1 Policy Impact Assessment

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1.1 Introduction

Public intervention in the agricultural sector is common in many developed and developing countries (Gardner, 1992). The rationales for government intervention in the agricultural sector include the need to correct market failures or to provide public goods, redistribution and/or stabilization of income, and concerns about food security and the self-reliance of food supplies. There is a wide cross-country variation in the priority objectives of agricultural policies, which also evolve through time in line with ever-changing societal demands. Whatever the objectives of the agricultural policy, the policy-making process involves the identification and assessment of alternative options to reach those objectives. Any policy change is designed with the expectation of improving the current situation, but the extent to which this can be achieved – even if it can only be known *ex post* – needs to be carefully assessed *ex ante*. The evaluation of public policies prior to their approval is a crucial step in policy design and usually consists of the assessment of the likely impacts of the new policy measures proposed with the final aim of maximizing the benefits to society and avoiding undesirable side effects.

As the assessment of policy impacts has gained focus in policy design, sectoral and/or fragmented studies have been integrated into a systematic process – impact assessment – which addresses impacts across the three dimensions of sustainability in a balanced way and, therefore, contributes to the mainstreaming of sustainability in policy making. According to the Organisation for Economic Co-operation and Development (OECD) (2010), sustainability impact assessment (SIA) has two main functions: (i) it is a tool for developing integrated policies that take full account of the three sustainable development dimensions; and (ii) it is a process for the *ex ante* assessment of the likely economic, social and environmental effects of policies, strategies, plans and programmes. SIA usually combines qualitative and quantitative assessment tools in a systematic framework, and it may involve a wide range of tools, depending on the issue at hand (Ness *et al.*, 2007). This type of assessment is being implemented in many OECD countries and is required for all initiatives of the European Union (EU) that are likely to have significant economic, environmental or social impacts.

In 2002, the EU adopted formal impact assessment procedures to improve the quality

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and coherence of the policy-development process (European Commission, 2002). Further, impact assessment aims at contributing to a more coherent implementation of the European Strategy for Sustainable Development (European Commission, 2001). Impact assessment evaluates the likely positive and negative impacts of proposed policy actions, enabling informed political judgements to be made about the proposal and identifying trade-offs in achieving competing objectives. Impact assessment guidelines were first published in 2002 and have been regularly updated since then in response to new developments in both policy and impact assessment areas (European Commission, 2005, 2009, 2015). Impact assessment is now compulsory for major EU policies, including the Common Agricultural Policy (CAP), one of the oldest common policies of the EU.

Since 2003, the EU has conducted *ex ante* impact assessments of the successive reforms of the CAP in order to inform the policy-design process of the economic, social and environmental consequences of changes in policy instruments. For each CAP reform, several impact studies have been conducted using a variety of existing and newly developed tools (European Commission, 2003, 2008, 2011). The EU Impact Assessment Guidelines insist on the need to quantify the relevant impacts of new policies and they promote the use of modelling tools to better inform policy design and improve the performance and coherence of European policies. There is a wide variety of models and tools used for impact studies, involving both qualitative and quantitative tools and both economy-wide and sectoral models. The specificities of the agricultural sector, together with the complexity of the interactions between economy, society and environment, call for specific modelling approaches. In this sense, agro-economic models have always played an important role in the *ex ante* analysis of agricultural policies. Furthermore, as CAP policy has evolved from market intervention towards non-market measures that directly target farmers and sustainability, conventional modelling approaches have been adapted and new models have been developed to better capture the complex economic, social and environmental interactions associated with the changes in CAP policy instruments.

Current agricultural policies put greater emphasis on farm-specific support and environmental performance. As a result, there is an increasing interest in developing farm models capable of properly representing the new CAP instruments and assessing their farm-level effects. Compared with partial and general equilibrium frameworks, farm-level analysis provides greater flexibility for capturing high farm heterogeneity and modelling the multifaceted interactions between farming practices, environmental effects and economic performance. This chapter discusses the increasingly important contribution of farm-level modelling to policy impact assessment. For illustration purposes, it focuses on the EU agricultural sector, where both policies and impact models have experienced a rapid transformation in recent decades.

The chapter is organized as follows. The following section (1.2) highlights how the evolution of agricultural policies over time has shaped the development of agro-economic models, with a focus on European policies. Section 1.3 discusses the role of farm-level approaches in *ex ante* impact assessments, with an emphasis on the diverse modelling approaches used rather than on empirical results obtained. Above all, it focuses on the capabilities of current modelling approaches to properly capture farm heterogeneity, farm-level adaptation strategies, agriculture–environment interactions and market feedback. Finally, the last section (1.4) summarizes the major challenges for farm-level modelling of agricultural policies and presents some concluding remarks.

1.2 Evolution of EU Agricultural Policies and Parallel Development of Impact Models

Early CAP measures were mostly based on price and market support (production subsidies, border protection measures). Accordingly, partial equilibrium models that depict the functioning of agri-food markets were commonly used in policy impact studies. Besides these, general equilibrium models were applied to cope with economy-wide impacts and spillover effects between sectors. As we will see hereafter, the evolving objectives of EU agricultural policy have guided the orientation and design of agro-economic models focused on policy impact assessment.

Since the 1990s, the CAP has been gradually reformed towards stronger market orientation and enhanced agricultural sustainability in response to ever-changing societal demands. Early reforms in the 1990s addressed problems such as overproduction, the high cost of CAP support and international trade tensions. These reforms replaced a large share of the price support in the EU by direct payments coupled to production (defined per hectare of land or per head of livestock), implying a shift from product support to producer support. The use of quantitative tools to analyse policy impacts became widespread in those years (Lansink and Peerlings, 1996; Barkaoui and Butault, 1998). Further, the rapid progress in computer and communication technologies, along with better access to international databases, boosted the development of increasingly sophisticated models. A review of partial and general equilibrium models commonly used for agricultural and trade policy assessment is provided by van Tongeren *et al*. (2001). With subsequent policy initiatives, the weighting of the different objectives of the CAP has changed, as well as the policy instruments used to achieve these objectives. A drastic reform of the CAP was adopted in 2003 to make European agriculture more competitive and market oriented and, at the same time, provide less trade-distorting support to farmers. The main elements of the reform were: (i) the introduction of the Single Payment Scheme that decoupled direct payments from production; and (ii) a greater emphasis on environmental quality, food safety and animal welfare standards.

The 2003 reform represented a major change in the way the EU supports the farm sector. Changes in agricultural policy instruments were accompanied by increased attention to the assessment of policy impacts. Uncertainty of the impacts of the 2003 CAP reform, together with greater sustainability concerns, stressed the need to provide comprehensive impact assessment. Following the recently established Guidelines (European Commission, 2002) – aligned with sustainability goals – a formal impact assessment of the 2003 reform was carried out (European Commission, 2003). This involved a scenario analysis, where a range of policy alternatives were compared against a 'baseline' or reference scenario reflecting the expected developments of EU agriculture in a 'non-policy' situation, while taking into account anticipated technological or societal developments as well as the policies already in place. Parallel to the official requirements from the European Commission on the *ex ante* impact assessment of policy initiatives, considerable progress took place on model development. On the one hand, while existing impact models were suited to analysing production decisions and evaluating the impacts of price support, decoupling was an unprecedented change and represented a great challenge for policy modellers. On the other hand, impact models required in-depth adaptations before being applied to the assessment of environmental effects. In the 2000s, many conventional impact models went through significant improvements that enabled them to better capture the interactions of policy incentives, farmer responses and environmental effects at various spatial and temporal scales. At the same time, new modelling approaches more targeted towards sustainability analysis were developed.

Economic theory suggests that decoupled payments provide a more efficient basis for income transfer and give rise to fewer market distortions than coupled ones. In principle, the decoupling of direct payments from production is expected to make production decisions more market oriented and, therefore, is supposed to lead to the same level of production that would exist without any payments. However, even fully decoupled payments may affect production decisions through: (i) the income effect, which influences farm labour allocation; (ii) the risk-related effect, including a wealth effect and an insurance effect; and (iii) dynamic effects, as payments may influence farmers' investment behaviour (Conforti, 2005). While there is little consensus on the indirect effects of decoupled support, a vast literature exists on the impacts of decoupling on risk behaviour (Sckokai and Moro, 2006; Serra *et al*., 2006), farm labour allocation (Gohin, 2006), investment decisions (Sckokai and Moro, 2009) and land markets (Guyomard *et al*., 2004). Bhaskar and Beghin (2009) provide a comprehensive review of the literature on decoupled payments.

Model-based analyses of payment decoupling are numerous. Balkhausen *et al*. (2008) review the results of selected partial and general equilibrium models used for assessing the production and land-use effects of decoupling, finding that, even though results differ across models depending on their specification and assumptions, all models foresee a decline in cereal production and an increase in fodder production as a consequence of decoupling. Also, with decoupled payments, production decisions are more determined by market signals and not by CAP payments. The focus on environmental and sustainability concerns from the 2003 CAP also implied a great challenge for conventional impact models, which were particularly well suited to assessing economic impacts but much less so to accounting for environmental implications. Further, as more disaggregated analysis was needed to quantify the complex interdependencies between agriculture and the environment, models capable of providing farm-level responses became more relevant. Farm-level approaches started to be widely used to assess the environmental implications of agricultural policies and to analyse the impacts of agri-environmental measures (Rohm and Dabbert, 2003; Schmid and Sinabell, 2007).

With the objective of increasing the efficiency and effectiveness of the European agricultural policy, a further step towards decoupled direct payments took place in 2008 with the Health Check package, which led to full decoupling in most countries and sectors (European Commission, 2008). Other measures were the phasing out of milk quotas, the abolition of compulsory set-aside and the increase in modulation; these have been extensively modelled (Britz *et al.*, 2012a). Other environmental concerns have also influenced the development of impact models. Bioenergy is a clear example of how agro-economic models constantly adapt to answer new policy and research questions. The promotion of the use of energy from renewable sources and the rapid development of biofuel markets throughout the 2000s motivated the introduction of new activities in agro-economic models to account for food–energy interactions (Blanco *et al.*, 2010). The 2013 reform further strengthens the environmental objectives of the CAP with the introduction of a Greening Payment, linking the 30% of direct payments to the provision of sustainable farming practices. The reform also aims to move towards a less asymmetric distribution of support, seeking the convergence of payments not only between Member States, but also within Member States. The new policy measures, in particular the greening measures,[1] will have differentiated effects at the regional/farm level. Most of the agro-economic models widely used to conduct impact assessment of previous CAP policies are unable to fully capture the impacts of these new policy measures (Ciaian *et al.*, 2013). The need to develop modelling tools that are able to analyse the socio-economic and environmental impacts of agricultural policies at a much disaggregated level is becoming a crucial issue. Farm-level models play an increasingly prominent role in impact assessment studies. While these models are better suited to assessing the effects of the new farm-specific policy measures, the disaggregated assessment also faces important challenges, namely extensive data requirements and higher complexity in order to extend spatial coverage and to account for market feedback. In brief, agricultural policies are shaped more and more by environmental and sustainability concerns, and policy measures are becoming more territory specific. Climate change and limited resources are identified as future challenges, and will probably be increasingly relevant for policy design. Accordingly, models capable of simulating agricultural policies specified at regional and farm levels become more relevant.

1.3 The Widening Role of Farm-level Modelling in Impact Assessment

As has already been mentioned, recent CAP developments call for more disaggregated assessment of the economic, social and environmental impacts of the increasingly targeted and farm-specific policy measures. As a result, there is a growing interest in developing farm-level models suited to capturing the impacts of agricultural policy instruments at a highly disaggregated level. Better access to databases, developments in computer power and big data tools are also important factors contributing to the advanced development of micro-level modelling tools.

Most farm-level models used for *ex ante* simulation of agricultural policies are built within the framework of mathematical programming (MP). Hazell and Norton (1986) provide a discussion on the standard applications of MP to economic analysis in agriculture. MP is an optimization approach that offers great flexibility: (i) for capturing farm heterogeneity; (ii) for representing the multiple interactions across farming activities and between farming practices and their environmental effects; and (iii) for modelling a wide variety of policy instruments designed at a regional or even a farm level. Broadly speaking, there are several approaches to farm-level modelling, including farm-supply models, bioeconomic models and agricultural household models. While farm-supply models mainly focus on economic objectives, bioeconomic models integrate economic and environmental objectives, and agricultural household models incorporate the social dimension. Furthermore, the models differ in the extent to which they account for spatial and farm heterogeneity, interactions between activities (on the same area or over space), agriculture–environment interactions and intra- and inter-annual variability.

1.3.1 Interactions between activities

Farm models assume that farmers allocate scarce resources among activities so as to obtain the outputs that optimize farm objectives. Agricultural activities are described through input–output coefficients that define the relationship between the amounts of inputs used and the outputs obtained, where outputs involve both agricultural products and externalities. An inherent feature of farm models is that decisions are taken jointly over activities so that interactions between the activities are accounted for. In particular, these models are well suited to account for the interactions between crop and livestock farming through on-farm production and the consumption of animal feed and organic fertilizer.

Farm models are widely used to anticipate the reactions of farmers to alternative policy scenarios. Thanks to their activity-based approach, they are able to capture interactions between activities as well as farm-level adjustments to face new technological, economic or institutional settings. Potential adaptations include changes in cropland allocation, adjustments in production intensity, changes in investment strategies and decisions to expand or exit the farm. While partial equilibrium models are well suited to analysing the effects of market-support measures, farm-level models have some advantages for assessing aid decoupled from production. Thus, since the introduction of decoupled payments in the 2003 CAP, the role of farm-level modelling in policy impact assessment has been steadily increasing. A number of studies have explored the implications of decoupling for the agricultural sector and this is a good example for illustrating the specific contribution of the farm-level approach. Balkhausen *et al.* (2008) discuss the modelling work done with partial and general equilibrium models, drawing attention to the difficulties of aggregated models in accounting for substitution effects between arable land and pasture land, and their implications for livestock production. Farm-level studies are also numerous (Offermann *et al.*, 2005; Buysse *et al.*, 2007; Shrestha *et al.*, 2007), and many of them focus on the substitution effects between crop and fodder areas. For example, Galko and Jayet (2011) used the AROPAj model to assess the effects of several decoupling options, concluding that land used for pasture increases at the expense of land used for cereals and protein crops. Farm-level modelling is a very flexible framework for incorporating a broad range of policy measures, ranging from subsidies to production quotas and conditionality (Mosnier *et al.*, 2009). Compared with more aggregated assessments, farm-level impact analysis is able to capture the interaction between activities in greater detail. Yet, as farm models alone are unable to account for market feedback, these models most likely overestimate the impacts of direct payments on farming practices and agricultural production.

1.3.2 Farm heterogeneity

Growing concern over agricultural sustainability has prompted greater demand for agricultural policy analysis at the local and regional levels. With the introduction of territory-specific measures in recent CAP reforms, the role of impact assessment at the farm level is becoming more relevant. Also, policy makers are increasingly interested in understanding the distributive effects of policies and the differentiated farmer responses when they are faced with various policy and market situations. Overall, farm-supply models applied to the analysis of EU agricultural policies capture farm heterogeneity by modelling a set of farm types, defined through a farm typology. Most of these models have been designed to perform analysis for specific countries or regions, such as FARMIS in Germany (Offermann *et al.*, 2005), AGRISP in Italy (Arfini and Donati, 2011), FAMOS in Austria (Schmid, 2004) or ScotFarm in Scotland (Shrestha *et al.*, 2014). Among the few farm-level models that cover the whole EU, there are CAPRI-FT (Gocht and Britz, 2011) and AROPAj (De Cara and Jayet, 2005).

Farm size and specialization are the main criteria used for defining farm typologies. These typologies greatly depend on data availability and important trade-offs exist between higher detail and the quality of the specification of the corresponding farm model. Within the EU, the main data sources used to build farm typologies are the Farm Accounting Data Network (FADN) and the Farm Structure Survey (FSS). A number of studies have analysed the effects of decoupling on particular countries or regions. Using the FARMIS model, Küpker *et al.* (2006) found that the regional implementation of decoupling in Germany induced a significant redistribution of direct payments and, therefore, led to differences in income effects depending on farm type, location and size. Shrestha *et al.* (2007) used a farm-level approach to estimate the regional effects of decoupling on agricultural production and farm income in Ireland. Their results show that under the historical decoupling scheme, the milk quota would shift from less efficient to larger more efficient farms in all regions. Moreover, switching to a national flat rate form of decoupling would mean that large beef and dairy farmers in the southern regions would lose, while small dairy and sheep farmers in the western and northern regions would be most likely to gain.

Despite evidence of the influence of direct payments on risk aversion, the treatment of risk and uncertainty is not sufficiently covered in farm modelling. Although some farm models incorporate risk, such models have been applied only to a limited number of representative farms (Petsakos *et al.*, 2009; Arata *et al.*, 2014) and their methodologies are not easy to apply when modelling a large set of farms including numerous farm types. Analysing decoupling at the farm level for the whole EU is very challenging, mostly because of data availability and data quality issues. In one of the few attempts that has been made so far, Gocht *et al.* (2013) used the CAPRI-FT model to assess how the harmonization of direct payments in the 2013 CAP reform will affect the distribution of farm income across regions and farm types. With the introduction of greening measures in the 2013 CAP, farm-level modelling becomes crucial. Assessing the effects of capping and greening measures requires the use of models that are able to capture the adaptation strategies followed by farms (Vosough Ahmadi *et al.*, 2015). The diversity of implementation options across Member States, together with the lack of data to adequately define the farm types involved, makes the assessments of greening particularly difficult. The first attempts to model greening measures for particular regions or countries have shown a diversity of effects (Was *et al.*, 2014; Solazzo *et al.*, 2015).

1.3.3 Agriculture–environment interactions

Over the last few decades, there has been increasing concern about the relationship between agriculture and the environment. Since the 1990s, the CAP has introduced agri-environmental measures in order to discourage negative environmental externalities and promote the positive externalities of agricultural activities. Two issues are crucial when addressing environmental issues: (i) the scale of impact assessment should be at the territorial level; and (ii) economic and environmental effects should be jointly assessed. On the one hand, compared with more aggregated approaches, farm-level modelling presents clear advantages for depicting the manifold interactions between agriculture and the environment. On the other hand, the joint *ex ante* assessment of the economic and environmental effects of agricultural policies presents clear advantages because it helps to better target policies towards their intended outcomes. Not only are farmer responses assessed but the environmental consequences of farmer reactions are also accounted for. Compared with more aggregated models, farm-level models are better suited to simulating the interaction of policy incentives, farmer responses and environmental outcomes.

A common approach to assessing the environmental impacts of agricultural policies is to monitor environmental indicators. Several sets of environmental indicators have been developed internationally. The OECD set of agri-environmental indicators (OECD, 2013) has been constantly developed and refined since the 1990s and the modelling of these serves as a basis for informed green growth policies. The European Commission also develops a set of agri-environmental indicators to monitor the integration of environmental concerns into agricultural policy (European Commission, 2006). The integration of environmental aspects into farm-level modelling is straightforward when we can assume a direct link between farm inputs/outputs and some environmental indicator. Based on technical coefficients, the nutrient, energy or carbon balances can be calculated for each activity. Many studies have analysed the impacts of agri-environmental policy measures by translating model outputs into changes in environmental indicators (Buysse *et al.*, 2007; Schmid and Sinabell, 2007). However, due to the complexity of the interactions between farming practices and the environment, even highly disaggregated models may fail to capture some environmental effects. For instance, establishing the relationship between nitrate percolation and groundwater quality, or analysing the impacts of land-use changes on biodiversity and landscape are challenging tasks. Also, data availability and accuracy are often major limitations for depicting the relationship between agricultural activities and the environment.

A more sophisticated way to account for the interactions between agriculture and the environment is the bioeconomic approach, which combines biophysical[2] and economic models (Janssen and van Ittersum, 2007; Flichman, 2011). Belhouchette *et al.* (2011) linked the FSSIM model (Louhichi *et al.*, 2010) to crop growth models to assess environmental externalities. Jayet and Petsakos (2013) coupled the economic model AROPAj with the crop growth model STICS (which enables the derivation of nitrogen-yield response functions) to assess the effects of nitrogen taxes in France under different agricultural policy scenarios. Schönhart *et al.* (2011) coupled the bioeconomic farm optimization model FAMOS, the crop rotation model CropRota and the biophysical process model EPIC to assess the cost-effectiveness of agri-environmental measures in a set of farm types in Austria. As biophysical models operate at a high spatial resolution and are data intensive, increasing the regional coverage of bioeconomic models without loss in accuracy is very challenging. Notwithstanding, the assessment of agri-environmental impacts has experienced major advances in relation to the development of bioeconomic models, the design of interlinked multidisciplinary modelling tools and the variety of environmental impacts considered.

Because decoupled payments encourage more extensive agriculture, they may improve soil and water conditions of the environment (Schmid *et al.*, 2007). None the less, the effects on biodiversity are less clear. To analyse the impacts of decoupling on land use and biodiversity, Brady *et al.* (2009) applied an agent-based approach – which links the dynamics of farm structure to landscape dynamics – to a set of EU regions. They found that decoupled payments may result in further homogenization of land use and loss of biodiversity. The territorial scale of recent policy measures has also motivated the development of impact models that integrate spatial issues. To assess biodiversity, Bamière *et al.* (2011) used a spatially explicit MP farm-based model which accounts for three spatial levels (field, farm and landscape), and showed that valuable insights into agri-environmental programme design are gained through a detailed representation of farming system management.

As already mentioned, models integrating the multiple dimensions of sustainability are crucial tools for assessing current EU policies. Often, the limitation of these approaches is the spatial coverage. As the EU is characterized by high regional variation in agricultural, environmental and socio-economic conditions, quantifying the potential impacts of CAP measures over the whole EU is a challenging task. In recent years, there has been a significant development of bioeconomic approaches, not only to address the multiplicity of objectives in new agricultural policies but also to assess the impacts of climate change in agriculture. Actually, the integration of biophysical and economic models is the most widely used approach to assessing the complex interrelations between climate change, agricultural production and natural resource sustainability (Fernández and Blanco, 2015).

1.3.4 Dynamics and structural change

Sustainable impact assessment involves many dynamic features: investment behaviour, changes in farm structure, the evolution of environmental conditions (soil fertility, water quality, greenhouse gas (GHG) emissions, etc.). Nevertheless, most farm-level models have been developed in a comparatively static framework, mostly because: (i) data on capital assets is not as available as production data; (ii) the dynamic interlinkages between farming practices and environmental quality are highly complex; and (iii) calibrating and solving dynamic models is very challenging. Few attempts to model livestock dynamics are found in the literature and these usually refer to specific regions or countries. For instance, to analyse GHG abatement in German dairy farms, Lengers and Britz (2012) developed a dynamic model that is able to cover a great variety of GHG abatement options and derive farm-specific marginal abatement cost curves.

The potential impacts of decoupled support on investment behaviour and structural change have received great attention in the literature, but current farm modelling approaches are not able to fully cover those impacts (Zimmermann *et al.*, 2009). Accordingly, farm models are often combined with other approaches. Hennessy and Rehman (2006) explored the effect of decoupled payments on production decisions and structural change in Irish farming. To this aim, they combined a multiperiod optimization model with the econometric estimation of farm labour allocation and entry and exit decisions. Similarly, Renwick *et al.* (2013) combined the CAPRI-FT model with a land-use model to analysis the impact of policy changes on land abandonment. The effects of decoupling on structural change vary across regions, farming systems and policy options. While Hennessy and Rehman (2006) found that farm numbers will decline more rapidly under decoupling relative to the baseline situation, Sahrbacher *et al.* (2007) showed that the decoupling scenario slows down structural change, mainly because decoupled payments provide additional income opportunities for farmers with grassland to remain in the sector.

Sahrbacher *et al.* (2007) used an agent-based model, AgriPoliS, in which production and investment decisions are made simultaneously (Balmann, 1997; Happe *et al.*, 2006). This approach is better suited to modelling the dynamics of farm structure. Brady *et al.* (2009) found that decoupled payments will increase land rental prices and that this, in turn, affects future farm income and production decisions. The drawback of this approach is the complexity of extending the analysis to the whole of the EU. Viaggi *et al.* (2010) developed a farm-household dynamic model to evaluate the effects of decoupling on farm investment behaviour and provides an application to northern Italy. These authors argued that, since the introduction of decoupled payments in the 2003 CAP, the use of instruments able to account for multiple objectives, dynamics and investment choices will become even more relevant in the analysis of EU agricultural policy.

1.3.5 Market feedback

While farm-level models are able to capture agriculture–environment interactions at a disaggregated level, these models focus at supply responses and do not take into account market interactions. That is, input and output prices are exogenous in this type of model and, therefore, price effects are not accounted for, at least endogenously. On the contrary, partial equilibrium agro-economic models, which have been standard tools for policy impact assessment to date, are well suited to representing not only the production but also the demand for and trade of agricultural and food products, but they fail to capture the effects of farm-specific policy measures. In the current context of increased globalization, the lack of market feedback is one of the main limitations of farm-level modelling. This limitation can be overcome by linking farm models to partial equilibrium tools. Applications of multi-scale approaches in impact assessment include the AGRISIMU modelling framework (Lehtonen *et al.*, 2010), which integrates a farm-level optimization model, a regional sector model and biophysical models to assess alternative policy options in Finland. The FARMIS model has also been linked to the market model ESIM to measure the impacts of liberalizing European agriculture on farm income distribution in western Germany (Deppermann *et al.*, 2014). In most cases, the link to markets is done through a soft-link approach in which the outcomes from the market model are used as inputs in the farm model. The CAPRI-FT model is a unique case because in this approach, farm-level models and a global market model are fully integrated and solved iteratively (Gocht and Britz, 2011). The distinctive feature of CAPRI-FT is that it enables the assessment of farm-level impacts while covering the whole EU and taking into account market feedback.

1.4 What Models Do We Need to Assess Tomorrow's Agricultural Policies?

The agricultural sector is facing continuous socio-economic and environmental challenges in a rapidly changing economic and institutional environment. In coming years, climate change and environmental concerns will increasingly influence agriculture and shape the design of agricultural policies. Even if current modelling tools designed to assess policy impacts are highly sophisticated, a number of challenges remain in the modelling of agricultural systems. Moreover, models also need to continuously adapt to changing policy and societal concerns. Due to the manifold objectives of agricultural policies and the multitude of environmental impacts associated with agricultural production, sustainability impact assessment requires an integrated approach to account for the interrelated economic, environmental and social impacts at different temporal and spatial scales. Tools for integrated assessment combine models from different disciplines that operate at varying time and spatial scales and provide a multitude of outcomes. Integrated assessments also need methods for scaling up economic, environmental and social variables from the farm level to higher aggregation levels (Britz *et al.*, 2012b). In addition, they require methods for scaling down data and baseline indicators from the administrative level (regional, national) to the farm level.

The development of multi-model multi-scale platforms faces several challenges related to aggregation issues: (i) the diversity of temporal and spatial scales through models and disciplines; (ii) the need to account for cross-effects (i.e. price endogeneity); and (iii) the need to account for the complex and interconnected links between economic and environmental outcomes. Scaling methods become a crucial aspect of sustainability impact assessment tools. Without scaling, the contribution of farm models to the assessment of policy impacts will remain limited. Current agricultural policies require methods that are able to represent farm heterogeneity and to model farm-specific policy measures. Still, these methods should also be able to capture interconnections between farms (i.e. exchange of inputs) as well as market adjustments for inputs and outputs. Relevant trade-offs exist between the benefits of developing more complex models and the costs of providing greater detail (greater data needs, increased complexity and transparency issues).

Environmental factors are another crucial issue. There is a wide diversity of environmental impacts (i.e. impacts on natural resources such as soil and water, biodiversity, landscape) and a wide range of agri-environmental policy measures. Impact models need to identify and measure the causal relationships between policy measures and environmental change. Despite the advances in the integration of environmental variables in impact assessment tools, current farm models are still lacking the capability to properly simulate the environmental impacts of policy measures, in particular those with a strong spatial component (i.e. biodiversity, landscape or hydrology).

Data availability and accuracy are the key limiting factors in model development. Aspects such as the definition of farm types are highly dependent on the available data sources. Even more limitations are found in the case of environmental variables, which also show a high spatial variability. Secondary data sources on the relationship between farming and environmental conditions are lacking, and collecting these data for a large number of regions may become extremely costly. Nevertheless, spatial data are increasingly available and, even if the link to farm practices is still missing, big data tools offer promising opportunities to improve data availability and processing.

The challenges encountered in *ex ante* assessment of recent CAP reforms have led to changes in impact models. Today, the rapid development of sophisticated modelling platforms has been made possible by the collaboration of multidisciplinary teams worldwide. Multi-scale multi-model perspectives require the joint work of research teams from different disciplines. Notable advances have been already achieved in database sharing and in the joint development of model coding. Recent research on climate change and resource scarcity is a clear example and shows how impact assessment will rely more and more on multi-model approaches, which are capable of covering more issues.

Moreover, integrated impact assessment tools also call for joint baselines. Important efforts have been made to homogenize baselines so that model outcomes are comparable when they are used to address the same policy question. Yet, conceptual differences between baselines exist, and it remains difficult to combine baseline indicators across spatial scales. Deficiencies in model validation and uncertainty analysis require special attention. Further efforts are needed in these areas to enhance the contribution of farm models to sustainability impact assessment.

Notes

[1] The three foreseen greening measures are: permanent grassland, crop diversification and ecological focus area.

[2] Biophysical models simulate the interactions between soil, climate, farm management, crop growth and water and nutrient cycles.

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