm data in space based on observed characteristics, despite the fact that there exists a confidential layer of data information able to locate the farms (Kempen et al. 2011).

3.2.2. Market inter-linkages

The up-scaling of farm level policy responses to regional or EU-level market effects is irrelevant for only locally applied policy measures like many pillar 2 measures. For policies applied at a larger geographical extent, the modelling of market linkages may be important if significant adjustments of input and output quantities take place across a large number of farms. The challenge here is not the aggregation of, for example, product supply responses to national or EU market level. We do not need sophisticated aggregation theory for deriving aggregate product supply models because today’s computing power allows us to simulate with many thousand farms or farm type models. Market equilibrium can be obtained with iterative algorithms even in multi-dimensional and highly interdependent product settings (Britz, 2008).

The challenge is here that supply determinants other than product prices which were exogenous at farm scale become endogenous at larger scale. Prices for other products, variable inputs and primary factors vary with larger farm adjustments rendering the behaviour of the aggregate different from the sum of its individual components. Consequently, an up-scaling from farm to product market level may require the representation of other markets on the way. What type of market feedback is relevant depends on the geographical extent, the size of production in the considered region relative to the overall market, implemented market policies, etc.

More generally, it depends on where in the process of up-scaling input supply and output demand functions significantly move away from being perfectly elastic. For land supply in farm models with a longer time horizon, the issue might already be relevant at the local level. Limits to “transportability” of certain agricultural inputs may require considering market feedbacks for manure, fodder, young animals, and labouring already at the sub-national level.

The relevance of market feedbacks on the input side increases with the time horizon of the analysis. When incorporating strategic decisions such as investments and disinvestments that lead to changes in size and specialisation or exit/entry of farms, the interaction between farms (especially on the land market) becomes important. This is where pure farm level considerations of policy impacts lead to questionable conclusions. For example, it has been widely acknowledged that even “decoupled” direct payments may influence yearly production and growth decisions via risk reduction and liquidity effects (e.g. Goodwin and Mishra, 2006, Scokai and Antón, 2005) significantly. Considering land market feedback, however, capitalisation of direct payments in land prices might offset such effects (references land value capitalisation with reference to direct payments). Consequently, farm level analysis cannot lead to conclusions regarding the WTO compatibility, i.e. regarding the trade effect of direct payments without considering input market feedbacks.
The challenge to correctly capture the market feedbacks increases with the representation of heterogeneity at farm level. Regional or farm type supply models often implicitly incorporate some of the regional market feedbacks in the empirical parameterisation of the models, i.e. they at least empirically correct (though not in a theoretically consistent fashion) for the emerging properties when moving from individual decision makers to aggregates. The non-linear cost functions in PMP, for example, will represent some of the limited factor mobility between production activities and farms implied by the interaction of individual farms within the regions or group considered. The same holds true for econometrically estimated supply functions where resulting parameters associated with (primary) input quantities will pick up these effects. If agricultural production is modelled at the individual farm level, then these interactions require a consistent and explicit modelling with all difficulties associated with the increasing model complexity and the higher demands put upon the information in the data. For example, the conditions under which individual farms may acquire or let land resources strongly depend on the spatial competition with neighbouring farms. Even if the data was available, methodologically convincing solutions for corresponding simulation models seem to exist only through evolutionary agent based models used in the literature on farm structural change (Balman, 1997; Happe, Kellermann and Balman, 2006; Happe et al., 2008) resulting in far more complex modelling systems that have not yet proven to work at EU extent up to date.

3.2.3. Dynamic adjustments

The considerations in the last section are strongly connected to the modelling of dynamic adjustments of farm resources and the structural change of the farming sector. For long run impacts of policy measures, the adjustment of primary factor use on single farms and overall and with it the corresponding technological change is of the utmost importance. The strategic, interdependent decisions of farms lead to changes in the use of land, labour and capital. This significantly changes marginal and total productivities of factor use, comparative profitability of production activities and with it the impact of market and farm level policies in the long run.

The economic analysis and therefore also the endogenous modelling of primary factor use in agriculture require a move to the farm-household level with all consequences regarding model complexity and data requirements. Strategic decisions such as a switch to part-time farming, sector exit, (re-) investment in certain production branches or growth decisions are strongly linked to household charactersitics. The opportunity cost of labour and capital depends on qualifications of the household members and specific regional labour market conditions. A simple profit maximisation assumption, which often works well for explaining annual or sub-annual management decisions, is far from real world behaviour in this context as long term expectations on relative prices and sectoral support policies or personal preferences for working on farm play an important role. Current resource endowments of the household lead to path dependencies in view of specific capital investments and imperfect capital markets.

Different ways to model structural adjustments of farm households and the farming sector can be found in the literature (for a fairly recent review see Zimmermann et al., 2009). Markov chain models have a long tradition in analysing farm structural change using aggregate information on numbers in farm specialisation and size classes. In a ‘reduced form’ approach, the non-stationary Markov models are most often used to explain transition probabilities for farms moving between these classes by time varying determinants characterising changing policy and economic conditions. The models were mostly restricted to specific farm types and single regions. Only recently new attempts were made to better include the cross-sectional domain, thereby allowing to empirically analyse the relevance of initial structure (path dependency) and regional competition for farm structural change in a region (Hüttel and Margarian, 2005; Zimmermann and Heckelei, 2012). Apart from this theoretical motivation, some of these activities are also motivated as background work to ultimately update farm numbers (or weights) of representative farm type models in ex-ante policy simulation model at larger scale. Recent IPTS explorative projects tested the possibility to update CAPRI farm type weights in baseline simulations (IPTS, 2012).

The disadvantages of Markov-chain models for the modelling of policy relevant dynamic adjustments are manifold. Employed classifications usually have to be coarse due to data availability and methodological limitations. Class delineations are often rather arbitrary for the same reason and no information is provided on changes within the classes which may, however, be rather important if the share of farms in a certain class is large. More importantly, the connection to adjustments of primary factor use and technology changes – and thereby to many agricultural and environmental policies and their impact – is at best very indirect. Policy relevance in the notion of the workshop can only be achieved in combination with more detailed supply models as just indicated for the CAPRI model. If conceptual problems of model linking can satisfactorily be addressed, however, then this approach may at least give better information on future farm numbers and (indirectly) employment than currently available agricultural sector and market models.

A contrasting approach is offered by Agent Based Models (ABMs) of farm structural change, or more generally, of dynamic adjustments in the farming sector (Balman, 1997; Happe, Kellermann and Balman, 2006; Happe et al., 2008). Sequential market clearing algorithms allow for the dynamic interaction of individual farms represented by detailed (mixed integer) optimisation models. The farm models not only allow for an endogenous treatment of primary factor adjustments but in addition the detailed representation of agricultural production technology as typical for programming models. The models are spatially explicit and spatial structure is relevant for market outcomes. The sequential, process-type approach to market clearing ensures a tractability of market linkages.
between complex agents which could not be achieved with neoclassic dynamic equilibrium approaches. Considerable challenges exist in validating model behaviour of ABMs using observed developments. Statistical meta model approaches as applied in Happe (2004) could be further elaborated for this purpose. So far, ABMs are also limited in their regional extent due to high data requirements, large model set-up and update cost as well as large personal investment when entering this type of modelling activity. Potential possibilities to simplify ABMs in the context of dynamics at regional scale could perhaps be investigated using experiences in the growing use of ABMs in financial market models (Hommes, 2006).

As already indicated above, the adoption of new technologies is tightly linked to investment decisions and often affects the whole farm. Technological decisions may also strongly affect indicators relevant for identifying policy needs or measuring policy impacts. Productivity and sustainability of agricultural production, for example, strongly depend on choices such as irrigation versus rainfed agriculture or conventional versus organic farming system orientation. Other technologies impact strongly upon employment and farm size (milking robot) or the efficiency of scarce resources (precision farming). The impact of certain technologies compared with others is a comparatively manageable task. Far more difficult is it to foresee technological responses to new regulations. Just to understand and enumerate the available options for alternative technologies is difficult for a modelling team, but even more difficult is to project extent and (spatial) dynamics of technology adoption processes. Here the distribution of adopter types, existence of social networks, currently implemented technologies and their depreciation status as well as external scale effects all play a role and are difficult to project. Even if one refrains from endogenous modelling adoption of technologies, it is already a challenge to parameterise technological change in existing static models. What non-linear PMP parameters do we give new production activities not observed in the past (Röhm and Dabbert, 2003) or how can we go beyond simple trend driven Hicks-neutral or labour saving technological progress in econometric models.

3.2.4. Biophysical inter-linkages

Detailed modelling of technologies and their adoption becomes especially relevant when links between farm management and the biophysical sphere are crucial for the motivation and success of policy measures. Agri-environmental policies are typically of this category and the increasing relevance of Climate Change (CC) adaptation and mitigation policies to be assessed in longer run simulation studies increase the pressure towards representing explicit technologies and endogenous adoption.

Links between crop growth and economic farm models at policy relevant scales (high resolution and extent) are most often restricted to adjusting mean yields of generic production activities (example references). However, it is today almost generally agreed upon that the most important impact of CC on agricultural productivity will be due to changed climate variability and occurrence of extreme events. Here even careful basic research on conceptual links between biophysical and appropriate economic models (with risk representation and technology adjustment possibilities) is still needed to be able to capture such impact of temporal and spatial variability changes.

3.3. Other challenges

One of the most important challenges to an improved representation of farm heterogeneity in policy modelling tools is the availability of data. For the EU as a whole, the FADN and FSS data sources are the only ones offered on a regular basis with some consistency of definitions across EU member states. Whereas FSS data offer insights on farm structure in EU regions at population level with no economic and limited production detail, FADN gives more comprehensive information for the single farm but lacks representativeness for most variables apart from size and specialisation classes.

Farm household information, identified above as highly relevant for primary factor adjustments at farm level and structural change is generally not available in connection to a detailed representation of the farm enterprise. Another generally lacking category of information especially relevant in agricultural CC research are detailed management data, i.e. fertilizer application rates and timing, planting times or pesticide applications. Surveys to fill such data gaps have been explored (Janssen et al., 2010) but are extremely expensive and would have to be a regularly repeated activity. Alternatively, statistical procedures using generic rules and correlations, validated by sample observations, could be used to generate synthetic data.

Computational limitations to farm level modelling are probably of less importance today. Before we have reached absolute limits in this respect it is likely that data and conceptual constraints are already binding. For example, 2000 non-linear CAPRI farm type models solve in 30 seconds on an 8 core desktop. More powerful machines are easily available to not only allow a larger number of models to be tractable in simulation runs but even keep development possible by limited waiting times in debugging phases. Nevertheless, such efficient computing performance requires considerable knowledge on the side of the modeller typically not obtained during the economics education. So the acquisition of appropriate human capital to develop and maintain large scale farm modelling systems is a far more serious challenge than the acquisition of appropriate hardware.

In a wider methodological sense, an additional important challenge for a large scale farm modelling system is to find a fitting institutional setting. Starting with an existing tool and involving modellers who have experience with this system may decrease the time to have a running system. It might also carry some of the weight of an established tool making it easier to “sell” results to clients. However, it comes at high potential cost of being constrained by certain characteristics not fitting
well to the objective of representing farm heterogeneity. Moreover, the resulting complexity of the system after adding on another layer may increase maintenance and updating cost if not designed carefully to avoid mutual dependencies of system elements.

Related to the institutional setting, another very important organisational issue is to secure the right modellers for a sufficient amount of time to develop the system. The flexibility will certainly be increased if strong academic partners are interested in joining the development of the system. Such a collaboration might also help to ensure a good balance between continuity and innovation to generate models’ policy relevance through short term availability and targeted specification as well as scientific credibility through publications. The latter will also help in motivating the researchers involved.

3.4. Discussion

The main hypothesis of the presentation by Heckelei (2012) is that one modelling approach cannot efficiently target all the objectives for farm level analysis of policies highlighted in chapter 1 of this report because of the constraints and limitations regarding data availability, methodology, model maintenance and update, institutional settings, and scientific incentives of the researchers involved. None of the currently available models is able to address all aims satisfactorily. Even though the challenges as a whole seem insurmountable when looked upon simultaneously, one could nevertheless argue that for each of the challenges discussed above, there are modelling solutions available if the focus of the modelling effort is sufficient enough.

Consequently, it is unclear to what extent a single future approach will be able to address the aims for the farm modelling system. Developing a completely new modelling system might be a useful possibility, but a prioritisation for the policies to be modelled and the type of impact of interest needs to come first. Such a list will be able to direct the planning and allows to also carefully evaluating what can be achieved with an appropriate extension of the existing systems and what requires a completely new approach.

It should also be clear that before all analytical methodology, there are the data - and the data deficiencies. There is no point in developing a new analytical concept without taking the data situation directly into consideration. One of the key difficulties for the assessment of climate change and agri-environmental measures arise from the lack of detailed management data with EU coverage. Here one needs to assess what can be done about this before building a modelling system which will provide little benefit without the data. Another issue is the limited representativity of the FADN samples. Here some research should look at how the combination of FADN with FSS data may allow for an optimal representation of heterogeneity given the objectives of analysis.

Currently, there seems to be no system out there with full representation of the farm heterogeneity comparable to the farm population level and at the same time offering a consistent link to the market level. The issue of up-scaling becomes more of a challenge the more differentiated and data intensive the farm model specification becomes. The question that always needs to be answered is how you deal with that part of the farm population for which you don’t have the data to specify the farm models the way envisaged. If they are left out at farm level then up-scaling is incomplete or highly difficult. In this respect, it is recommended to develop as much as possible links to existing frameworks and not to re-invent the wheel. However, these conceptual links should be considered already at the planning phase of the farm level system. If the links are clear, then different teams can also rather independently work on their part. One could think of a modular approach in achieving the objectives when the conceptual approach to linking different efforts or in which respects they can be complementary are clear.

Some areas of policy impacts or areas relevant for better modelling policy impacts in a heterogeneous farm modelling system still require basic methodological and empirical research to improve the possibilities for a EU scale policy modelling. These include investment, technology adoption including knowledge diffusion, structural change with explicit farm interaction, and the conceptual integration with crop growth models that allows including variability of climate change and its impacts in a bio-economic evaluation.

The institutional setting of a new modelling system (or module) needs to be considered. It requires a good balance between continuity and innovation. The collaboration between IPTS and several research institutions and universities has proven to work and should be implemented here again from the start. The challenges of a farm level modelling at large scale (and access to individual farm data for the population) will offer opportunities to publish in good level journals to keep researchers at academic institutions sufficiently motivated and to build a basis for credibility of the policy modelling work for the client.

How to appropriately validate a farm modelling system is to be thought of from the beginning. Some researchers give the impression in discussion of aggregate models that modelling behaviour at individual level is easier. The opposite is true. With no “averaging-out” of individual idiosyncrasies the share of explanatory power will be lower than with more aggregate models. It is highly advisable to not validate the fit to individual behaviour but instead to the changes in the distribution. It is the heterogeneity that is to be captured well, not the individual. This type of validation is rarely done in the literature and concepts and competence need to be developed.
Chapter 4. Modelling the impact of policy reforms (including CAP) on markets and farm income

Thomas Heckelei
Department of Food and Resource Economics, University of Bonn, Germany

4.1. Introduction

This section moves from the general challenges associated with the modelling of farm heterogeneity to those that arise from the policies to be analysed. First some general policy modelling aspects in this regard are picked up, then four modelling systems (CAPRI-FT, AGRISP, IES-FADN, AROPAj) with farming agents that already have been applied to specific CAP policies are briefly introduced to understand how they addressed general methodological and specific policy challenges. Finally, conclusions are drawn for the IPTS modelling work which also incorporates the discussion in the session.

4.2. Modelling challenges

Let us first have a look at the policy reforms likely to be analyzed in the future. The commission recently put forward a set of legal proposals for the reform of the CAP, one related to the regulations on direct payments (European Commission, 2011b). The proposed redistribution of payments between regions within member states and, in a more limited fashion, between member states could be satisfactorily analyzed with current tools in the context of the impact assessment (European Commission, 2011c). The basic impacts of different redistribution schemes on farm income are even fairly well captured without a sophisticated modelling tool and instead based on accounting methods using the Farm Accountancy Data Network (FADN, see Bureau and Witzke. 2010) as second order effects in a world of widely decoupled direct payments are limited. More challenging, however, are analyses of farm size related regulations (capping) and of the “Greening” measures. They generally require detailed information on distributions of farm size characteristics and at the same time may have relevant effects at market level. For example, the requirement to have at least three crops in the rotation (European Commission, 2011b) can only be assessed based on farm level information indicating how many farms of what size and located where currently violate such a requirement. At the same time, modelling is required to understand how those farms affected are likely to adjust to the new requirements and also what type of market level effect, if any, follows from the adjustment.

Even though recent proposals on direct payment regulations pose new challenges which cannot be handled by current aggregate or representative modelling tools alone, the formulation of the policies are still fairly homogeneous across member states (and will likely stay like this as long as direct payments remain a Pillar 1 policy without national co-financing) and they are “quasi mandatory” for all farms eligible for direct payments because opting out generally proves too costly. The EU-wide analysis of Pillar 2 policies in contrast poses a different challenge. The EU regulation and reform proposals here provide only guidelines for the national implementation including a procedure for national and regional programming and a set of generally admissible activities. The ultimately applied policy mix across the EU regions is very heterogeneous. The budget allocated to the four “axes” (competitiveness, environment, diversification, Leader) and for the activities within each axis may still be taken from the reported programs. The specific implementation of farm related activities including the rules relevant for their impact at farm level is however difficult to collect at EU-27 scale. More importantly, the targeted modelling of opt-in rates and related impacts of many very heterogeneous voluntary programs with highly differentiated objectives (by area such as productivity or environmental impacts or by time horizon of desired effect such as short and long term) is impossible to do by one modelling system at EU 27 scale.
4.3. The way models presented address these challenges

The farm type layer of the CAPRI model, CAPRI-FT, was introduced by Gocht (2012)\(^9\). After a brief "reminder" on the general structure of the CAPRI modelling system, the main features of this module and an application analysing proposals for a reform of the direct payments with the farm type layer are presented.

The definition of the farm types is different in each NUTS 2 region. From 39 possible farm types following from a FADN/FS5 classification with 13 specialisations and 3 size classes, a maximum number of 9 of the most important farm types is selected for each region. "Most important" is defined by the contribution to the agricultural production value of the region and complemented by a residual farm type. The latter ensures representativity of the modelled farm types for the agricultural sector in the region under consideration. The definition of the farm types is based on the FS5, but model parameterisation also relies on the sample farms in FADN as they offer more detailed information on production activities including economic variables.

Market linkage of the 1900 farm type models is achieved in a fully integrated fashion as the farm type modules simply replace the regional models in the standard CAPRI version. Consequently, an equilibrium outcome is generated in an iterative sequential calibration with the global multi-commodity market module (Britz, 2008). Post-model analysis allows for aggregation to farm type aggregates, NUTS2 or higher geographical levels and provides corresponding economic and environmental indicators. The income effects are included in the welfare analysis across producers, consumers, and government expenditures. This full market integration of the farm models requires that the farm types cover the complete agricultural sector as defined by the EAA to stay consistent with the market representation.

The farm type version of CAPRI has been used for EU-wide analyses of redistribution effects from reform options to harmonize direct payment rates differentiated by the geographical extent of the harmonization (Britz et al., 2012). The large number of farm types already allows for a good illustration of the differences in distributions of losses and gains across farms between the options even though some aggregation effect and therefore underrepresentation of farm heterogeneity is still caused by the definition of farm types. Other applications of CAPRI-FT include an ex-post assessment of the EU CAP (Morredu et al. 2011) and the analysis of land abandonment and policy reforms in combination with a geographical land use model (Renwick et al., 2013).

The modelling system AGRISP was introduced by Arfini and Donati (2012). It aims at regional and sub-regional impact analysis of Pillar 1 policies but has some ability to also model Pillar 2 measures. The system shall represent the complete farm population and agricultural land use in the region considered. A key feature is the integration of the FADN database with the Integrated Administration and Control System (IACS) to specify the PMP driven farm type models. The IACS is the database on each farm applying for EU direct payments and offers better information on land use per crop production activity as well as animal heads per farm compared to FADN. This offers a more realistic picture of the agricultural activities in the region but comes at significant cost for setting up the integrated database due to different structures of data records over time and across the databases.

The farm types or “models” of AGRISP represent 90 “macro farms” in a NUTS3 region (province). Each of those comprises the full set of agricultural activities and is divided in up to ten size classes and can be grouped by sub-regions (altitudes). For all of Italy, 900 sub-regions are distinguished. Macro farms are linked not only by regional constraints but also by a PMP cost function that is aggregated over sub-regions, i.e. there is one per NUTS3 region. A "Generalised PMP cost estimator" of the non-linear objective function results in variable cost per activity adding up to observed total variable cost. This estimated allocation of variable inputs may be replaced by observations in case that variable cost per activity is available (as for many activities in the Italian FADN database). Pillar 1 policies are modelled either by entries in the objective function (premiums and price support) or constraints (quotas, dynamic modulation). Specific support payments under pillar two may also be included in the objective function entries.

Henry de Frahan (2012) presents the Integrated Estimation and Simulation FADN (IES-FADN) model\(^10\). This approach is distinguished from all other model structures presented at the workshop as it combines an econometrically estimated cost function with an explicit profit maximisation framework in simulation. Compared to "pure" programming type models, this structure comprises a more consistent empirical base and less restrictive assumptions on technology, but compromises on the differentiation of input and output categories. Relative to full econometric models, the explicit optimization at simulation stage offers the possibility of varying behavioural assumptions (with and without output uncertainty and risk, for example) without re-estimation and the ability to introduce relevant constraints across farms. Simulation is performed for the individual FADN farm.

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\(^9\) Further details on the farm type layer of CAPRI are offered by Gocht, Britz and Adenauer (2011) and Gocht and Britz (2011).

\(^10\) Further conceptual information is given by Henry de Frahan et al. (2011); De Blander, Henry de Frahan and Offermann (2011); De Blander, Brunk and Henry de Frahan (2011).
In application, the implemented constraints comprise grass and arable land as well as milk and sugar quotas. The model is calibrated based on the price-equal-marginal-cost equation (presumably with shift factors of marginal cost). Model outputs are typical indicators of purely economic supply models (cost, revenue, profit, output and input quantities per farm, region and member state). Shadow values on constraint indicate scarcity of resources (land) or marginal economic relevance of policy measures (quotas). Technically, model results are exported to excel files.

A noteworthy market linkage is the use of elasticities from IES-FADN in the market and trade model AGMEMOD. This is similar to the conceptual link between FSSIM and CAPRI elaborated in the SEAMLESS project (Perez-Domiguez et al., 2009), but it does not require an extrapolation to regions as IES-FADN models all FADN farms and has at least the same representativity for the sector as the database offers. It keeps however the disadvantage of transferring only the marginal response behaviour of the differentiated supply models to the market model which will lead to large errors and potentially very unrealistic supply responses of the market model for simulations that move far away from the calibration base.

The FARMIS model (Offermann 2012) is offers similar possibilities in interlinking market and farm models. It has successfully been linked with ESIM (AGMEMOD) with an iterative exchange of variables until convergence. FARMIS belongs to the group of comparative-static farm models with PMP. It consists of approximately 600 farm groups for 27 crop and 22 livestock activities. Data are taken from national FADN datasets. Devoted to the representation of production activities in European regions, the model has a modular nature and has been used for environmental impact assessment (nitrogen, greenhouse gases). It is based upon a cluster of "farm group" mathematical programming models with PMP. The current version of the model has about 120 regions, and the clustering of farms is based on FADN datasets within each region. Each farm group is associated with one of 5 soil types, 3 sowing dates or varieties, 2 preceding crops and an indicator for irrigation. It is coupled with an agronomic simulator (STICS, INRA) to calibrate crop yield response functions, and with a hydrogeological module for specific sites, in order to simulate environmental impacts on climate and water quality. In terms of coverage, the model takes into account extension of the European Union to new member states as well as reforms of the Common Agricultural Policy.

The final modelling system of this session, AROPAj, is presented by Jayet (2012). It is in the line of traditional programming models and is therefore well suited to analyse typical Pillar 1 policies at farm level (premiums, quotas, price scenarios). However, the system specialises in the detailed representation of biophysical conditions allowing for a comparatively well targeted analysis of agri-environmental measures or other policies with an environmental objective. Specifically, the link to crop growth models has been established. Mixed Integer Programming (MIP) models for farm types are formulated linear in production activity levels. The models turn non-linear through the introduction of yield functions linking crop output per ha to the Nitrogen application per ha. Data are obtained from FADN and supplemented by several pan EU databases.

The Nitrogen-yield relationship is estimated for five soils, three sowing dates or three varieties per crop, two preceding crops and for irrigated versus non-irrigated management (Godard et al., 2008). Yields for systematically varied Nitrogen amounts are simulated with the crop growth model STICS and then fitted by a non-linear yield function. In addition, N-loss functions can be estimated and included for the analysis of results. The inclusion of the N-yield functions allows for a distinction between intensification and activity-composition effects in the aggregate Nitrogen-yield relationship. However, some aggregation error still remains conceptually as the models are specified for farm types and not individual farms and plots. Similar to the spatialisation in CAPRI and the spatial localisation of farms and activities in FSSIM, AROPAj also provides probabilities of land use activities at low resolution in simulation using empirically based probabilities on activity and farm group location (Chakir et al. 2009; Cantelaube et al., 2012). The estimation procedure deriving the probabilities uses the Lucas land-use database, and is based on a combination of a cross-entropy approach with a multinomial logit prior, simultaneously exploiting consistency relations with the FADN sample.

The inclusion of yield functions as an alternative to current management options allows the model to pick the best alternative by a gross margin criterion. As the crop growth model may be run for different climate scenarios, this approach renders the ability to endogenously model adaptation of management to climate change. Other currently developed applications include impact of farm management on water quality using the N-loss functions and a coupled geohydrological model or the impact of Ozone concentration on agriculture. For future applications, this approach seems to offer a good basis for also addressing crop yield variability depending on weather variability of current or future climates. However, activity definitions for different states of nature (and corresponding yields) need to be carefully modelled to avoid input substitution across states that cannot occur in reality under uncertainty. Moreover, such a model extension in not conceptually sound if the modelled objective function of the farmer is not also extended to account for uncertainty and risk behaviour.

AROPAj is an interesting compromise between a full coverage model and a complex interlinked model for impact assessment. It is however dependent on downscaling procedures involving a significant effort in statistical treatments, and on an agronomic simulator which needs to be calibrated on many crops for various soil and climate types (see, e.g., Guérif et al., 2006). More detailed cropping practices could be considered, but they would rely on the
development of the agronomic simulator and the translation of agronomic “decision rules” into economic variables (input levels). In particular, pesticide management is challenging to incorporate in agronomic crop growth simulators, because of the very large number of commercial active ingredients.

4.4. Discussion

The four models presented in this session all have their own specific and unique contribution to modelling CAP policies with heterogeneity at farm level:

- **CAPRI-FT** offers overall 1900 farm type models for the EU-25 (up to 10 in each NUTS-2 regions). It is the only model where the farming agent models directly represent the supply part in a market equilibrium model. The disaggregation is fully consistent with EU level statistics.
- The **Italian AGRISP** uses PMP farm type models based on a combination of FADN and IACS, i.e. direct payment claims related data. It further allocates total variable cost to production activities simultaneously with the estimation of the non-linear cost function.
- The **IES-FADN** is the only one in this section modelling individual farms. The unique feature of this model is the use of an econometrically estimated total cost function in a simulation model under explicit profit maximisation. This combination allows for the incorporation of policy and regional constraints at simulation stage while still keeping the estimated behavioural function valid.
- **AROPA** is clearly the one model in this section that is best suited to model economic consequences of changes in the biophysical environment and the impact of agricultural production decisions on the environment (for a more detailed discussion of these issues please see chapter 7). This comes together with the usual flexibility of programming models to rather directly model farm level instruments of the CAP. The introduction of alternative production activities simulated with a crop-growth model opens the door for endogenously capturing adaptation to climate change.

The discussion after the presentation of the models touched upon the issue of primary factor markets. In all of these models, the annual land use and animal activity level decision is in the focus. Land transfer between farms or between activities within farms is easily modelled and widely implemented. Generally, total agricultural land in a region is fixed with the exception of CAPRI that does include land supply functions. However, an explicit substitution with forestry is not modelled by any of the models. Capital and labour market are also not considered but limitations of primary factor capacities are captured by model parameters. The lack of a more explicit treatment of these factors is likely not only due to the short to medium term horizons of these models but also to the limited data availability and quality.

None of the four models currently offer an explicit treatment of risk and uncertainty which could be a drawback for the modelling of climate change impacts and market and income stabilisation measures still discussed at global and EU level. Also, there exists no combination of really detailed biophysical heterogeneity in activity and farm specification with full market integration at EU level which might severely limit the analysis of future trade policy measures in a world of climate change and EU markets continuing their integration into global markets. If a new farm modelling system is developed, then a clear vision for the market linkage is highly recommended.
Chapter 5. Modelling structural change and risk/uncertainty in decision making

Paolo Sckokai
Dipartimento di Economia Agro-alimentare
Università Cattolica del Sacro Cuore
Piacenza
Italy

5.1. Introduction

Most models routinely used for modelling the impact of agricultural policies at the farm level are (implicitly or explicitly) based on a rather standard set of assumptions: perfectly competitive markets, both at the farm level and in the upstream and downstream industries (i.e. agricultural input industry and food processing industry), perfect information and rational behaviour by all agents, no uncertainty, stable factor endowment, stable structure of the farm sector. Since some of these assumptions are clearly rather restrictive and somehow unrealistic, the objective of this chapter is to analyse a set of models that try to relax some of these assumptions.

First, models wishing to analyse structural change issues are considered. In these models, the impact of agricultural policies is evaluated considering the potential changes in the number and size of farms, in their territorial distribution, as well as in the use of land and labour. Second, models considering farmers decisions under uncertainty are analysed. These models consider explicitly the impact of agricultural policies on the riskiness of the farm business (i.e. price and output volatility), as well as the impact of risk attitudes on farmers decisions taken in an uncertain environment.

For the above reasons, the models analysed in this chapter should provide a more accurate measure of the impact of policies at the farm level, as well as the size of the distortions that are implied by the use of more standard models.

5.2. Modelling challenges

5.2.1. Structural change: definition of the problem and modelling challenges

The issue of farm structural change has always been extremely relevant in the agricultural policy debate. The broad subject of structural change cover a large range of policy issues: the impact of policies on the evolution of the number of farms, of their size distribution and of their territorial distribution, with a special reference to disadvantaged areas; the impact of polices on land prices and on the distribution of rents between landowners and tenants; the impact on policies on labour use, including the allocation between hired and family labour and between off-farm and on-farm labour.

These issues have always been present in the agricultural policy debate and have certainly influenced the decisions of policy-makers in many countries, since structural change in the farm sector has very important social and territorial implications that make such issues extremely sensitive from a political point of view.

This is certainly true also for the CAP of the EU. For example, in the recent proposal of the European Commission (2011a) for the post-2013 reform of the CAP, several policy tools are related to these aspects. In the proposals concerning Pillar 1 of the future CAP, and especially those related to the new structure of the direct payments, there are two instruments that are clearly targeted to address structural change: the Young Farmer scheme, whose objective is to favour new entrant young farmers, through the provision of a specific payment, and the Small Farmer scheme, that tends to favour small farms through a strong simplification of the direct payment mechanism. Moreover, some specific tools addressing the structural change problem are included in the Second Pillar package of proposals, mainly in the form of direct payments to farmers: additional payments for young entrants and small farms; grants for restructuring/investments/modernisation of farms; support to a large number of initiatives targeted to innovation, knowledge transfer and cooperation between agriculture and research,
including also a strengthened Farm Advisory service. Finally, the main proposals related to the market management mechanisms, like the strengthening of producer and inter-branch organisation, aimed at improving the farmers’ negotiating position in the supply chain, can somehow be interpreted as tools trying to maintain in business the weakest farms.

As it is clear from the proposals of the Commission, as well as from the policies that have been in place in recent years, especially in the Second Pillar of the CAP, the policy tools addressing the issues related to farm structural change take mainly the form of direct payments. Thus, in principle, any farm-level model wishing to analyse the impact of policies on structural change should start from a proper modelling of the impact of direct payments on farmers’ decision making, taking into account all the relevant variables that have to do with structural change. This general modelling approach should consider not just the policies specifically targeted to structural change, like those listed above, but all forms of “decoupled” direct payments (like for example the current SFP and the basic payment scheme proposed by the Commission for the post-2013 CAP), as well as any other form of coupled payment and/or price support mechanisms. In fact, all these policy tools are likely to affect farm structural change, since, for example, they are likely to influence the most fundamental decision of the farm entrepreneurs: entering/exit the farm business.

An example may clarify this issue. Consider the following static model, in which a single-output profit maximizing farmer makes his output decisions based on $\max \pi = pq - C(q)$, where $q$ is the output quantity, $p$ the output price and $C(\cdot)$ the cost function. The short-run decision on whether the farm will produce at the optimal level ($q^* > 0$), or will not produce and exit the market, depends on the relation between output price and average variable costs, that is, $q^* = 0$ if $p < C'(q)/q$ if. In this simple framework, a decoupled payment does not influence output decisions at the margin, but if it is linked to the agricultural activity (as it is the case of the SFP, which is granted to farmers being active on eligible land), then we have that the farm will exit the sector if $p < C'(q)/q - G/\gamma$ where $G$ is government support. Therefore, even in this simple framework, a decoupled support will impact the farmer’s decision to stay in business, thus affecting the process of structural change of the sector. The result may be output distortion at the sector level and possible inefficiency due to the persistence of infra-marginal firms. Finally, it is straightforward to understand that price support and coupled payments may affect both marginal output decisions and, following the same logic, the decision of staying or not in business.

Thus, all forms of direct payments may affect structural change under several aspects: not just the crucial entry/exit decisions (Chau and de Gorter, 2005; de Gorter et al., 2008), but also labour allocation, as long as we assume that farm household production and consumption decisions are not separable (Serra et al., 2005; Ahearn et al., 2006; El-Osta et al., 2008; Key and Roberts, 2006 and 2009), as well as land prices and its distribution between landowners and farmers, given the potential capitalization of payments in land rents (see the excellent review of the most recent literature by Latruffe and Le Mouel, 2009). This means that any model wishing to analyse the structural change problems should consider explicitly the impact of policies on variables like:

- number of active farms, territorial distribution of farms and their evolution over time
- farm size distribution and its evolution over time
- land rental prices
- hired and family labour allocation
- on-farm and off-farm labour allocation
- farm income disaggregated by farm type/size/regions.

When models are able to internalise the dynamics of structural change adjustment (i.e. the change over time of farm numbers and size distribution), specific ex-ante analysis can be carried out in order to predict the impact of policies on the pattern of structural change. These models are typically based on Markov chain analysis (see for example Tonini and Jongeneel, 2007; Huettel and Jongeneel, 2011; Zimmermann and Heckelei, 2012 and the review provided by Zimmermann et al., 2009) and incorporate some policy tools as determinants of structural change. These modelling exercise are extremely valuable, because they can provide policy makers with possible alternative scenarios of structural change adjustments, but they are still rather undeveloped in the policy evaluation practice.

### 5.2.2. Risk and uncertainty in decision making: definition of the problem and modelling challenges

Agricultural production is largely characterized for being a risky business; market risk (i.e. price risk) and technological risk (i.e. output risk) are distinctive features of agricultural production, and production theory and empirical analysis have devoted a large effort to account for uncertainty in farming. The general message of this literature is that, if farmers are risk averse (an assumption that seems rather reasonable), their optimal production decisions are likely to be affected by the size of the risky outcome, since higher price/yield volatility should decrease their optimal output, and by its direction, since farmers are likely to be more concerned of the probability of a strong decrease in prices/yield than the opposite. The former phenomenon is typically measured by the second moment of the price/yield distribution (the variance), while the latter is measured by the third moment (the skewness).

Again, these general considerations have led to the formulation of important policy issues, like the impact of policies on risk producers’ attitudes towards risk, or the impact of direct payments on output when farmers are risk averse. Moreover, policy makers have often considered the possibility of intervening in agricultural markets for reducing the adverse effects of risky outcomes (i.e. price/yield volatility). This debate has become extremely relevant in recent years, when agricultural commodity prices have shown a marked increase in their volatility over time.
The above type of issues have led many countries to intervene in agricultural markets with specific policies addressing farmers’ risk management. The typical examples can be taken from the US policy: the Counter-Cyclical Payments (CCP), introduced in 2002, are payments available to arable crop farmers when the market price of a commodity falls below a given target price; their objective is clearly to reduce farm revenue variability. Moreover, in 2008, the US introduced also the optional Average Crop Revenue Election (ACRE) Program, that each year provides participating producers a revenue guarantee based on market prices and average yields for the respective commodities, while in exchange they become no longer eligible for receiving the CCP. In the recent proposals for the post-2013 CAP, the European Commission is proposing, for the first time, the introduction in the EU of an income stabilisation scheme, that will cover up to 70% of losses if crop income drops by at least 30% as compared to the average regional income of the previous five years. This is certainly one the most important innovations of the post-2013 CAP proposals, and shows how relevant is the risk problem in years of high price and yield volatility.

In this context, models wishing to analyse risk behaviour by farmers have to consider explicitly the impact of policies on risky outcomes, like the mean and the variance of the price/yield distributions and, if possible, also the skewness of the same distributions, given the crucial role of downward variability. However, as in the case of structural change, the objective of such models should not be only that of modelling policy tools explicitly targeted to farmers’ risk management, like those mentioned above, but, in general, they should properly address the impact on producers’ attitudes toward risk and risk behaviour of more general policy tools like price support mechanisms (especially those creating a floor to price variability), coupled payments and even decoupled payments. In fact, one of the most debated issue in the literature is whether decoupled payments may have an effect on risk averse farmers’ production decisions.

Following the seminal work by Sandmo (1971), showing how fixed costs have non-neutral effects on production under price uncertainty and producer’s risk aversion, a decoupled payment may alter production decisions once uncertainty is accounted for. Hennessy (1998) provides a theoretical framework for analysing the impact of income support policies under uncertainty, based on the neo-classical expected utility paradigm, where he identifies two specific effects: the wealth effect and the insurance effect. Taking the simple case of a single output farm with price risk only, a well-known result (Sandmo, 1971; Pope and Just, 1991; Hennessy, 1998) is that the wealth effect (i.e. the increase in farm wealth due to the decoupled payment) will increase production under DARA (Decreasing Absolute Risk Aversion). Further, if decoupled payments were dependent on the source of randomness/uncertainty, as it is the case for support programs aiming to provide insurance against risk, then a positive insurance effect can be detected (Hennessy, 1998). Thus, a decoupled payment providing insurance to farmers (i.e., mitigating risk) will increase production (input use) 12.

In terms of empirical results, a common feature of the expected utility framework is the estimation (and testing) of farmers’ risk preferences: evidence of risk aversion has been found in most empirical analyses (Serra et al., 2008; Sckokai et al., 2006; Sckokai and Moro, 2006; Koundouri et al., 2009). However, the most important policy contribution of these analyses relates to the empirical measure of the impact of decoupled payments on production decisions. Despite the evidence of risk aversion, the estimated wealth effect is low, and so is the impact on production (Serra et al., 2006 and 2011; Sckokai and Moro, 2006 and 2009). Only Femenia et al. (2010), modelling the effect of decoupled payments on farm wealth through its capitalization in the value of owned land, found a larger wealth effect.

Results from such models have thus important normative implications, since they may be used to tailor actual policy instruments aiming to augment farmers’ welfare. However, a recent critique has deeply questioned the relevance of the above approach (Just, 2008), since the most common specifications would prevent from identifying preferences (i.e. attitude towards risk) and perceptions (i.e. agent’s subjective probabilities) on uncertain events. This may have serious consequences on the relevance of all the above studies, at least for their normative implications (i.e. identification and measures of risk preferences), and alternative methodologies are likely to be developed in the near future (see also Lence, 2009; Just and Peterson, 2010; Just and Just, 2011; Just, 2011 for further evidences on this problem and for proposals of alternative methodologies). Nonetheless, from a policy analysis perspective, the expected utility framework maintains its positive value, in the sense that it is the best available tool for identifying the size of distortions (i.e. production change) due to risk.

From the above analysis, and from the recent debate in the literature, any model wishing to analyse the impact of risk in farmers’ decision making should consider explicitly the impact of policies on variables like:

- mean, variance (and possibly skewness) of the output price distribution, measured both across farms and over time;
- mean, variance (and possibly skewness) of the output/yield distribution, measured both across farms and over time;

12 Sckokai and Moro (2006 and 2009) have implicitly considered a further possibility, arising when the decoupled payment may alter the distribution of prices, and thus of farm’s income. For example, the introduction of the SFP, accompanied by a reduction in guaranteed prices, modified the price distribution, increasing volatility, possibly leading to a ‘negative’ insurance effect. However, their notion of the insurance effect is not the same as that in Hennessy (1998).
• input demand function (fertilisers, pesticides, water, energy), in order to analyse the impact of risk on production intensity;
• land allocation among crops, since some crops may be “less risky” than others and this may influence land allocation decisions;
• farmers’ wealth (possibly including both farm and non-farm assets)
• farmers’ risk preferences (typically measured by a risk aversion coefficient).

5.3. How the models presented in the workshop address these challenges?

5.3.1. Models addressing structural change issues

The AgriPolis model is by far the most comprehensive attempt of analysing the impact of policies on structural change issues. In fact, the model can address simultaneously issues like: farm exit, farm size growth, farm size distribution, land rent evaluation and land rental price evolution, labour use, farm income.

AgriPolis is a spatial explicit Agent-Based Models (ABMs) of the agricultural sector, based on the original paper by Balmann (1997). ABMs have the objective of capturing the fundamental behaviour at the micro-level of the individuals farms, as well as the dynamic interactions of heterogeneous farms when they deal with competition over common finite resources, e.g. land.

AgriPolis allows to model heterogeneous farms behaviours under various external situations (typically, under different policy scenarios) and observe regional results by aggregating these micro-level behaviours. In AgriPolis agents are mainly farmers, who are assumed to maximise household income. To achieve this objective, agents are assumed to solve a Mixed Integer Programming (MIP) problem that, in some aspects, is specific to each farmer. Outside the linear programming problem, they can also decide to rent other agricultural plots or to release rented land; thus, farms interact mainly through the spatial land market, although other markets can be explicitly modelled (i.e. quotas, outputs).

The use of a MIP approach to simulate each agent behaviour makes modelling rather flexible, as it can cover the whole range of farm activities, from growing specific crops to investing in new machinery or hiring new labour units. These choices are modelled in a dynamic framework, such that structural change becomes endogenous (i.e. farm size change and farm exit); furthermore, the number of activities can be expanded to add new regional-specific activities. On the other hand, however, linear programming techniques require a long calibration phase to real data in order to avoid unrealistic outcomes.

In the present version of the model, 14 regions are modelled in 8 EU member states. In each region, some typical individual farms are selected for representing the regional features of the agricultural sector. Data describing the regional characteristics are taken from regional statistics (i.e. Farm Structure Survey (FSS) and similar), while the individual farm data are taken the FADN database. The MIP problem considers several production activities (that are however rather aggregated: arable crops, dairy, pig/poultry etc.), labour use (on-farm and off-farm), financial indicators (debt/loans), investment options (mainly buildings and machinery), market and policy conditions (crop revenues, direct payments, interest rates, milk quotas, off-farm salaries, transportation costs). The regional farm sector is stratified by some ad hoc indicators (farmers’ age, presence of a successor, management skills, age of assets).

The main model outputs are of two types. At the individual farm level, AgriPolis generates results on farm production, land use, labour use, investments, loans, farm income, direct payments, as well as information on growth/shrinking/exit of each farm. At the regional level, results allow to analyse the development in the number of farms over time, as well as land use, agricultural production and employment in the region. Moreover, the spatial model solves for land rental prices for different soil qualities, and one can also obtain distributions of individual data across farms. A detailed documentation of the model can be found in Kellerman et al. (2008).

Thanks to its structure, Agripolis can answer several diversified policy questions like the impact of the post-2013 CAP proposals (both first and second pillar measures) on farm structures (i.e. number of farms and spatial distribution), production, land use and investments. The same type of output can be obtained while modelling scenarios like price shocks, credit constraints and the phasing out of milk quotas. Moreover, environment-related issues can also be investigated through appropriate ad-hoc extensions of the model, like the impact of agriculture on the production of renewable energies and the reduction of GHG emissions.

In conclusion, Agripolis seems to be a very flexible tool for answering questions that are often neglected by many standard modelling systems, especially those related to the pattern of structural change of the farm sector as well as those related to a key issue like land rental prices. The methodology is validated by the original paper by Balmann (1997), which has been a pioneering work in this area. The results are spatial in nature and account for the territorial aspects of the model, although they tend to emphasise more the direction of changes rather than the pure quantitative results. Obtaining an individual/regional specific quantitative assessment of all the variables mentioned above implies a strong effort in terms of calibration of the model for each region, in order to appropriately run the MIP problem. Thus, any application at the EU-27 level, considering the standard NUTS-2 regions, would be very demanding in terms of model development and calibration.
The PASMA-FAMOS modelling system is also targeted to address farm structural change issues, and is also based on a MIP approach. The main objective of the model is to represent land use and structural change in a spatial framework. The model in its present version covers only Austria.

The database on which the model is built is extremely rich, since it draws from several sources, encompassing official statistics (Agricultural Structure Census, Economic Accounts of Agriculture, Price statistics, etc.), farm-level accounting data (FADN and national farm-level data), GIS territorial data, environmental/natural conditions data (soil, topographical and climate information), transport costs and CAP payments. Thus, the database is extremely detailed, with more than 5,500 farms stratified on several criteria (production types, regions, size classes, conventional/organic, part time/full time).

The FAMOS optimisation model is solved using a MIP approach that assumes revenue maximisation by farmers. Its focus is mainly on land use, in terms of alternatives among cropland, grassland, permanent crops and forest land, as well among different farming systems (organic vs. conventional; minimum/reduced tillage vs. conventional). Land use choices are driven by the opportunity cost (shadow prices) of the different activities. In terms of scenarios, special attention is given to the CAP reform process and to the impact of climate change, given the richness of the database in terms of environmental data. Moreover, the spatial dimension of the model allows to project land use in a spatial context (i.e. different landscapes under different scenarios). One of the most interesting features of the model is that structural change (i.e. developments in farm entry/exit, farm size and farm specialisation) is modelled endogenously by adjusting the weights of the 8000 represented farms over time based on estimated logistic functions (Weiss, 2007).

The PASMA model is a more standard Positive Mathematical Programming modelling system, which uses the same database which FAMOS, whose focus is again mainly on land use and input use (feed and fertilisers) for the different farm stratifications considered in the database. The general idea is to derive conclusions on farm management practices under different policy and climate change scenarios. Applications and documentation of the FAMOS/PASMA modelling system can be found in Schmid and Sinabell (2007) and in Schonart et al (2011).

As potential future developments of the FAMOS model, the authors foresee a more careful focus on factor adjustment (capital and land) as well as on on-farm/off-farm labour choices, thus covering aspects already developed in AgriPolIS. For the PASMA model, the main future developments should be related to the analysis of land markets and the modelling of intra-regional trade.

In general, the main comparative advantage of the FAMOS/PASMA modelling system seems to be the richness of the database, where the standard FADN database is integrated with many differentiated sources. This allows to explore several aspects that cannot be analysed with similar models: climate change scenarios, land conservation issues. However, the data requirement may also become its main limitation, in view of a possible extension of this model to the EU-27 scale. In fact, the model now covers only one small EU country (Austria) and is extremely detailed in terms of regional and farm type disaggregation. Thus, extending such model to the EU-27 level, considering an adequate regional/farm disaggregation, may be extremely demanding in terms of data requirement, as well as in terms of adaptation and calibration of the MIP and PMP models. One may think to develop a simplified version, but in this case the model may lose its distinctive features, becoming a much more standard programming model.

5.3.2. Models addressing risk and uncertainty in decision making

The only model presented in session 4 that addresses explicitly the issue of risk in farmers’ decision making is the econometric model developed by Schokai and Moro (2006). This model is part of a class of models that have been made available in the literature in the last 10-15 years, all addressing the issue of studying the potential impact of agricultural policies on farmers’ behaviour under uncertainty. The main focus of the policy oriented literature has been the evaluation of the impact of price support and direct payments on farm choices, with a special focus on decoupled payments like the SFP.

The simplest model specification is that of the risk neutral farmers, where they are assumed to maximise expected profits and both quantity and prices are assumed to be random. This implies that, in order to estimate the model, one has to assume a specific modelling of quantity and price expectations; for example, for price expectations, one may resort to adaptive expectations, rational expectations, futures prices.

Empirically, a tractable specification of the risk-neutral model can be retrieved by resorting to either the primal approach or the dual approach, leading to a system of equations producing information on (variable) input demands and output supplies. Estimating the model on farm-level data will then provide input demand and output supply elasticities that can be employed in policy simulation models (either PE or CGE models).

The models under risk aversion are typically based on a neoclassical expected utility paradigm. Farmers are assumed to maximise the expected utility of profit, either assuming a specific form for their risk preferences (typically DARA) or estimating such preferences directly. As mentioned in section 3.1.2, the key feature of these models is that even a decoupled payment can affect marginal production decision, while in the case of risk neutrality only coupled payments and price support play a role in farmers’ choices.
The empirical specification of these models is typically an extension of the primal and dual approaches of the risk neutral framework. An example of the primal approach can be found in Serra et al. (2006), who extend the model by Leathers and Quiggin (1991) under both price and risk uncertainty, adopting the well known Just and Pope (1978) specification of the production function under risk. Flexible functional forms can be specified for the expected utility and the production function, and then both the production function and the First Order Conditions for expected utility maximization can be estimated jointly (see Serra et al, 2006, for details).

The dual approach under uncertainty has been less exploited. A possible route, proposed by Coyle (1992 and 1999) and implemented by Sckokai and Moro (2006), relies on the specification of an indirect utility function, obtained from maximizing the expected utility of wealth. Again, the derivative properties allow to define a system of output supply, input demand and land allocation equations that can be consistently estimated. In addition to the standard input demand, output supply and land allocation elasticities, one can derive wealth elasticities (the variable that changes with decoupled payments like the SFP) as well as elasticities with respect to the second moments of the stochastic variables (i.e. price variances/covariances) (see Sckokai and Moro, 2006, for details).

Finally, a much simpler alternative is that of introducing risk preferences in reduced form empirical supply/demand models by means of explanatory proxy variables, as in Sckokai and Anton (2005) and Goodwin and Mishra (2006).

For all these approaches (primal, dual, reduced form), a relevant empirical concern is the computation of the moments (the mean and the variance) of the distribution of the stochastic variables, for which it is common to resort to the approach by Chavas and Holt (1990) and Pope and Just (1991), based on adaptive expectations. This approach is extremely interesting for the analysis of price volatility related policies, since it allows to explicitly account for any truncation of the price distribution (i.e. a price floor like the intervention/safety net price). A second relevant issue is that of aggregating outputs and prices, since the standard index number approach must be properly extended to account for risk in either prices or outputs, in order to define the correct mean and variance for the aggregate index (see Coyle, 2007, and Sckokai and Moro, 2009, for an application).

The main advantage of these models is that they are not very demanding in terms of data requirement. All these models can be estimated on FADN data, and the database must be supplemented with very few additional information (typically variable input prices, that are not recorded in the FADN). The estimation codes are of course rather sophisticated and must be prepared by an expert econometrician, since the estimation techniques for unbalanced panel data, where censoring (i.e. farms not producing a given output) plays an important role, are continuously evolving (see Platoni, Sckokai and Moro, 2012). However, given the homogeneity of the FADN database, once the econometric code has been prepared, it can easily be estimated for other EU countries, potentially to all EU-27. The model by Sckokai and Moro (2006), originally developed for Italy, has now been estimated for France, Germany, Spain, UK and Ireland.

Once estimated, the equations of the model can be used to run policy simulation scenarios against the baseline of the policy in place when the FADN data were collected, but in these scenarios price and payment changes are exogenous and must be taken from other partial or general equilibrium models. Results can be extended at the regional/national level assuming representativeness of the FADN sample and using appropriately the FADN weights. Given the feature of these models, all the analysis concerning changes in the structure of the CAP direct payments (i.e. degressivity, capping, redistribution among MS, regionalisation, greening) can be analysed, together with the issue of price volatility (see above).

The main limitation of these models is likely to be the number of inputs and outputs that can be simultaneously considered. As one can easily see from the examples in the literature, the number of outputs is always rather limited. For example, if the focus is on arable crops, one may estimate separate supply equations for maize, wheat, barley, oilseeds and other arable crops, while all other crops and livestock products are aggregated in one or two residual categories. If the number of products increase, the estimation burden may become unmanageable.

In the FP7 FADNTOOL project, which will end in March 2014, a simplified user-friendly version of the econometric models under risk aversion will be developed, thus solving the problem of the complexity of the econometric estimation. However, input/output categories will continue to be rather aggregated, because of the limitations described above.

A totally different methodology for modelling Farmers’ decision-making under uncertainty is the use of a mathematical programming approach. The introduction of risk in farm linear programming models has been pioneered by Hazell and Norton (1986), who developed several alternatives all based on the expected utility paradigm. More recently, after the development of the PMP approach, there is a need to incorporate risk in a more sophisticated programming approach like PMP, but, at present, the literature on this topic is rather scarce. In the FP7 FADNTOOL project, it is planned to propose a PMP approach incorporating price volatility and risk attitudes by farmers.
5.4. Discussion

Based on the above analysis, modelling the impact of policies on structural change issues (i.e. evolution in the number and the size distribution of farms; evolution in the spatial/territorial distribution of farms; evolution in land use and land rental prices; evolution in labour use, including on-farm and off-farm labour allocation) at the EU-27 level seems to be a very challenging task.

The first problem seems to be the data requirement. Based on the experience of the AgriPolIS and of the FAMOS/PASMA modelling systems, the FADN database seems to be largely insufficient, since it has to be supplemented by data coming from a variety of sources, ranging from the official farm structure regional statistics to environmental and geo-referenced databases. Since these models are typically developed at the regional level (NUTS 2 or even NUTS 3), this implies an enormous effort in terms of data collection at the EU-27 level.

The second problem seems to be the very demanding calibration work that is needed to develop an appropriate MIP problem of farmers’ decision making. Calibration is needed to avoid unreliable outcomes and must be regional-specific, such that developing a comprehensive model at the EU-27 level may become an enormous task.

Of course, one may conceive to develop a simplified version of these models: national instead of regional scale; reduced number of activities; reduced (or no) representation of the spatial elements of the model. But in this case, it is likely that the models would lose their distinctive features, becoming a much more standard mathematical programming model.

Given these difficulties, in order to address the issue of the impact of policies on the number and the size distribution of farms, one may resort to a totally different class of models (of which no example has been provided in the workshop), based on Markov chain analysis. Examples can be found in Tonini and Jongeneel (2007), Huettel and Jongeneel (2011), Zimmermann and Heckelei (2012) and in the recent IPTS explorative project testing the possibility to update the CAPRI-farm type weights in baseline simulations.

Modelling the impact of policies considering risk behaviour by farmers at the EU-27 level may be easier from a technical point of view, but the outcome may not be optimal anyway. The only modelling tool presented in the workshop was an econometric model, that is actually part of a class of models presented in the literature in the last 10-15 years. These models are much less demanding in terms of data requirements (the FADN database can be easily integrated with a few more data) and, once the econometric code has been prepared, the model can be (potentially) estimated for all member states. The preparation of the code requires a strong expertise in econometrics, and, of course, any structural change in the policy environment requires re-estimating the model. However, a simplified version of such models, estimated for all EU-27 member states, is under development in the FADNTOOL project, and this may become a base for a user-friendly utilisation of these models. The type of scenarios that can be run cover all major first pillar tools (all forms of direct payments and the safety net/price support tools) as well as the specific risk management tools that are likely to be introduced with the post-2013 CAP reform.

However, the outcome of these models (i.e. output changes under different output price, direct payment and price volatility scenarios) typically refer to aggregate categories of outputs: cereals, oilseeds, milk, meat products, with a possible more detailed focus on one of these categories (i.e. a specific focus on the most important arable crops; wheat, maize, soybean, etc.). At this stage, a very detailed and comprehensive estimation of a very large system of output supply/input demand equations is impossible to manage given its computational difficulties. In fact, the number of parameters to be estimated increases enormously with the number of outputs/inputs considered, and the only strategy to reduce such number is to make more restrictive (and somehow unrealistic) assumptions on the representation of the agricultural technology.

A more viable option would be to integrate the output of these models with other models providing more detailed responses in terms of the inputs/outputs of interest. For example, if the risk model predicts a given percentage drop in aggregate cereal output due to an increase in price volatility, one may use this result as exogenous input for a mathematical programming model that may calculate the changes in land allocation for each crop and the changes in input use, based on relative prices.
Chapter 6. Modelling financial and dynamic investment behaviour

Paolo Sckokai
Dipartimento di Economia Agro-alimentare
Università Cattolica del Sacro Cuore
Piacenza
Italy

6.1. Introduction

As discussed in the introduction to chapter 3 of this report, most models routinely used for modelling the impact of agricultural policies at the farm level are based on rather unrealistic assumptions. One of the most common is the assumption of static behaviour by farmers. In fact, most models assume an immediate response to a policy and/or a market change, without modelling the adjustment path that leads farms from the initial equilibrium to the new one. Of course, modelling the dynamic path of farmers decision-making makes the models much more realistic, especially when they aim to analyse issues for which the time component is essential. Thus the objective of this chapter is to analyse a set of models that try to relax the assumption of static behaviour by farmers.

First, models wishing to analyse the financial viability of farms are considered. In these models, the impact of agricultural policies is evaluated considering the crucial issue of the long term financial viability of farms. Second, models considering farmers investment decisions are analysed. These models consider explicitly the farmers’ decision to invest in new assets (typically buildings, machinery and other technological innovations) in order to obtain adequate returns over time.

Again, the models analysed in this chapter should provide a more accurate measure of the impact of policies at the farm level when the time component is essential for modelling farm behaviour.

6.2. Modelling challenges

6.2.1. Financial viability of farms: definition of the problem and modelling challenges

Modelling the financial situation of farms under different policy scenarios is extremely important for obvious reasons, since farm survival perspectives depend upon their financial situation, and policies like price support or coupled and decoupled direct payments have an immediate impact on solvency, liquidity and other financial indicators. Thus, getting precise balance sheets of representative farms under different policy scenarios can be extremely relevant for judging the impact of policies.

Thus, any model wishing to analyse the financial viability of farms, should explicitly consider detailed financial indicators of the farm business. From this point of view, an accounting database like the FADN provides an excellent starting point for this type of analysis, since it provides detailed information on all major financial aspects of the farm. The corresponding modelling exercises should be able to analyse the impact of different policy scenarios on farm finance, taking key variables like prices, yields, direct payments and land allocations as exogenous, typically as outcome of partial or general equilibrium models run under alternative policy scenarios.

However, the linkage between agricultural policies and farm finance is more complex. For example, when farms are entitled to receive some form of (coupled or decoupled) direct payments, this right may relax their credit constraints. In fact, the “sure” yearly revenue represented by the direct payment may help an indebted farm to obtain further credit by the banking system and increase its investment in fixed assets; this may result in a permanent long run increase in farm output. For this reason, the relaxation of credit constraints is considered as one of the channels through which decoupled payments may affect aggregate agricultural output. Examples of specific modelling of the credit constraint effects of agricultural policies are rather scarce in the literature (and no example has been provided in the workshop). Bezlepkina et al. (2005) and Kumbhakar and Bokusheva (2009) have developed different but complementary approaches to
analyse the impact of government payments under credit constraints, while Goodwin and Mishra (2005) provide indirect empirical evidence that this phenomenon may be rather important.

6.2.2. Dynamic investment behaviour: definition of the problem and modelling challenges

The relevance of modelling agricultural policies in a dynamic framework is linked to the capability of analysing long-term farmers' decisions, like investments in land and/or in other capital goods. Traditional policy tools like price support and coupled direct payments are expected to have a relevant effect on long-term investment and output decisions by farmers, but decoupled payments are also expected to play a role. In addition, many countries have often implemented specific policies aimed to stimulate farm investment in several capital items (typically buildings and machinery), through specific forms of direct payments. These measures have also been part of the CAP, and in recent years have been included in the second pillar, among the rural development policies.

While the potential impact of price support and coupled payments on investment decisions is rather straightforward, the potential linkage between decoupled payments and farm investments has been the subject of a strong debate in the literature. Such potential linkage has been typically related to imperfect capital markets, which means, for example, gaps between borrowing and lending rates, binding debt constraints, high bankruptcy risk and other financial problems. In these cases, even a fully decoupled payment may stimulate farm investments, thus affecting future farm output (Vercammen, 2007).

Moreover, the impact of decoupled payments on investment decisions is even more complex when farmers make such decisions under uncertainty. The most recent literature on investment has focused on the role of uncertainty, through the so called real option approach: the irreversible nature of investment may induce a farm to delay investment decisions, and the delay is longer the greater the degree of price variability (McDonald and Siegel, 1986; Dixit and Pindyck, 1994). Thus, the presence of a direct payment may reduce such uncertainty and stimulate farm investment. This phenomenon may be even stronger when farmers are risk averse, since the payment may reduce income volatility over time. For these reasons, empirical analyses of investment decisions should explicitly recognise the uncertainty faced by farmers, especially price uncertainty, and consider explicitly the structure of their risk preferences.

Thus, models wishing to analyse dynamic investment decisions by farmers should be multi-period models in which the investment demand for capital goods (typically buildings and machinery, but also land, if proper data are available) is explicitly modelled. Moreover, they should explicitly incorporate all variables related to the impact of risk on farmers' decision making, that have been discussed in chapter 3 of this report (i.e. mean and variance of price and yield distributions, risk aversion coefficient, farmers' wealth). In fact, the typical linkage between decoupled payment and investment decisions is through their impact on farmers' income/wealth.

Despite this rather clear theoretical framework, the relationship between policies and investment is rather difficult to model with the available data, for several reasons. First, investments are discontinuous over time: they are typically a one-shot decision, that may be difficult to capture using an unbalanced rotating panel like the FADN. Second, the investment reluctance described by real option theory is linked to the information available to farmers; thus, expectations play a crucial role and must be properly modelled. Finally, we observe a typical asymmetry between investment and disinvestment decisions, since for the latter farmers tend to be more reluctant.

Given all these difficulties, empirical analyses concerning the impact of policies on farm investments (and especially the impact of decoupled payments) are still rather scarce in the literature, and results cannot be considered conclusive. Kallas et al (2012) found a relevant impact of partially coupled payments on investment, while Scokai and Moro (2009) found a rather small impact of decoupled tools on investment and, consequently, on arable crop output. On the contrary, in Serra et al. (2009) investment demand elasticities with respect to decoupled payments turned out to be rather high, and their simulated impact turns out to be even stronger then the output price impact. Given these non-conclusive evidences, additional research efforts in this area are certainly needed.

6.3. How the models presented in the workshop address these challenges?

6.3.1. Models addressing the financial viability of farms

The Financial Economic Simulation (FES) model, developed by the LEI in the Netherland, has the objective of simulating the financial-economic development of Dutch farms under different policy scenarios. FES calculates only “first-order effects”, in the sense that it assumes that the production structure of each farm in the database does not change as a result of the policy (i.e. same size, same land allocation, same products, investments made only to replace obsolete capital goods). Thus, the focus of the model is to give indications on size and direction of changes in the financial situation of the farms, capturing heterogeneity due to size, region and type of production.

Information on individual farms are taken from the FADN database, which is the fundamental source of data for the FES model. In addition, several sources are used for the exogenous variables needed to run the different scenarios.
For example, output and input prices under different scenarios are taken from partial and general equilibrium models like CAPRI, AGMEMOD, ESIM and LEITAP, which are all managed and maintained by the LEI team. Other exogenous variables, like interest rates, are taken from the banking information system, while policy and legislation constraints (i.e. manure management) are also exogenous to the FES model. Thus, the FES model is part of a network of models maintained by LEI and its functioning is conditional on the output of several other models (for a detailed description of the LEI modelling network see Helming and Banse, 2008).

Simulations are made for both the short and the medium term development of farm finance, and the main output of the model is a detailed balance sheet and profit-loss account, together with a series of financial indicators (i.e., liquidity, cash flow, solvency, age of assets, etc.). These indicators are then processed, through a specific weighting scheme, in a single indicator called "continuity perspective", whose aim is to evaluate the survival probability of farms. Results are typically analysed by group of farms, distinguished by region, size, production type, etc., in the form of averages and standard deviations, in order to have a picture of the distribution of such key variables among farms of the same group.

In terms of scenarios, FES is clearly suitable to analyse the impact of all CAP first pillar scenarios affecting prices and direct payments, as long as the other models can provide the appropriate exogenous variables (i.e. equilibrium prices under different scenarios).

The Farm Level Income and Policy Simulation Model (FLIPSIM), developed by the Agricultural and Food Policy Centre at Texas A&M University, has similar objectives and a similar structure with respect to FES. Its objective is, again, to simulate the financial situation of some representative individual farms under different policy scenarios. Once again, FLIPSIM calculates only "first-order effects", assuming that the production structure of each farm in the database does not change as a result of the policy. The main difference with respect to FES is that FLIPSIM does not produce only a deterministic outcome (i.e. the level of farm income under different scenarios) but a probability distribution for the same outcome. In fact, some of the key exogenous variables (i.e. prices and yields for both crop and livestock products) are simulated in the form of a multivariate distribution, based on actual and projected values over the years, such that the outcome of the model is also a probability distribution of revenues, income and all the other financial variables. Thus, the main relationships of the model are identities or stochastic formulas, that generate the "first order effect" results defined above.

The other important difference with respect to FES is the farm database. FLIPSIM maintains a database of 100 "representative" farms distributed across the whole US continental territory, differentiated by size and type of production. Farmers are directly interviewed by the FLIPSIM team and all farm-specific variables are defined/computed together with the interested farmer (crop/livestock mix, farming system, budget, assets, land tenure, machinery, investment plans to replace obsolete capital goods, historical yields and policy variables).

The model can run in deterministic mode, thus producing average values of the probability distribution for all the main outputs: detailed income statement, cash flow, balance sheet, financial variables, income tax, cash receipts and policy entitlements. On the contrary, when running in stochastic mode, the model produces standard statistics (mean, standard deviation, minimum, maximum, etc.) for all the above variables at the farm level. As for the case of FES, FLIPSIM needs as input a number of exogenous variables that are typically produced by other models. For example, commodity prices under different scenarios are taken from the partial equilibrium FAPRI model that produces a 10-year baseline every year. More information on the structure and functioning of FLIPSIM can be found in Agricultural and Food Policy Centre (2012).

As it is clear from the above description, a financial simulation model like FES and FLIPSIM does not seem to be very demanding in terms of data requirement, since an accounting database like the FADN is for sure an excellent starting point for this type of analysis. Some of the exogenous variables that are needed to run the model (i.e. policy variables, interest rates, legislation constraints,…) are not difficult to obtain. However, in order to be operational, a model of this type must be part of a network of models, since some key exogenous variables, like commodity prices under different policy scenarios, must be taken from the outcome of a partial or general equilibrium model.

The outcome of financial simulation models are of course extremely relevant, since any change in the CAP, both in the first and in the second pillar, may affect the financial viability of farms. Nonetheless, these models carry also a very important limitation, since they produce "first order effects", assuming that the structure of production of the modelled farms does not change as a results of the policy. In this respect, a clear improvement would be a linkage with a programming/econometric model able to predict changes in land use and product mix under different policy scenarios.

6.3.2. Models addressing the dynamics of investment decisions

The only model presented in the workshop that addresses explicitly the issue of dynamics in investment decision is the econometric model by Sckokai and Moro (2009). Both the FES and the FLIPSIM model analyse farm investment over time, but the investment path of the farm is fixed a priori and they only analyse the financial viability of such investment plans under different policy scenarios.

The model by Sckokai and Moro (2009) is a dynamic structural econometric model based on expected utility theory that
extends the static model under risk discussed in chapter 3 of this report. Farmers are assumed to choose the investment path that maximises the discounted flow of future expected utilities of wealth. The indirect expected utility depends on the same variables as the static model under risk (output and input prices, quasi-fixed inputs, price and yield variability, farmers' wealth and farmers' risk preferences), but is based on a long-run time-dependent technology which in turn depends on the level of investments. By solving this dynamic optimisation problem, one can obtain a system of output supply, input demand and investment demand equations that can be estimated simultaneously. The model by Sckokai and Moro (2009), that has been recently applied to the Spanish case by Kallas et al. (2012), considers only price uncertainty, although the extension to output/yield uncertainty does not add more complexity to the structure of the model.

In terms of output, the value added of this model is the estimation of the elasticities of investment demand with respect to prices, payments, price/yield volatility measures and wealth, thus allowing to measure the impact of decoupled payments.

An alternative to this complex structural model is the reduced form estimated by Serra et al. (2009) on a sample of Kansas farms, where the lower complexity of the estimated equations allows the authors to adopt more realistic assumptions on investment farm behaviour. In fact, Serra et al. (2009) distinguish between three regimes of investment behaviour (investment, disinvestment and no investment) with different adjustment cost functions, while Sckokai and Moro (2009) assume a less realistic strictly convex adjustment cost function, with smooth adjustment of the level of quasi-fixed inputs. An alternative methodology for analysing the investment reluctance phenomenon (i.e. the sub-optimal investment rates observed in many farming systems) was also proposed in Hütten et al. (2010), as an extension of the traditional q-model proposed by Abel and Eberly (1994).

All these variants of the model share many of the features of the static model under risk discussed in chapter 3. They face the same empirical issues (i.e. proper computation of the moments of the price/yield distribution; proper aggregation of outputs and prices under risk) and similar econometric problems (i.e. proper treatment of censoring; proper treatment of unbalanced panel data), such that developing the econometric code requires a strong econometric expertise. On the other hand, they are not very demanding in terms of data (the FADN database must be supplemented with a few more data) and, once the code has been developed, it can be potentially replicated on all EU countries.

Again, when using the model for running policy scenarios, price and payment changes are exogenous and must be taken from a partial or general equilibrium model. These models are especially useful for running scenarios concerning the first pillar CAP tools and the issue of price volatility, in which

their value added is the possibility of evaluating the long-run impact of policies on farm investment and output.

Finally, the main limitation of the model (that may become even stronger than for the static model under risk) is the number of inputs and outputs that can be treated simultaneously: in all studies published up to now, the number of input demand, output supply and investment demand equations does not exceed 10–12. Thus, one may use these models for simulations only when the objective is evaluating the impact on farm investment rates, while for the simultaneous impact on output a further disaggregation is likely to be necessary.

### 6.4. Discussion

Based on the above analysis, modelling the financial situation of farmers does not seem very difficult to implement. The FADN is an accounting database that provides virtually all variables needed to analyse farm finance.

Of course, this type of models needs important inputs in terms of values of exogenous variables. While variables like direct payments or interest rates can be taken from official sources, other variables, like commodity prices, must be the results of partial/general market equilibrium models run under different policy scenarios. Thus, in order to be operational, models of farm finance must be part of a network of models that includes such partial/general equilibrium models. This is the case of both the FES model (part of the LEI network of agricultural policy models) and the FLIPSIM model (connected with the FAPRI modelling system). It is also the case of the analyses currently carried out by the DG-AGRI FADN unit, which uses as input the market outlooks and the policy scenarios regularly carried out using models like AGLINK-COSIMO, CAPRI and others.

However, all these models (FES, FLIPSIM, the analyses of the FADN unit) carry a very important limitation, since they all calculate “first-order effects”, thus assuming that the structure of farm production remains the same under different policy scenarios. A relevant improvement would be a linkage between this type of models and a mathematical programming/econometric farm level model that allows to derive changes in land use/production mix under different policy scenarios. This may produce more reliable results also on the financial perspectives of farms.

On the contrary, modelling dynamic investment decisions by farmers in a systematic way, covering all EU-27 Member states, seems to be a rather challenging task. The literature in this area is still rather scarce and proposes complex farm-level econometric models that require a strong econometric expertise to be estimated. Their main advantage is that they are not very demanding in terms of data requirement (the FADN database must be supplemented with a few more data), but their main limitation is the level of aggregation, which does not allow to obtain detailed responses in terms of output...
changes of a given crop under different policy scenarios. Thus, when the objective is to obtain detailed responses for specific crop/livestock outputs, the role of such models may be that of a complementary study, which can give insights on the long-run investment and output response of farmers to the main policy changes (i.e. change in price support, direct payments and/or provision of specific investment-related subsidies), while other models are needed to explore more detailed output/input changes. As suggested also in chapter 3, the long term projections resulting from these econometric models may be used as exogenous input for a more detailed mathematical programming model, which may calculate the changes in land allocation for each crop and the changes in input use, based on relative prices.
Chapter 7. Linking farm-level models with environmental impact models

Alban Thomas
Toulouse School of Economics (LERNA, INRA)
Toulouse
France

7.1. Introduction

The recent proposals regarding the post-2013 reform of the CAP (Common Agricultural Policy) have confirmed the increasing “greening” of the European agricultural policy (see Matthews, 2011; Baldock et al., 2010). In order to provide European decision makers with consistent recommendations regarding policy instruments, economists have been developing models dedicated to predicting environmental impacts of production decisions, with the objective of representativeness and support for public policies.

Section 7.2 presents the challenges associated with the development of interlinked models of production (economics) and environmental impacts (other disciplines), in a context of a widening range of environmental issues and more farm-targeted policies. Such challenges include methodological issues in interlinking economic and biophysical models and in modelling environmental impacts through land-use change models, the role of environmental indicators, and the impact of second-pillar policies on production and land-use decisions. A review of selected interlinked models is proposed in Section 7.3, which discusses the way such models address these challenges. Concluding remarks and considerations of the issues of linking farm-level models with environmental impact models towards development of a novel generic farm level model are made in Section 7.4.

7.2. Modelling challenges

Interlinking is defined in this section as the procedure of coupling together economic and environmental models in a functional way. More precisely, outputs from one category of models are inputs to another category, so that a full “reaction chain” can be constructed. Various forms of interlinked models exist: a) top-down or “channelled-down” models in which economic decisions from representative agents entirely drive the environmental components; b) multi-level models consisting of several decision makers at different scales and with various local and global environmental impacts; c) fully integrated models in which feedback loops are allowed, in particular from the environmental back to the economic modules.

What is expected from interlinked models? Such models should help:

a) predicting environmental outcomes following a change in agriculture-related variables such as production level, input use level, acreage of crops, herd size, etc.
b) predicting the change in an environmental indicator following the change in prices (output, input) and policy instruments
c) understanding the possible trade-offs at the farm level, depending on technological substitutability patterns, between various inputs or practices under technical or regulatory constraints
d) identifying the major sources of environmental degradation originating from agricultural activity, as well as farmers’ sensitivity to changes in policy instruments (policy reforms, in particular).

Interlinked models are also useful in conducting cost-benefit or cost-efficiency analysis of public policies, i.e., evaluating the environmental performance of policy measures compared to their economic cost. This type of analysis allows the analyst to rank various policy options in terms of cost-efficiency or cost-benefit ratios, e.g., to select the most cost-effective policy measure(s) or the ones with the highest...
welfare improvement for agriculture or society as a whole (see for example Brouwer and Pearce, 2005).

The first generation of interlinked models has consisted of crop-specific models dedicated to single environmental issue (e.g., nitrogen, pesticide, water, greenhouse gases). The optimal (from an economic view) level of production and input use was first computed from estimated production technology or an agronomic simulator (e.g., EPIC-PHASE). A biophysical simulator was then taking land, crop yield and input level as inputs to predict the final environmental impact, possibly calibrated from site-specific soil and climate data. In practice, econometric analysis was used to construct a simplified representation of agricultural production technology, which was then applied to a typology of farms. Alternatively, some models have used agronomic or zootechnical (animal-science) simulators to calibrate the technology for various agricultural products.

Although such a coupling approach has rapidly been extended to multi-output settings and has accommodated risk preferences to better represent farming activities as a portfolio of random choices, it has remained for some time restrictive as regards the detailed description of cropping practices as well as the range of environmental impacts. These models were often designed to analyse the impact of production decisions on a limited number (often, a single) of environmental components, e.g., water contamination by nitrogen fertiliser. Other limitations of these first-generation interlinked models include the lack of a possible feedback from the environment to farmers (except through public policy and environmental regulation), the absence of interactions between farmers, and their poor suitability to incorporate technical change and innovations.

As discussed in Chapter 3, a consistent treatment of heterogeneity across farms (and farmers) is essential in better representing policies and their impacts. Not all first-generation models were designed at the farm level however, and aggregate-level versions of interlinked models have been developed to represent, in particular, global environmental impacts (greenhouse gases, etc.) In such a case, farm heterogeneity may be partly controlled for by using soil and climate data for each geographical unit (district, region), but modellers have then to pay a particular attention to assumptions underlying the joint distribution of such local conditions and farm types.

The second generation of interlinked models is based on a mathematical programming approach for the economic part, used to solve a general maximisation problem in terms of input choice and production and land decisions, based on a vector of observed prices and unit activity costs, and on a set of technical constraints. In most models, farmers are assumed to be price takers, and farm groups or types can be used on to limit the dimension of the optimization problem. The advantage of second-generation models when interlinking economic and environmental models is to provide a more comprehensive representation of the farm activity, while allowing for technical constraints to be introduced explicitly, some of which being possibly related to environmental regulation. For example, bans or restrictions of use (quotas) of some environmentally-harmful inputs can be easily introduced in such models, and the implicit "cost" of such constraints can be interpreted in economic terms. With second-generation models, production decisions are always consistent from an economic viewpoint, while first-generation interlinked models are calibrated for a particular, production-specific technology and are less suited to modelling the indirect impact of policy instruments on production decisions (for example, through a change in the cropping system).

With second-generation models, it is possible to evaluate the consequences of a wider range of policy instruments, including for example the expected impact of a tax on nitrogen fertiliser or pesticide, a water allocation quota for irrigation farmers, a new technology adoption, or a change in the land set-aside requirement. Most of these models are "supply models": price-taking farmers making decisions on land, crops, and input and output levels, ultimately resulting in environmental pressures (Lacroix and Thomas, 2011). Supply models have been popular especially because of the ability to link them to partial or general-equilibrium models providing them with prices from agricultural and input markets.

The first challenge faced by interlinked models (of first- or second-generation) concerns the degree of precision regarding agricultural (cropping) practices, as opposed to land use and output decisions, which are easier (and less costly) to observe. Most farm-level economic models are constructed from price data (dual approach) or from input and output levels (primal approach), which are obtained from databases such as FADN. It is however likely that changes in environmental pressures are directly related, not just to these variables, but also to cropping practices which are typically not available in these databases. Some countries have a parallel statistical system to obtain regular information on cropping practices. France, for example, has implemented in 1998 a "Cropping Practices Survey" very similar to the USDA (United States Department of Agriculture) one. Unfortunately, such survey is very difficult to use in conjunction with other databases, because it focuses exclusively on technical (not economic) information, is at the land plot (parcel) level and not at the farm level, and access to identifier variables is necessary to allow for direct merging with FADN. Another drawback is that the cropping practices survey is not exhaustive in terms of crops at the regional level: only major production districts (départements) are concerned for each particular crop. This means that significant effort has to be devoted to translate the technical information from cropping practice surveys in a form directly used by economic models at the farm level. This is particularly true for data on fertiliser, pesticide, manure management and irrigation water. Typically, technical data from the cropping practices survey would be used at the district level to construct district-specific technical coefficients (e.g., share of nitrogen...
in NPK-type chemical fertiliser) which are then used to break down the input expenditures into estimates of physical input level, using also additional data on input prices.

A second challenge is associated with the fact that most interlinked economic and biophysical models are able to predict, not the ultimate environmental impacts, but rather environmental pressures, because biophysical processes are at play between the two. Since biophysical processes involving detailed data on soil and climate characteristics also need to be modelled at some point, it is very difficult to evaluate the genuine impact of a change in agricultural practices and production decisions at the micro level. For this reason, farm heterogeneity is sometimes overlooked and regional or watershed models are used, in which one assumes farmers behave more or less in a homogenous way, with similar local soil, water and climate conditions. Their decisions are then translated into environmental pressures, and compared to observed environmental indicators at the region, district, or watershed level. Heterogeneity in this case is transposed from the farm to the (small) region level, for which biophysical processes may be easier to model. This is true in particular of models predicting the level of greenhouse gas emissions from livestock and cropland, based on average soil and climate conditions.

The linkage between economic and environmental models requires interactions between economists and environmentalists, in particular to determine which model assumptions lead to first-order effects as opposed to more marginal, second-order effects. In the majority of cases, such interactions have the objective of designing and updating environmental indicators, which can be used for policy analysis. There exist many experiences at national levels to construct databases of environmental indicators (often called indicators of sustainable development), some countries having developed geographical representations of environmental situation, while in other cases, environmental indicators are still at the regional or district level. In the case of biodiversity for instance, Natura 2000 data on habitats, species and impacts are currently managed by the European Topic Centre for Biological Diversity. According to the European Environment Agency (2010) however, knowledge gaps are still significant, and a global base of species level assessments would cost about EUR 45 million according to Stuart et al. (2010). For other environmental components such as water quality and availability, databases are already available (e.g., European Environment Agency and FAO-Aquastat). Depending on the scale of measurement and the scope of the models, interlinking models to produce such indicators, or using indicators to calibrate interlinked models, may be challenging. This is mostly due to the fact that the relationship between agricultural practices involving environmental impacts and environmental indicators may not be a straightforward mapping. Methodological advances are still called for in terms of indicator design and construction (thresholds, aggregation issues), including spatial and dynamic aspects, before the connection to farm-level models can be effective for most environmental impacts of agricultural production.

A third challenge is to better describe the environmental impact of Pillar 2 policies, based on agri-environmental measures (AEM). The latter translate into more or less homogenous contracts between an environmental regulator and individual farmers, with technical terms of reference (requirements) and limited ex post inspection in practice. A first issue is to understand the typically low degree of adoption observed in many EU member states. This is challenging, as most existing production models are designed to predict changes in output prices or input costs, not fixed payments affecting agricultural practices. A second issue is to model spatial interactions between farmers, both in the process of adopting such voluntary agreements (the AEMs) and in reporting the expected environmental impact on a larger scale. This is the question of spatial concentration or dispersion at the heart of green corridors or protected areas. However, many models do not allow for such interactions, beyond a mere aggregation of results from individual-farm models (total output and land used, etc.)

There is a notable difference between primal (technology representation in physical terms) and dual (representation of technology from information on price and unit cost) approaches, in particular regarding the difficulty to account for environmental constraints (originating from public regulation) and technical constraints. For Pillar 1 policies, economic instruments all translate into prices which ultimately determine farmers’ decisions from a programming (primal approach) or a dual (cost, profit) system. In some cases, it is possible to convert agricultural practices into input costs, so that a change in an input unit cost can be converted back into a change in agricultural or cropping practices. For second-pillar policies, the process is different: the economic instrument is a subsidy designed to compensate for a higher production cost. The question is then, not just the expected change in production decisions (assumed to follow the required terms of the contract underlying the agro-environmental measure anyway), but the adoption process. However, for some agro-environmental measures, the conversion from technical measures to production costs can be difficult. Note that, since measures targeting a collective of farmers is not (yet) implemented within the CAP framework, models integrating the interactions among farmers are not developed (unless these interactions are expected to play a role in adoption decisions through social and professional networks).

Most interlinked models for policy assessment are based on a "positive" approach, i.e., representing the environmental impact of a policy in terms of "pressures" (potential degradation of environmental conditions) without considering the "best" nature or level of the policy instrument. By contrast, a normative approach would evaluate the "socially optimal" level of the policy instrument and would also contain elements for discussing the most relevant type of instrument (see Caplin and Schotte, 2008). This means that the optimal policy design of instruments needs to include a minimum
degree of “social preferences” in order to recommend the best-suited instrument as well as its level (tax, quota, etc.) This more political–economy oriented approach requires tools which are often outside the typical toolbox of production economics: social preferences regarding the environment need to be elicited with Contingent Valuation, Contingent Analysis, transportation cost or hedonic methods, in order to derive the optimal level of environmental conditions to be achieved with policy measures. Again, the difficulty in calibrating social preferences for site-specific or regions is challenging (Bateman, 2009), and a way often advocated is the method of “benefit transfer”, from which preference estimates (willingness to pay or to receive) are translated into other national or regional settings (Pierce et al., 2006). Together with this issue of preference elicitation is the problem of ranking environmental priorities with a synthetic indicator obtained as a weighted sum of social valuations for each environmental component (water and air quality, climate, biodiversity, etc.) Expert views are of little help here, as the economic analysis is required to construct such “sustainability” indicators from social preferences, not biophysical considerations.

A fourth challenge has to do with spatial considerations, which constitute a major difference between interlinked economic-biophysical models and most market models. In the case of global environmental impacts such as GHG, the “stock” of emissions is the critical variable to regulate, and the geographical origin of contributions to global warming is less relevant in a biophysical sense (although it may be when regulation of emissions or international agreements on climate change is considered). In this case, spatial considerations matter less than modelling decisions among competing land uses (with different GHG emission ratios) under a global land availability constraint. But for other environmental concerns, most agricultural activities have a local impact on the environment and landscape (water and soil pollution by nitrogen and pesticide). Furthermore, the “flow” of economic activity may constitute a “stock” of “bad outputs” (pesticide accumulation, etc.) on specific areas, implying that a spatial representation is needed to assess the degree of environmental damage due to excess concentration of pollutants, for instance. This is true in particular for nonpoint source emissions from agriculture affecting the quality of raw water resources. The concentration or the scattering of farms on a given watershed has a direct impact on expected contamination of surface or ground water and, as such, requires a detailed geographical representation.

Models can also be used in the future to help evaluating the potential payment for new ecosystemic services (Heal and Small, 2002). In this case, a comprehensive geographical representation of farm activities at a small scale is required.

Existing agricultural models using farm types are able to deal with specialisation issues, i.e., determining the optimal combination of activities from a set of crops or livestock, given constraints on available land and determinants of profitability. However, with the exception of the EU-FASOM (European Union – Forest and Agricultural Sector Optimization Model) project by IIASA (International Institute for Applied Systems Analysis), few of them include forestry in the set of possible activities. This separability assumption is motivated on the grounds of very different time horizons when computing expected returns to production, and of equally different technical knowledge and management skills for farmers and forest managers. However, when designing and evaluating policies of mitigation or adaptation to climate change, the trade-off between agriculture and forestry activities is needed at the national or regional level. A first possibility is to develop separate production and impact models, one for each activity, and to link them through a condition on total available land (excluding urban and other artificial areas). In this case, the allocation of land to crops, pasture or forestry is determined by expected rents per hectare in decreasing order of profitability. This type of analysis requires an adequate representation of the opportunity cost of land, and of marginal areas as well as arable land suitable for crops. Models for evaluating the impact of biofuel mandate policies in the US and in Europe are being developed with the objective of jointly conciliating food and energy security requirements (Khanna et al., 2011; Britz and Hertel, 2009).

Local or global potential environmental impacts can be estimated from scientific references through calibration or field measurements (which are much more costly). A scientific debate concerns the assumption of constant technical and biophysical parameters used in assessing environmental impacts. For example, the GHG “content” of agricultural production and practices for crops and cattle is often assumed independent from production and input level, whereas alternative (nonlinear) specifications may be more appropriate. There is also the question of the unit of production to consider: should one compute environmental impacts of cropping systems by unit of quantity produced or by land area? By animal (head) or pasture area for livestock? When a complete environmental assessment of agricultural production is needed, Life-Cycle Analysis (LCA) can be used, and the ultimate impact of production of a particular agricultural good on natural resources including energy consumption can be estimated from available databases of technical coefficients (ECOINVENT database and SIMAPRO software, for example).

Another use of interlinked models is to evaluate the economic impact of environmental regulations. In this case, environmental impacts are not predicted but rather, the objective of the environmental policy is assumed to be achieved (in particular, in terms of emission reduction, improvement of biodiversity, etc.) Such models translate environmental requirements to constraints modifying the production set of farmers; based on these additional restrictions, the optimal production choices are computed from a mathematical programming approach. The interesting aspect of such modelling is the fact that there is a feedback from production to the environment, while environmental aspects have been integrated as constraints. In its simplest form, this approach converts environmental constraints
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For example, the French policy “Ecophyto 2018” aimed at achieving a 50 percent reduction in overall pesticide use in France by the year 2018 compared to 2008 levels. The drawback with such objective is that it is not clear whether a 50 percent reduction in pesticide will correspond to a proportional improvement in environmental quality. An alternative policy could have been to formulate the environmental objective explicitly in terms of the latter: find the pesticide reduction ratio that corresponds to a 50 percent increase in environmental conditions. In the latter case, the interlinking issues discussed above still apply (e.g., difference between environmental pressure and impact).

One could think that, when the policy is expressed in terms of input reduction, the interlinking issue is not relevant, as a purely economic model of production can be used to evaluate the impact of a reduction in the level of a particular input. This may be true if the cropping system is assumed to be unchanged by the policy. On the other hand, if one wishes to simulate a large decrease in, say, pesticide use, it is very likely that a modification of the cropping system is the only possibility to preserve some degree of profitability for farmers. If this is the case, economists need to consider expert views and more importantly, collaborate with agronomists, plant and soil scientists, etc., to validate the relevant alternative cropping systems to be considered. See Jacquet et al. (2011) for an assessment of the Ecophyto 2018 policy for pesticide reduction in France.

7.3. The way models presented address these challenges

- AROPaj (P.A. Jayet)

AROPaj is a farm-type model developed at INRA in Grignon (Jayet et al., 1992), and is discussed in Chapter 3. Its modular nature has been used for environmental impact assessment (nitrogen, greenhouse gases), in particular through its coupling with an agronomic simulator (STICS, INRA) and a hydrogeological module for specific sites, in order to simulate environmental impacts on climate and water quality. AROPaj is continuously improved by coupling biophysical models to the economic model for farming systems, with an application to nitrogen emissions. At the same time, down-scaling procedures are developed for the regional (farm group) models, in order to provide results at a fine resolution scale, relevant for interlinking with biophysical models. More detailed cropping practices could be considered, but they would rely on the development of the agronomic simulator and the translation of agronomic “decision rules” into economic variables (input levels). In particular, pesticide management is challenging to incorporate in agronomic crop growth simulators, because of the very large number of commercial active ingredients.

- FSSIM (K. Louhichi)

FSSIM is a generic bio-economic farm model developed within the FP6 SEAMLESS project (van Ittersum et al., 2008). It is dedicated to the assessment of agri-environmental policies and technological innovation in agriculture. The FSSIM model considers farm-type models as building blocks, with a primal approach based on static nonlinear optimisation through PMP (Positive Mathematical Programming) and input-output technological coefficients. Several sources of risk are accounted for, notably market and climate risk, with a mean-standard deviation approach providing a local approximation to risk aversion. FSSIM contains a detailed representation of land heterogeneity (by agri-environmental zones), significant commodity and practices (including crop rotations) coverage, and focuses mainly on CAP first-pillar policies as far as policy instruments are concerned.

FSSIM combines several modules: input-output coefficients are obtained from FSSIM-AM, total profit optimization is provided by FSSIM-MP, while activity-specific modules describe the production technology for livestock, crops, perennial crops, etc. Three modules are devoted to policy, risk and PMP calibration. The database used to calibrate the various modules is from FADN. FSSIM is a supply model which is linked to the CAPRI market model through an econometric up-scaling procedure (EXPAMOD). Extrapolation is performed at the NUTS 2 region level for aggregate supply responses.

The linkage with biophysical model APES (Agricultural Production and Externalities Simulator) is made at the NUTS 2 level. This model is used to evaluate environmental impacts from agricultural activities. Therefore, the FSSIM model is based on heterogeneous data sources: FADN for farm typology and resource endowments, and expert surveys for current and alternative agricultural activities. In its present form, FSSIM is calibrated on 13 NUTS regions from EU 27, resulting in 58 farm types. In a way similar to AROPaj (see above), the model spatially allocates farm types according to their typology.

The advantages of FSSIM include the fact that it accounts for partial heterogeneity across farms, and for switching between farm management practices. The model also accommodates a detailed list of first-pillar CAP policy instruments. However, it suffers from several drawbacks. First, it is only calibrated for 13 out of 271 NUTS-2 regions in the EU, and the parameterization and calibration procedures are challenging, requiring extra data to complement FADN and FSS databases. Second, there is the issue of consistency between expert surveys and FADN data. Third, the complexity of up-scaling environmental effects. Last, the FSSIM model cannot capture structural change and interactions among farmers.
The SAPIM (Stylised Agri-Environmental Policy Impact Model) model is a small-size model, illustrating environmental effects through changes in intensive, extensive and entry-exit margins. Contrary to most interlinked models with agricultural production, SAPIM can be used to assist in the design of optimal or cost-effective policies, with a normative approach. Moreover, SAPIM deals explicitly with agricultural and environmental issues in the presence of spatial heterogeneity. The model considers various cropping systems, and combines economic models with site-specific stylised biophysical models. A fairly wide range of policy instruments is accounted for: tax, quota, conservation auction, etc. The design of the model is based on Hochman and Zilberman (1978) and Lichtenberg (1989). It has been applied to southern Finland, Switzerland, the US Corn Belt and Japan, with environmental effects including nitrogen and potash balance, greenhouse gases and biodiversity.

The analysed policies which can be considered in SAPIM include various fertiliser taxes, buffer subsidies, and a policy combined fertiliser reduction and buffer strips. Other sectors can be considered (although modelled in less detail) as illustrated by Lankoski, Lichtenberg and Ollikainen (2008) with an application to point and nonpoint nutrient trading between agricultural and municipal wastewater treatment facilities under heterogeneous marginal damage. In this application, GIS data are used on 120 km stretch of a river valley in Finland, to evaluate the policy impact regarding nitrogen nutrient loading to the Baltic Sea.

In the SAPIM model, there is the acknowledgment that, since farms are heterogeneous, so are compliance costs and environmental effects, in particular with respect to landscape. Another point is the fact that it is not sufficient to focus on a single input for policy evaluation, even though policy instruments are targeting a single one: all relevant inputs need to be controlled simultaneously, and policy package matters.

- MIDAS (R. Kingwell)

The MIDAS (Model of an Integrated Dryland Agricultural System) model is calibrated for Australian agriculture. It is an interesting illustration of the way economic modelling can be used in policy analysis, even though production systems are different from the EU (the average size of an Australian farm being about 2000 ha). MIDAS consists of a series of steady-state profit-maximising representative farm mathematical programming models. The degree of disaggregation is very important, with about 50,000 matrix coefficients, 8 soil types, 20 to 50 possible rotation options per soil. All major crops are considered, as well as pasture, trees for timber, bioenergy and the process of carbon sequestration, and 25 animal types for livestock. The model accounts for leisure and labour requirements and can incorporate constraints regarding soil conservation and animal welfare requirements. Concerning risk, a moderate risk aversion is accounted for, and farmers are assumed to be price takers (no price endogeneity).

A recent illustration of using MIDAS for policy modelling with MIDAS concerns the reduction policy of greenhouse gases from agriculture. The Australian government proposed in 2008 to set up a national emission trading scheme (ETS) for carbon emissions by 2015, with a starting price of 20$/ton C, including agriculture. The MIDAS model was used to evaluate the expected outcome of this policy, by predicting the percent change in CO2-equivalent emissions as a function of percent crop areas (% farms in crop), using international emission (standards) coefficients instead of in-situ measurements. Results of the simulation show that a typical broad acre farm would experience 16% to 32% reduction in profit if it is required to pay for its emissions.

The limitation to agricultural farms means that the policy impact on the agrofood chain is not computed. However, even if agriculture is excluded from the ETS, farm businesses would be affected by pass-through effects (through agri-business). This is however a common limitation of partial equilibrium and supply models. Other weaknesses include the fact that MIDAS incorporates only single objective functions of profit, has limited possibility to accommodate stochastic production, and models provides only the steady-state planning horizon.

In conclusion, the models presented with a significant linkage with environment aspects (AROPAJ, FSSIM, SAPIM, MIDAS) operate at different scales, with various degrees of complexity and coverage. While AROPAJ, FSSIM and MIDAS are suitable for regional analysis based on farm types, with an adequate coupling to partial or general-equilibrium models for agricultural and input prices, they are not yet adapted to an accurate representation of environmental impacts at a small scale with a large degree of heterogeneity. On the other hand, the SAPIM model serves such a purpose, but with a limited coverage. A direct implication is therefore that these models can be used for different policy analyses, depending on the objectives and the required coverage. In any case, they are all very demanding in terms of model calibration and therefore, adaptation to other environmental settings.

A distinction could be made at this stage between different types of models and environmental aspects. First, “global” environmental issues such as greenhouse gases and some biodiversity issues, can be based on land-use and output modelling with in-situ or expert-based emission or biodiversity coefficients. The interlinking procedure in this case is fairly limited to a small number of “interface” variables (land, crop yield, livestock), especially when greenhouse gases for instance are assumed to depend on fixed crop yields and that inputs are not adjusted. Models involving broad land uses such as crops, pasture or forest are interesting to consider at the national or regional level, in a context of climate change mitigation, in particular. The EU-FASOM model developed at IIASA aims at integrating agricultural and forestry land-
use decisions with such an objective in mind. Models such as AROPAJ and F5SIM are obvious candidates for use with predefined agricultural systems (crops, livestock).

On the other hand, more complex interlinked models would be associated with local environmental components, for which the interlinking of economic and biophysical models is more demanding. This is the case of water contamination by fertiliser and pesticide, for which cropping practices play a crucial role in relation with the spatial distribution of farms. Farm-type models with a spatial allocation procedure are relevant in this case, but they require coupling with geographically-referenced activity and environmental variables (local communities, ground and surface water, etc.)

Bamire et al. (2011) provide an example of an interlinked model for a conservation policy design based on an agro-environmental measure. By coupling a mathematical programming model with an ecological spatial pattern index for extensive grassland, they obtain the optimal payment level and the corresponding spatial pattern of grassland to maximise ecological benefits for local bird species. The SAPIM small-scale model is typically the kind to be developed in addressing such local environmental issues. Because the SAPIM model has a normative side, it requires the measurement of the social value of environmental benefits (or, equivalently, the evaluation of the environmental damage function) to determine the socially-optimal policy instrument. In its simplest form, the model can be calibrated using Willingness To Pay (WTP) or Willingness To Accept (WTA) estimates for environmental benefits, which can be obtained from the method of benefits transfer by correcting estimates obtained in other settings for income and demographic factors (see Pierce et al., 2006). However, for the social value of environmental impacts to be fully consistent with local conditions, WTP or WTA estimates need to be obtained “on the field” by more demanding approaches (field surveys and contingent valuation methods, in particular).

- FARMIS (F. Offerman)

The FARMIS model belongs to the group of comparative-static farm models with PMP. As it is essentially dedicated to interlinking market and farm models with only a limited potential for assessing environmental impacts, its detailed description is found in chapter 4.

7.4. Discussion

Environmental impacts of agricultural production may be numerous, but most can be characterised in relation with soil, water and air pollution, and biodiversity loss. This implies that full EU coverage of the major environmental components above is relevant, even though European countries are heterogeneous in their production specialisation. The first task when considering environmental impacts at the European level is to design a harmonised database of environmental indicators. Methodological issues regarding the design of environmental indicators have been introduced above, in particular in relation with agricultural practices. Once this database of indicators is harmonised, a decision should be made concerning the degree of complexity or precision required, as far as environmental impacts are concerned. In particular, dynamic and spatial models are being developed to better represent the linkage between agricultural practices and the environment, but they require detailed data at a small scale and over a long time span, so that the expected gain from such modelling exercises is questionable. This is true for example of models interlinking agronomic and hydrological simulators with economic models of production, to represent the nonpoint source pollution from agriculture at the watershed level.

The fact that economic instruments for environmental regulation do not always consist of taxes or pricing mechanisms implies that mathematical-programming (MP) models are better suited to evaluate the consequence of a change in policy than supply models based on a purely dual approach (i.e., only based on a system of prices). However, MP models still have a long way to go to incorporate Pillar II policies in the form of constraints at the farm level. Models of adoption dedicated to agro-environmental measures are required to obtain estimates of the adoption rate depending on socio-economic characteristics, for each type of second-pillar measure. Such an adoption rate can then be applied to the population of eligible farmers for up-scaling at the regional level. As for Pillar I policies, agro-environmental measures can be incorporated in production models at various levels of complexity: with crude assumptions on their impact on production decisions, or with a more detailed description of their implications in terms of cropping practices.

Moreover, interlinked models with environment impact simulators need to be adapted to provide valuation of eco-systemic services supplied by farmers. This implies that more interdisciplinary research is needed, in order to properly identify the “best practices” to be used as reference when designing the level of payment for such services. As mentioned above, there is often a difference between environmental impacts and environmental pressures, the latter being provided by model predictions while the former is typically required by environmental decision makers.

Very few available models are able to provide a feedback loop from the environment back to the farmers. For example, irrigation water decisions may be based on production models involving irrigation cost and crop expected market prices, by the level of ground water or surface water availability is more difficult to model in an integrated way, as it requires a linkage with agronomic and hydrological models at the local (even, farm-) level (see Bulatowicz, 2010).

CAP Pillar II policies have been less accounted for by most models, possibly also because of methodological issues. As agro-environmental measures can be considered voluntary agreements (non-mandatory measures), the socio-economic determinants of policy adoption by individual farmers need to be characterised. This introduces a stochastic ingredient in
profit-maximisation models because of the probability that the farmer may not accept the agro-environmental measure. Furthermore, CAP Pillar II measures are heterogeneous across European regions and their number, even in a single member state, makes their introduction in a farm-level model challenging (Ducos et al., 2009).

When dealing with the linking of economic and biophysical (environmental) models for environmental impact or environmental policy assessment, there are specific methodological issues to consider. First, environmental modules of interlinked models have their own issues in terms of biophysical data and modelling (aggregation, thresholds, choice of indicators and variables definition, etc.). Second, initiatives for achieving a successful development of operational models from a multidisciplinary approach are needed, and this also requires a clearer definition of the role and responsibilities of scientific and institutional partners in a modelling network. Third, on this point, and especially regarding normative approaches for policy design and agro-environmental policy evaluation, the valuation of environmental benefits need to be generalised to the widening range of environmental components. This means that policy and market impacts need to be evaluated, not only in terms of agricultural revenue and profitability, but also in terms of net social welfare including the environment.
Chapter 8. Conclusions and recommendations

Maria Espinosa, Pavel Ciaian, Stephen Langrell, Kamel Louhichi, and Sergio Gomez y Paloma

Institute for Prospective Technological Studies (IPTS)
Joint Research Centre (JRC)
European Commission

8.1. Introduction

While market and farm models have experienced significant advances over the past decades, some methodological challenges and data issues remain. Assumptions underlying optimal farmer choices obtained from profit maximisation under economic, agronomic and policy constraints may need to be revisited and extended in the light of the constantly changing policy and economic environment. Structural change in European agriculture, including long-term trends, deserves further analysis, which implies that the definition and estimation of the opportunity cost of land and labour require further discussion among researchers. It also implies that technical change and technology adoption in agriculture should be better accounted for in existing models. From a methodological point of view, mathematical-programming models are generally considered better suited to accommodate technology changes at the farm level than econometric supply approaches. For the latter, the development of contingent production functions (Chambers and Quiggin, 2002), providing more flexibility in technology switching, is an interesting stream of research, but applications of this approach remain limited (Thomas, 2012).

This is also true for the estimation of farmer preferences and behaviour, including attitudes towards risk, information management, assumption of profit-maximisation, trade-off between farming and non-agricultural activities, etc. Most models have been developing with the objective of reaching a satisfactory degree of detail regarding products and activities, and/or trying to calibrate the same model on more regional settings. At the same time, their structure has not evolved as rapidly regarding farmers’ behaviour and preferences. This is particularly true for preferences towards risk, the developments in the literature being particularly slow to be incorporated into production models beyond special case analyses at a small scale (Thomas, 2012).

Indeed, the need for more detailed description of CAP economic and environmental impacts at a disaggregated level (regarding farms and products), and by geographical/spatial scale, has become a central issue for both EU policymakers and researchers as policies become increasingly targeted and more farm specific. In this chapter we attempt to provide a summary of the key issues and challenges related to more targeted CAP impact analysis and to guide development of farm level modelling activities able to analyze CAP impacts using the two EU wide farm level data sources FADN and FSS. The analyses are based on previous chapters’ contents reflecting the workshop presentations and discussions.

Although there is a growing literature on farm level modelling, a large number are developed for a given specific purpose and/or location and subsequently, are not easily adaptable and reusable for other applications and contexts (e.g. climate, soils and socio-economic conditions, etc.). Farm level models that allow flexible impact assessment for a range of issues and functions at EU-wide scale are scarce. This seems to be due, on the one hand, to the limited data availability and the diversity of situations and policy schemes across the EU-27, and, on the other, the need of a considerable collaborative effort between scientists, programmers and software engineers to provide a user-friendly, easily-accessible modelling system. Having in mind these limitations, the models presented in the workshop, and analyzed extensively in this report, were selected according to four main criteria (i) scientific soundness; (ii) their potential for application at EU-wide scale; (iii) relevance for policy impact analysis; and (iv) reliance on FADN/FSS data. In total 13 models have been selected: 10 are EU based, and 3 are non-EU based, models.
8.2. Technical conclusions and considerations

The main report conclusions relate to data-sources, methodology and model characteristics, policies and organizational issues and can be summarized as follows:

Data-sources

- A key starting point for any modelling activity requires availability of data. However, data requirements can be enormous depending on the type of modelling approach employed (e.g. agent-based versus econometric models) and on the degree of detail covered in the model.
- FADN/FSS represent key data sources at EU level used extensively by various models (e.g. AGRISP, CAPRI-FT, FES, AROPA). An important advantage of the FADN/FSS is their representativeness of farms across the EU. Another important value of the FADN is its panel structure and its high frequency (survey conducted annually). It facilitates model calibration and the estimation of parameters. One of the main drawbacks is derived from the fact that it is a sample of the complete population, and therefore for capturing farm structural change the use of FSS is suggested (every 10 years there is a complete census of the farm population).
- However, farm level modelling often requires the need to go beyond FADN/FSS data sources to address some of key issues related to farm behaviour. FADN/FSS data provides robust representation of heterogeneity across the EU farming sector, but often needs to be supplemented by other data sources in various areas especially in the area of environmental impacts, physical quantities of inputs, information on farm-household characteristics, disaggregation of investments (e.g. in machinery and buildings) and analysis of downstream agro-food chain data. Experience shows that there is a possibility to link FADN data (i.e. farm economic data) with plot-level/technical data (cropping practice information), which are available in several MS (e.g. France, Germany, The Netherlands), allowing more detailed economic and environmental analysis.
- An interesting experience from the AGRISP model relates linking the IACS database with FADN data.
- An effort towards transparency and harmonization of definitions of variables by the different models is crucial to help improve the flow of data in the various stages of model development, model comparisons and, ultimately, to facilitate model inter-linkages. An attempt in this direction is currently ongoing in the FP7 FADNTOOL project.13
- From the workshop discussion, a general consensus emerged regarding the need to maintain the FADN database, at least in its present structure. This is especially important because of the representativeness of the FADN at regional level, but also because long time series are essential for analysing investment decisions and structural change.
- Further elements of research are required with respect to building data synergies between various farm level data sources in particular by linking the available EU databases (e.g. FADN, FSS, IACS, LUCAS). This will facilitate a better exploitation of available databases as well as smoothing the process towards the update, maintenance and result comparison of farm models.

Methodology and model characteristics

- In general farm models currently used for policy analysis are very heterogeneous: comparative static versus dynamic, individual versus farm-type (representative) deterministic versus stochastic, etc.
- Five approaches are often used for building a farm level model: mathematical programming (MP) (including linear programming (LP), non-linear programming (NLP), mixed integer programming (MIP) and positive mathematical programming (PMP)), econometric-mathematical programming (EMP), simulation approach and agent based model (ABM). The selection of farm modelling approach depends often on data availability, model specification and research scope. However, most of the currently applied EU farm level models are based on mathematical programming.
- The majority of selected models are comparative static. Only two models (FES and econometric model) apply dynamic approaches. The main reason behind this choice is that the use of the dynamic approach is not always suitable as it can be a complicated task in terms of data requirements and model complexity. Moreover, several aspects which are time dependent can be represented in a simplified manner by a static model, such as crop rotations or herd dynamics.
- An important suggestion, emerging when contrasting available model approaches and the needs of policy analysis, is the ability to vary the model/approach based on the specific question being posed. Even though the selected 10 EU-based models fulfil the selection criteria (scientific soundness; application at large scale; relevance for policy impact analysis; and based on FADN/FSS databases) no single model seems to suit all purposes. Each of the models has its own merits, given the goals addressed and the issues treated with the model.
- In terms of capturing farm heterogeneity, which is relevant for modelling future CAP development, an important distinction emerges between models based on individual (real) farms, or on farm-type, models. Out of 13 selected models, four are individual farm models, while the rest are farm-type models.
- The modelling of individual farms presents some advantages, in comparison to farm-types: (i) it can better represent the heterogeneity amongst farms in terms of policy representation and impacts (e.g. CAP greening/distribution of direct payments); (ii) it provides the highest possible disaggregation regarding farms and activities, and (iii) it reduces aggregation bias in response to policy and market

Conclusions and recommendations

• In general, modelling of CAP Pillar I measures is more advanced than modelling of Pillar II due to the fact that the former policies (i.e. Pillar I) were implemented much earlier than the latter ones, therefore more theoretical and empirical work was conducted. On the other hand, the intervention logic of Pillar I measures is much simpler, and their modelling is thus less complex than Pillar II measures. In addition, Pillar I measures are better covered in the standard statistical sources (FADN and IACS).

• Pillar II policies are also very diverse in terms of intervention logic, targeted farm activities, and variation in regional implementation and, thus, cannot be easily captured through a single model approach. Besides, some of these policies consist of voluntary, contract-based arrangements which can be simultaneously chosen by farmers. Further research with respect to modelling second pillar policies to allow their representation in a farm level model is required.

• From the ongoing and future policy development perspective, most relevant areas for modelling include income and environmental impacts. Therefore, it is important to consider the development of farm level modelling from a multidisciplinary approach.

• The MIDAS and FLIPSIM modelling approaches (from Australia and the USA, respectively), as well as the FES model (LEI University), consider a 5 year time-horizon for conducting impact analysis. Advocates of this time span stressed that longer term impacts are less relevant for policy makers due to the high uncertainty on macro-economic variables, structural change and decision variables. Additionally, there is a trade-off between the reliability of results and the modelling time-horizon.

Organizational issues

• The resources needed to construct a farm model vary considerably depending on model structure, methodological approach, designation level and data requirements.

• There is a trade-off between financial and human resources needed on data collection and construction and maintenance of farm models and time-horizon needed to reach a robust farm model.

• Experience often supports the “network approach” in developing and maintaining different farm level models/approaches to answer different policy questions. This approach implies a need for a clear definition of the research questions and priorities (in order to choose the relevant models) as well as the roles and responsibilities of each institution member of the network (which must be well specified).

8.3. Recommendations

Based on the report, three different strategies for analyzing CAP impact at farm level emerge:

• a “single” model,
• multiple models/approaches,
• an intermediate approach.

The advantages of an ambitious “single”, multi-purpose model, is the economies of scale in investing resources by researchers and policy makers in model development. Moreover, such a model could be updated and improved more transparently if used by several institutions. On the other hand, an all-purpose model is challenging to develop, precisely because its structure have to comply simultaneously with many (and sometimes) conflicting objectives, and therefore, methodologically, is extremely challenging.

The advantage of the second approach (multiple models/approaches) is that it does not impose a common
methodology across all policy issues analysed, but combines various approaches. A multiple models/approaches have the advantage to address a wide variety of policy questions with the best methodological approach in each case. Synergies between different approaches could be exploited where, for example, various activities can be shared (e.g. data processing), or where results from one approach may be used as input into other approaches (e.g. behavioural parameters). In contrast, inherent disadvantages include problems derived from maintaining, using and interlinking the models (see chapters 3 and 7) as well as requiring extensive expertise across all modelling methodologies.

Between these two approaches, an intermediate scenario could be envisaged where most of the resources are put into a model that addresses most of the policy questions, and a set of other supporting approaches are effectively built-in to answer other policy questions. As in the previous case, synergies between the development and maintenance of a main model, and supporting approaches, could be developed to save resources on data processing and model parameterisation.

An important consideration to note is that each of the three proposed strategies of developing a farm model for CAP analysis can be developed and maintained either within one institution or a closed set of cooperating institutions, or within a functional network of institutions. Experience often supports the "network approach" in developing and maintaining farm modelling activities, as it reduces cost, whilst permitting a wider and more effective exploitation of human resources and expertise available in the specific area. However, this approach implies a need for a clear definition of the research questions and priorities, as well as the specific roles and responsibilities of each potential institutional network member.

The choice of the methodology is a key element for analysing CAP impact at farm level as it should allow flexibility in terms of capturing farm behaviour as well as for allowing the possibility for inclusion of various policy instruments in the model. As identified in the report, there are different methodological approaches for farm level modelling. However, the most prominent, and most extensively tested/applied, in literature in the area of agricultural policy modelling is mathematical programming. This is considered due to several reasons which convey a particular overall advantage on this approach, including (i) it allows explicit representation of behaviour and technology; (ii) it permits the modelling of complex policy constraints under which behavioural function cannot be easily derived, or not at all; (iii) it is flexible in terms of incorporating policy, economic and environmental constraints; (iv) contrary to an econometric approach, which is limited to ex-post analysis of policies/technologies for which past observations are available, mathematical programming is suitable for both ex-post analysis, as well as for the appraisal of new technological/policy options (ex-ante); (v) contrary to the simulation model approach (i.e. FES, FLIPSIM), which focuses only on financial impact analysis (income effects, farm viability, cash flow), mathematical programming can deal with both technical (in terms of land allocation, production, technological choice) and financial aspects; and finally, (vi) data requirements to run a programming model are not excessive, compared to the econometric and simulation approaches.

An important aspect of farm model development relates to the level of disaggregation. We have seen with the overview of the methods that a key issue in relation to modelling future CAP developments is indeed related to aggregation problem and incorporation of sufficient farm heterogeneity within the farm model. Policies are increasingly targeted and more farm specific (e.g. the "greening" of the CAP). This new policy orientation affects farms differently according to their location (i.e. specialization, technology; structural change, resource endowment and socio-economic contexts but also policy orientation affects farms differently according to their resource endowment and socio-economic contexts but also location (i.e. specialization, technology; structural change, soil preparation, fertilization, feeding practise). There are two distinct approaches that can address this issue with a varying degree: individual (real) farm model and on farm-type model. Both approaches have their advantages and disadvantages (Table B.1). Farm-type modelling is more advanced and its application for CAP analysis at EU scale is relatively well developed in the scientific literature. However, this approach reduces significantly farm heterogeneity and thus is not fully able to model policies targeted at farm level without considering additional model adjustments or/ and imposing additional behavioural assumptions. Individual farm model are better suited to capture farm heterogeneity and to model farm specific policies. However, comparably less is available in the literature in terms of application in particular with respect to CAP modelling at EU scale. Additionally, parameterization and calibration of individual farm models is more demanding than is the case of farm-type models. The actual choice of the modelling approach rests also on financial and human resource availability as both approaches require different efforts in terms of model development, data preparation and maintenance.
### Table 8.1: Overview of advantages and disadvantages of farm-type and individual farm models

<table>
<thead>
<tr>
<th>Farm-type model</th>
<th>Individual farm model</th>
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<tbody>
<tr>
<td>• Builds an average farm (i.e. virtual farms) distinguished by typology</td>
<td>• Based on individual farms observed in reality</td>
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<tr>
<td>• Representative for a group of farms that meet the group criteria</td>
<td>• Representative for farms that are included in the model</td>
</tr>
<tr>
<td>• Covers more production activities as it is representative for a group of farms</td>
<td>• Only the production activities of a specific farm are observed</td>
</tr>
<tr>
<td>• Lower additional data requirements (compared with individual farms).</td>
<td>• Farm scale data are required which are not always available</td>
</tr>
<tr>
<td>• Averages-out a significant share of farm heterogeneity. It capture only certain level of farm heterogeneity (e.g. by specialization, farm size) depending on model design.</td>
<td>• Provides the most detailed disaggregation possible regarding farms and activities</td>
</tr>
<tr>
<td>• Reduces aggregation bias to policy and market signals but does not eliminate it</td>
<td>• Avoids aggregation bias</td>
</tr>
<tr>
<td>• Easy to model farm interactions</td>
<td>• Farm interactions is possible to be captured but computationally it is demanding</td>
</tr>
<tr>
<td>• Parameterization and calibration is less demanding</td>
<td>• Parameterization and calibration is demanding as it requires information at individual farm level</td>
</tr>
<tr>
<td>• Easily linkable to others models (biophysical and market models)</td>
<td>• High computational requirement for model interlinkeage</td>
</tr>
<tr>
<td>• Cannot fully model farm specific policies</td>
<td>• Suited to model farm specific policies</td>
</tr>
<tr>
<td>• To model ongoing CAP reform, important assumptions/adjustments may be required to be introduced in the model.</td>
<td>• Can model ongoing CAP reform with minimal adjustments/assumptions</td>
</tr>
</tbody>
</table>
References


Farm level modelling of CAP: a methodological overview


IPTS (2012). Modelling the Effects of the CAP on Farm Structural Change. Final report on the tendered project IPTS-2010-J05-23-NC. Johann Heinrich von Thünen Institute (vTI) and EuroCare GmbH, Bonn.


References


## Programme/agenda

### Day I – 06 June 2012

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<td>Welcome. Background of workshop</td>
<td>Jacques Delincé, JRC-IPTS</td>
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<td>Policy Background</td>
<td>Tassos Haniotis, DG AGRI, European Commission</td>
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<td>09:30-10:00</td>
<td>EU-FADN: tools used to assess CAP post 2013</td>
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<td><strong>Coffee Break</strong></td>
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<td>10:30-12:30</td>
<td>Session 2: Horizontal/methodological issues and model comparison</td>
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<td>10:30-10:35</td>
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<tr>
<td>10:35-11:20</td>
<td>Implications of methodological choices for farm model development and application</td>
<td>Thomas Heckelei, University of Bonn</td>
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<td>11:20-12:05</td>
<td>Overview of model comparisons</td>
<td>Sergio Gomez y Paloma, JRC-IPTS</td>
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<td>14:05-14:25</td>
<td>The farm type layer in CAPRI</td>
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<td>14:25-14:45</td>
<td>Modelling CAP reforms trough regional integrated database: the AGRISP model</td>
<td>Filippo Arfini, University of Parma</td>
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<td>Agri-environmental interactions and policy impacts assessments via the AROPAj model</td>
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15:45-16:05  AgriPolis: Analysing Policy Impacts on Structural Change, Efficiency and Distribution  
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16:05-16:25  The modelling of consequences of farm structure changes in PASMA and FAMOS  
Erwin Schmid, Universität für Bodenkultur, Vienna

16:25-16:45  Econometric models dealing with uncertainty and dynamics  
Paolo Sckokai, Universita Cattolica, Piacenza

16:45-17:00  Open discussion III

17:00-17:15  Coffee Break

17:15-18:15  Session 5: Modelling financial and investment behaviour  
Chair: Thierry Vard, DG-AGRI

17:15-17:20  Introduction from the chair and setting the scene

17:20-17:40  Analysing CAP impacts using the FES (Financial Economic Simulation) model  
Gideon Kruseman, LEI

17:40-18:00  Reflections on 30 Years of Farm Level Policy Analysis Using FLIPSIM for the US Congress  
James Richardson, Texas A&M University

18:00-18:15  Open discussion IV

DAY II – 07 JUNE 2012

09:00-10:20  Session 6: Models inter-linkages  
Chair: Alban Thomas, INRA

09:00-09:05  Introduction from the chair and setting the scene

09:05-09:25  Linking farm and market models: Experiences with FARMIS  
Frank Offerman, vTI

09:25-09:45  FSSIM, a generic bio-economic farm model for economic and environmental assessment of EU agricultural systems  
Kamel Louhichi, JRC- IPTS

09:45-10:05  Stylised integrated modelling of agriculture-environment linkages: OECD Stylised Agri-Environmental Policy Impact Model (SAPIM)  
Jussi Lankoski, OECD

10:05-10:25  Farm modelling and farm policy: the MIDAS experience in Australia  
Ross Kingwell, University of Western Australia

10:25-10:45  Open discussion V
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<tr>
<td>13:30</td>
<td>End of workshop</td>
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</tr>
</tbody>
</table>
List of participants

**Prof Filippo Arfini**  
Department of Economics  
Università degli studi di Parma  
Via J. Kennedy, 6  
43125 Parma  
Italy  
Telephone: +39 0521 032496  
Fax:  
E-mail: filippo.arfini@unipr.it  
Website: http://www.unipr.it/persona/filippo-arfini-271511

**Prof Dr Alfons Balmann**  
Leibniz Institute of Agricultural Development in Central and Eastern Europe (IAMO)  
Theodor-Lieser-Str. 2  
D-06120 Halle (Saale)  
Germany  
Telephone: +49 3452928300  
Fax: +49 3452928399  
E-mail: balmann@iamo.de  
Website: http://www.iamo.de/nc/en/iamo/institute/staff/staff-detail.html?tx_institute_pi1%5Bgo%5D=staff_cv&tx_institute_pi1%5Bmid%5D=1

**Mr Marco Artavia**  
Agriculture and Life Sciences in the Economy Unit  
Institute for Prospective Technological Studies (IPTS)  
European Commission-Joint Research Centre (JRC)  
Edificio EXPO  
E-41092 Seville  
Spain  
Telephone: +34 95 4488402  
Fax: +34 95 4488434  
E-mail: marco.artavia@ec.europa.eu  
Website: http://www.jrc.es/home/index.html

**Mr Piotr Bajek**  
Directorate General – Agriculture and Rural Development  
European Commission  
BRU-L130 03/146  
Brussels 1040  
Belgium  
Telephone: +32 2 2965991  
Fax: +32 2 2965991  
E-mail: piotr.bajek@ec.europa.eu  
Website: http://ec.europa.eu/agriculture/index_en.htm

**Mr Alexander Bartovic**  
Directorate General – Agriculture and Rural Development  
European Commission  
BRU-L130 03/116  
Brussels 1040  
Belgium  
Telephone: +32 2 2962807  
Fax: +32 2 2965991  
E-mail: alexander.bartovic@ec.europa.eu  
Website: http://ec.europa.eu/agriculture/index_en.htm

**Mr John Bensted-Smith**  
Institute for Prospective Technological Studies (IPTS)  
European Commission-Joint Research Centre (JRC)  
Edificio EXPO  
E-41092 Seville  
Spain  
Telephone: +34 95 44 8 8273  
Fax: +34 95 44 8 8274  
E-mail: john.bensted-smith@ec.europa.eu  
Website: http://www.jrc.es/home/index.html

**Mr James Brady**  
Directorate General – Agriculture and Rural Development  
European Commission  
BRU-L130 03/132  
Brussels 1040  
Belgium  
Telephone: +32 2 2983098  
Fax: +32 2 2965991  
E-mail: james.brady@ext.ec.europa.eu  
Website: http://ec.europa.eu/agriculture/index_en.htm

**Dr Pavel Ciaian**  
Agriculture and Life Sciences in the Economy Unit  
Institute for Prospective Technological Studies (IPTS)  
European Commission-Joint Research Centre (JRC)  
Edificio EXPO  
E-41092 Seville  
Spain
Mr Tassos Haniotis  
Director  
Directorate L  
Directorate General – Agriculture and Rural Development  
European Commission  
BRU-L130 07/100  
Brussels 1040  
Belgium  
Telephone: +32 2 2991381  
Fax: +32 2 2987186  
E-mail: anastassios.haniotis@ec.europa.eu  
Website: http://ec.europa.eu/agriculture/index_en.htm

Prof Dr Thomas Heckelei  
Institute for Food and Resource Economics (ILR)  
University of Bonn  
Nussallee 21  
53115 Bonn  
Germany  
Telephone: +49 228732332  
Fax: +49 228734693  
E-mail: thomas.heckelei@ilr.uni-bonn.de  
Website: http://www.ilr.uni-bonn.de/agpo/staff/heckelei/heckelei_e.htm

Mr Martin Hradisky  
Directorate General – Agriculture and Rural Development  
European Commission  
BRU-L130 03/138  
Brussels 1040  
Belgium  
Telephone: +32 2 2961822  
Fax: +32 2 2965991  
E-mail: martin.hradisky@ec.europa.eu  
Website: http://ec.europa.eu/agriculture/index_en.htm

Dr Pierre-Alain Jayet  
INRA-Économie publique  
Avenue Lucien Brégnigères  
78850 Thiverval Grignon  
France  
Telephone: +33 01 30 81 53 49  
Fax: +33 01 30 81 53 68  
E-mail: jayet@grignon.inra.fr  
Website: http://www4.versailles-grignon.inra.fr/economie_publique/PagesPerso/Pierre-Alain-Jayet

Mr Argyris Kanellopoulos  
WU Plant Sciences  
Plant Production Systems  
8130  
6700EW Wageningen  
The Netherlands  
Telephone: +31 0317-487220  
Fax:  
E-mail: argyris.kanellopoulos@wur.nl  

Mr Shingo Kimura  
OECD  
2, rue André Pascal  
75775 Paris Cedex 16  
France  
Telephone: +33 1 45 24 95 35  
Fax: +33 1 45 24 85 00  
E-mail: shingo.kimura@oecd.org  
Website: www.oecd.org/agriculture

Prof Ross Kingwell  
School of Agricultural and Resource Economics  
University of Western Australia  
35 Stirling Highway  
Crawley WA 6009  
Australia  
Telephone: +61 9368 3225  
Fax: +61 6488 1098  
E-mail: rkingwell@agric.wa.gov.au  
Website: http://www.uwa.edu.au/people/ross.kingwell

Mr Andreas Kolodziejak  
Directorate General – Agriculture and Rural Development  
European Commission  
BRU-L130 08/026  
Brussels 1040  
Belgium  
Telephone: +32 2 2995221  
Fax: +32 2 2921735  
E-mail: andreas.kolodziejak@ec.europa.eu  
Website: http://ec.europa.eu/agriculture/index_en.htm

Mr Gideon Kruseman  
LEI-Wageningen UR  
Agriculture & Entrepreneurship Group  
Sustainable Agricultural Development Unit  
PO Box 29703  
2502 LS The Hague  
The Netherlands  
Telephone: +31 703358189  
Fax: +31 703615624  
E-mail: Gideon.kruseman@wur.nl  
Website: http://www.iei.wur.nl/UK/
Dr Stephen Langrell  
Agriculture and Life Sciences in the Economy Unit  
Institute for Prospective Technological Studies (IPTS)  
European Commission-Joint Research Centre (JRC)  
Edificio EXPO  
E-41092 Seville  
Spain  
Telephone: +34 95 4488256  
Fax: +34 95 4488434  
E-mail: stephen.langrell@ec.europa.eu  
Website: http://www.jrc.es/home/index.html

Dr Jussi Lankoski  
OECD  
2, rue André Pascal  
75775 Paris Cedex 16  
France  
Telephone: +33 1 45 24 9528  
Fax: +33 1 44 30 61 02  
E-mail: jussi.lankoski@oecd.org  
Website: www.oecd.org

Mr Jean Lazzaoui  
Directorate General – Agriculture and Rural Development  
European Commission  
BRU-L130 03/128  
Brussels 1040  
Belgium  
Telephone: +32 2 2986986  
Fax: +32 2 2965991  
E-mail: jean.lazzaoui@ext.ec.europa.eu  
Website: http://ec.europa.eu/agriculture/index_en.htm

Ms Marianne Lefebvre  
Agriculture and Life Sciences in the Economy Unit  
Institute for Prospective Technological Studies (IPTS)  
European Commission-Joint Research Centre (JRC)  
Edificio EXPO  
E-41092 Seville  
Spain  
Telephone: +34 95 4488314  
Fax: +34 95 4488434  
E-mail: marianne.lefebvre@ec.europa.eu  
Website: http://www.jrc.es/home/index.html

Mr Mariusz Legowski  
Directorate General – Agriculture and Rural Development  
European Commission  
BRU-L130 07/157  
Brussels 1040  
Belgium  
Telephone: +32 2 2981488  
Fax: +32 2 2988345  
E-mail: mariusz.legowski@ec.europa.eu  
Website: http://ec.europa.eu/agriculture/index_en.htm

Mr Pierluigi Londero  
Directorate General – Agriculture and Rural Development  
European Commission  
BRU-L130 09/233  
Brussels 1040  
Belgium  
Telephone: +32 2 2991255  
Fax: +32 2 2959236  
E-mail: pierluigi.londero@ec.europa.eu  
Website: http://ec.europa.eu/agriculture/index_en.htm

Dr Kamel Louhichi  
Agriculture and Life Sciences in the Economy Unit  
Institute for Prospective Technological Studies (IPTS)  
European Commission-Joint Research Centre (JRC)  
Edificio EXPO  
E-41092 Seville  
Spain  
Telephone: +34 95 4488409  
Fax: +34 95 4488208  
E-mail: kamel.louhichi@ec.europa.eu  
Website: http://www.jrc.es/home/index.html

Dr Sebastien Mary  
Agriculture and Life Sciences in the Economy Unit  
Institute for Prospective Technological Studies (IPTS)  
European Commission-Joint Research Centre (JRC)  
Edificio EXPO  
E-41092 Seville  
Spain  
Telephone: +34 95 4480579  
Fax: +34 95 4488208  
E-mail: sebastien.mary@ec.europa.eu  
Website: http://www.jrc.es/home/index.html

Dr Frank Offerman  
Institute of Farm Economics  
von Thünen Institute  
Federal Research Institute for Rural Areas, Forestry & Fishery  
Bundesallee 50  
38116 Braunschweig  
Germany  
Telephone: +49 531 596-5209  
Fax: +49 531 596-5199  
E-mail: frank.offermann@ti.bund.de  
Website: www.agribenchmark.org

Prof James Richardson  
Co-Director  
Regents Professor & Texas AgriLife Research Senior Faculty Fellow  
Department of Agricultural Economics  
Texas A&M University  
College Station, TX 77843-2124  
USA
List of participants

**Ms Rachele Rossi**  
Directorate General – Agriculture and Rural Development  
European Commission  
BRU-L130 03/138A  
Brussels 1040  
Belgium  
Telephone: +32 2 2985696  
Fax: +32 2 2965991  
E-mail: rachele.rossi@ec.europa.eu  
Website: http://ec.europa.eu/agriculture/index_en.htm

**Mr Mariusz Safin**  
Directorate General – Agriculture and Rural Development  
European Commission  
BRU-L130 03/132A  
Brussels 1040  
Belgium  
Telephone: +32 2 2963918  
Fax: +32 2 2965991  
E-mail: mariusz.safin@ec.europa.eu  
Website: http://ec.europa.eu/agriculture/index_en.htm

**Dr Christoph Sahrbacher**  
Leibniz Institute of Agricultural Development in Central and Eastern Europe (IAMO)  
Theodor-Lieser-Str.2  
D-06120 Halle (Saale)  
Germany  
Telephone: +49 345 29 28 234  
Fax: +49 345 29 28 299  
E-mail: sahrbacher@iamo.de  
Website: http://www.iamo.de/en/iarn/iamo/institute/staff/staffdetail.html?tx_institute_pi1%5Bmid%5D=35

**Dr Erwin Schmid**  
Institute of Sustainable Economic Development  
Universität für Bodenkultur  
Feistmantelstraße 4  
1180 Vienna  
Austria  
Telephone: +43 1 476543653  
Fax:  
E-mail: erwin.schmid@boku.ac.at  
Website: https://forschung.boku.ac.at/fis/suchen.person_uebersicht?sprache_in=en&menue_id_in=101&id_in=5396

**Mr Josef Schmidhuber**  
Food and Agriculture Organisation  
Viale delle Terme di Caracalla  
00153 Rome  
Italy  
Telephone: +39 06 57056264  
Fax: +39 06 570 53152  
E-mail: josef.schmidhuber@fao.org  
Website: http://www.fao.org/index_en.htm

**Dr Paolo Sckokai**  
Istituto di Economia Agroalimentare  
Università Cattolica  
Via Emilia Parmense, 84  
29100 Piacenza  
Italy  
Telephone: +39 0523 599.290  
Fax: +39 0523 599.282  
E-mail: paolo.sckokai@unicatt.it  
Website: http://docenti.unicatt.it/ita/paolo_sckokai/

**Dr Alban Thomas**  
Toulouse School of Economics (LERNA, INRA)  
1 rue des Amidonniers  
31000 Toulouse  
France  
Telephone: +33 (0)5 61128513  
Fax: +33 (0)5 61128520  
E-mail: thomas@toulouse.inra.fr  
Website: http://www2.toulouse.inra.fr/lerna/chercheurs/thomas/

**Mr Thierry Vard**  
Directorate General – Agriculture and Rural Development  
European Commission  
BRU-L130 03/124  
Brussels 1040  
Belgium  
Telephone: +32 2 2958423  
Fax: +32 2 2965991  
E-mail: thierry.vard@ec.europa.eu  
Website: http://ec.europa.eu/agriculture/index_en.htm
European Commission  
EUR 25873 - Joint Research Centre - Institute for Prospective Technological Studies

Title: Farm level modelling of CAP: a methodological overview

Author(s): Pavel Ciaian, Maria Espinosa, Sergio Gomez y Paloma, Thomas Heckelei, Stephen Langrell, Kamel Louhichi, Paolo Sckokai, Alban Thomas and Thierry Vard

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Abstract
This report synthesises the findings from the workshop on “Developments and Prospects of Farm Level Modelling for post 2013 CAP impact analysis” organised jointly by the IPTS-JRC and the Directorate-General for Agriculture and Rural Development in Brussels, 6-7 June 2012. The report constitutes a comprehensive overview of the state of approaches and modelling platforms currently employed for micro-level policy analysis at farm-level, representing a specific response to, and consideration of, recent policy developments within the evolving CAP context. Particular attention was given to the methodologies and approaches applied for policy impact assessment, from the general perspective to specific impact of policy reforms, not least structural change and risk/uncertainty, as well as financial and dynamic investment behaviour and technological choice, to market and biophysical inter-linkages. An important part of the report represents conclusions and recommendations towards developing a generic farm level modelling approach able to capture impacts of future CAP developments.
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Key policy areas include: environment and climate change; energy and transport; agriculture and food security; health and consumer protection; information society and digital agenda; safety and security including nuclear; all supported through a cross-cutting and multi-disciplinary approach.