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A Synthesis on Agent-Based Impact Assessment Models from the Perspective of the EU Rural Development Policy Measures

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ABSTRACT
The second pillar of the European Union's (EU) Common Agricultural Policy (CAP) aims at supporting rural areas by meeting the economic, environmental and social challenges. To deal with these challenges, countries are faced with the question of selecting the best tools among a large set of policy instruments. The problem of choosing the best policy instruments is aggravated by the very heterogeneous character of the societal demands that differ among member countries with very different economic and institutional structures. This study aims to introduce the agent-based modelling platforms that have been widely used in the impact analysis of recent rural development policies in the EU in a comparative manner. It also aims to explain how the above-mentioned sources of heterogeneity are handled in these models. To achieve the stated objectives, the study first examines the historical development of rural development policies within the EU. Subsequently, it proceeds to analyse several agent-based platforms that have been employed for the purpose of assessing the impact of agricultural policies with respect to certain features such as integration of land market, modelling unit, decision rule, rules of exit, labour market and price formation. To conclude, it is observed that as the rural development policies are formulated on farm-basis and as farms have a heterogeneous structure within themselves, in addition, the expansion of databases and the development of empirical analysis tools and technologies have led to a shift in empirical analyses towards agent-based models. However, these modelling platforms still embody various problems, especially in terms of database adjustments and parameterization and calibration of the model.

Keywords: European Union, Rural development policies, Agent-based modelling

1. Introduction

The international empirical literature shows that studies of impact analysis and policy modelling regarding the agricultural sector are gradually shifting towards the use of agent-based methods. The two most important reasons behind this shift are that the policies are targeting more farms rather than sector and product, and the non-homogenous structure of the farms.

The agricultural and rural development policies of the EU set a very good stage for the above-mentioned reasons. Both the policies implemented within the Union have become increasingly farm-oriented and the farms within the Union exhibit an extremely heterogeneous structure.

From this perspective, the paper discusses the argument that agent-based models are more appropriate tools for impact analysis of changing agricultural and rural development policies in the EU. It does so within the framework of a literature review, thus providing both a broad overview of changing EU policies and an assessment of the advantages and disadvantages of agent-based models.

Due to the complexity of the agricultural sector and the many roles it plays, conducting an effect assessment on agricultural policies is no simple task. Although agriculture is the primary economic force in rural areas, the primary component in agricultural production -land- is increasingly being put to non-agricultural purposes. The industry is vital to the bio-economy and has strong ties to cultural preservation, tourism, and rural development. One further distinctive trait is the sector's multidimensional linkage with the environment, which calls for consideration of such links in the impact assessment evaluations. The industry is also distinguished by its focus on organic species, which brings up questions of plant and animal welfare, biodiversity, and humane treatment of animals. Further complicating agricultural policy impact assessment is the fact that different countries are at different stages of development, which in turn affects the sector's and farms' structures, as well as farmers' management techniques. The institutional makeup and public expectations are both influenced by the level of development. Therefore, it becomes a significant difficulty to model policies affecting rural communities and the agricultural sector.

Since the inception of the Common Agricultural Policy (CAP) there has been a move from heavily interventionist to more market-oriented policies meaning a move towards decoupled, direct payments. There has been a shift in concerns from food security to more social and environmental aspects and to rural areas/development was also observed. Finally, a shift in interests from aggregate behaviour to farm behaviour took place. In terms of rural development policies again a few changes were observed simultaneously. These include; a change from limited farm restructuring measures towards multi-annual financial frameworks, from limited regional funds towards fundamental principles of regional funding and from agriculture–oriented policies towards reinforcement of rural development policies (rural policies to support non-agricultural actors). Moreover, a shift from regional policies towards rural policies, from economic concerns to sustainability of agricultural land use, a change towards promoting sustainable farming and innovation to support jobs and growth in rural areas and finally a move in financial assistance towards the productive use of land is also observed.

2. A Brief on the EU's Rural Development Policies

Since its effective inception in 1962, the CAP of the EU has undergone significant revisions. In most cases these reforms were attempts to remedy internal and external unforeseen outcomes of policies with regard to agricultural sector itself, rural livelihoods and environment. Sometimes societal demands that reflect the heterogeneity among member countries were the main factors behind modifications to the CAP.

Initial policies relied on price support, import taxes, and export subsidies to provide farmers with an appropriate environment for production. These measures also encouraged the widespread use of agricultural technologies like chemical fertilisers and mechanised harvesting, which ultimately led to higher crop yields. In place of price support, the 'MacSharry reform' of 1992 included hectare-based direct aid payments and compulsory set aside under the CAP. The MacSharry reform also encouraged environmentally conscious agricultural practises. Income support is provided on the condition that farmers take care of the land and meet food safety, environmental, animal health and welfare standards under the "Agenda 2000 reform," which acknowledged the multi-functionality of European agricultural systems (Emmerson et al. 2016), and the "decoupling" reform of the CAP in 2003. In 2007, the European Agricultural Fund for Rural Development was established, bolstering agro-environmental schemes. The 'health check' of the CAP in 2008, along with the elimination of arable set aside and the introduction of additional cross-compliance requirements, finalised decoupling. The "health check" resulted in a reduction of direct payments to farmers, with the money going instead into the Rural Development Fund. To better promote smart, sustainable, and equitable growth and to better contribute to the goals of Europe's 2020 strategy, the CAP underwent a significant change in 2013. The CAP 2014-2020 prioritised the conservation of agricultural land, the protection of biodiversity, and the regulation of climate change. These first two goals, together known as "Pillar I" of the CAP, deal with issues like rural development programmes and income support for farmers. In addition, the CAP regulations for the 2014–20 period will be extended under a transitional regulation that will also ensure an easy transition to the eventual framework of the CAP strategic plans (European Commission 2023).

3. A Summary on Alternative Empirical Approaches Used for Agricultural Impact Assessment

The literature provides a rich toolbox that includes various qualitative methods and quantitative models to use for policy impact assessment regarding the agricultural sector. If qualitative methods are left aside as these are not at the main focus of the paper, the quantitative modelling is carried out by various approaches. These include cost-benefit analysis, multi-criteria analysis, counterfactual analyses, life-cycle analyses, input-output models, micro-simulation models, econometric analysis, general equilibrium models, partial equilibrium models and integrated approaches. The temporal parameters of these tools vary in terms of time horizon and the choice between static and dynamic settings. Additionally, they differ in spatial resolution levels, ranging from plot, farm, parcel, region, to country. These tools also incorporate several components, including biophysical, environmental, and social factors. Furthermore, they possess additional distinguishing qualities, such as the inclusion of policy instruments. Certain colleagues employ alternative methodologies to categorise these quantitative instruments. Millington et al. (2017) used the term "telecoupling" as a means of describing the integration of agricultural markets with the environment and rural economies, both at local and global scales. The empirical approaches in question are categorised as partial equilibrium economic models, system dynamics modelling, and agent-based modelling. Rizojewa-Sileva et al. (2018) examine the topic via the lens of "simulation" and categorise the empirical techniques as system dynamics (including both partial and general equilibrium models), agent-based models, hybrid models, and discrete event simulation.

While policy impact assessment regarding agricultural sector is not an easy task and embodies various challenges, reviewing the alternative methodologies is difficult as well due to its wide coverage. Therefore, the methodologies has to be limited accordingly with the aim of the paper. In this review, our concern is not the modelling of individual events and therefore discrete event simulation methods is not elaborated. The use of hybrid models introduces new challenges such as extensive data requirement, theoretical consistency, and representation problems. Besides, each hybrid model is self-tailored to a specific problem and so comes with its own distinguishing and structural features. Hence hybrid models are not reviewed here either.

Due to the complexity of the topic, analysing alternative approaches for assessing the impact of policies on the agricultural sector is also a challenging task, and this paper's focus should be narrowed to avoid digressing. Discrete event modelling approaches are not expounded upon because it is not the focus of this review. Each hybrid model is self-tailored to a given problem and hence comes with its own differentiating and structural elements. These hurdles arise when using hybrid models and include a large amount of data, theoretical consistency, and representation issues. Consequently, hybrid models are not discussed further here.

4. The Aim and Plan of the Study

This review adopts the terminology of "agricultural modelling platforms" and places particular emphasis on agent-based models that do not incorporate any type of "representative behaviour in activities/countries/regions/land and or farm typologies". By narrowing the scope of empirical methods in this way, the study first describes the evolution of EU rural development policies and thus aims to justify the motivation of the study. Then, by comparatively reviewing agent-based models from various perspectives, it aims to show which aspects of these models are advantageous and which aspects are problematic in impact analyses.

After an introduction with a brief overview of the EU agricultural and rural development policies and alternative empirical methods, the study continues with a detailed review of these policies in the second section. The literature review provides a comprehensive overview of the fundamental and specific attributes of the agent-based approach in a comparative approach. The study concludes in the last section.

5. Evolution of the EU's Rural Development Policies (RDP)

Meeting the economic, environmental, and social challenges that rural areas face is the core objective of the EU's second pillar of the CAP. The RDP's primary goals are the enhancement of agricultural competitiveness; the sustainable management of natural resources; the mitigation of agriculture's effects on climate change and the creation of a climate-resilient agricultural sector; and the achievement of a territorially-balanced development through the maintenance of employment.

According to a standard definition, rural areas in the EU include 91% of the terrain and 56% of the total population. There are serious ecological and societal problems in many of these rural places. Agricultural methods strain the increasingly diverse rural ecosystem. The agricultural and food processing industries still contribute significantly to the economies of rural and peripheral communities. Public goods are created through agriculture and forestry, including scenic views, species richness, a steady climate, and safety from natural disasters. These concerns are the focus of the European Union's rural development programme (European Commission 2023).

The first element of the regional policy was European Social Fund (ESF) aiming at more employment and workers' mobility and rendering guidance section of FEOGA. Delors package developed in 1988 setting up and automatic budget system allowing longer term regional development strategies boosted the rural development role in the EU. The programme's guiding concepts were as follows: concentration, planning, collaboration and monitoring and evaluation of projects and programmes.

The goals of regional development include, among other things:

- The development and structural adjustment of underperforming regions.
- The revitalization of areas affected severely by industrial decline.
- Reducing long-term unemployment rates.
- Helping young people break into the workforce.
- Speeding up the restructuring of agriculture and fostering growth in rural areas (Table 1).

Commission announced its first rural development policy by the document called "The Future of Rural Society" first in 1988 (EC 1988). In parallel with the MacSharry programme, Commission launched a pilot programme for the rural development called LEADER. Following 2005's CAP Mid-Term Review, EC revised its rural development policy and beginning in 2007, the new policy went into implementation. There are many different initiatives under the EU's rural development policy, but they can be broken down into three main categories: 1) boosting the competitiveness of agriculture and forestry, 2) enhancing the environment and countryside by bolstering land management , and 3) enhancing the quality of life in rural areas and encouraging diversification of the rural economy (via the LEADER programme). Rural development funds clearly separated into a special subheading in 2007-2013 for financial perspective and programming period and it is not a part of the regional polices linked to the CAP.

As part of Agenda 2000's reforms, the Rural Development Regulation (EC Regulation 1257/99) was enacted to promote and support thriving rural communities, building on the multi-functionality and Living Countryside concept introduced in the Cork Declaration (EC 1996). It outlined three primary strategies (Renting et al. 2006).

1. Multi-functionality (i.e. paying farmers for the variety of services they give while emphasising the creation of other sources of income).
2. A multi-sectoral strategy to foster growth in rural areas' economies and societies.
3. Enhanced efficiency supported by strategically integrated and streamlined programmes endowed with the flexibility they require.

Table 1- Origins and Evolution of EU Regional and Rural Policy

1964	Launch of the CAP	Prioritise financial support.
1972	Introduction of Rural Development Funds	Implementation of limited agriculture reorganisation measures.
1975	Creation of Regional Funds	Introduction of inter-member state transfers.
1988	Delors I Package	Foundation of the current budget structure; introduction of multi-year financial frameworks and basic regional funding principles.
1992	Delors II Package	Significant increases in regional funding.
1992	MacSharry Reforms of the CAP	Introduction of direct payment mechanisms; elimination of price support; bolstering rural development policies.
1996	Cork Declaration	Introducing multifunctionality and the concept of a Living Countryside, as well as advising the Commission on policy orientations for an innovative, integrated, and inclusive rural and agricultural policy.
1999	Agenda 2000	Advancing the reform of the CAP.
2000	Lisbon Strategy	Concentrate on growth and employment via innovation.
2003	Mid-term Review of the CAP	Reform of agricultural markets and decoupling of direct income support from production in the CAP.
2005	Reform of Rural Development Policies	Expanding the scope of rural policies to include assistance for non-agricultural actors.
2007-onward	New EU Financial Perspectives	Budgetary reform, increased emphasis on employment and innovation.
2013	Treaty on the Functioning of the European Union (TFEU)	Promoting agricultural competitiveness; assuring sustainable natural resource management and climate action
2016	Cork 2.0 Declaration for 2020-27	Advising the Commission on the policy orientations for an innovative, integrated, and inclusive rural and agricultural policy, based on the Cork Declaration of 1996.
2020		Guidelines for rural development expenditures in 2021 and 2022.

Source: Adopted partly from FAO/WB. The Evolution and the Impact of EU Regional and Rural Policy, Working Paper, EU, 2016 and expanded by the authors.

Economic, social, and environmental policies for rural development are under the purview of the CAP's so-called "second pillar," which was first outlined in 1988 as part of Agenda 2000. The CAP's second pillar is meant to provide support to rural areas throughout the EU, and it is far more adaptable than the first. It's designed to tackle numerous economic, social, and environmental problems plaguing the modern world. By providing a European "menu of measures", it helps local, regional, and national authorities create their own multiannual rural development programmes. The rural development programmes are funded in part by the EU and in part by national or regional money, in contrast to the first pillar, which is funded solely by the EU (European Parliament 2023).

Rural development policy legally based on the Treaty on the Functioning of the European Union (TFEU); Regulation (EU) No 1303/2013 (common provisions concerning the European Structural and Investment Funds); Regulation (EU) No 1305/2013 (support for rural development); Regulation (EU) No 1306/2013 (financing, management and monitoring of the common agricultural policy); and the Omnibus Regulation (Regulation (EU) 2017/2393 (introducing changes to Regulation No 1305/2013 and 1306/2013).

Achieving sustainable management of natural resources and combating climate change are two further goals of the rural development policy, which also seeks to achieve a balanced territorial development of rural societies and economies. One component of this goal is the enhancement of steady employment. EU priorities for rural development policy in the 2014–2020 period are indicated as:

- Promoting knowledge transfer in the fields of agriculture, forestry, and rural areas.
- Improving the competitiveness of various agricultural sectors and ensuring the sustainability of farming operations.
- Enhancing food chain organisation and risk management in agriculture.
- Improving agricultural and forest ecosystems through restoration and preservation.

- Encouraging businesses in the agricultural, food, and forestry industries to become more resourceful and productive while also helping them make the transition to a low-carbon, climate-resilient economy.
- Encouraging economic growth, lowering rural poverty, and broadening social participation (European Parliament 2023).

Member states or member state regions design the rural development programmes through which rural development policy is implemented to meets the specific needs of member states. The programme has to relate at least to four of the six rural development priorities. A combination of measures for the programmes is selected from a 'menu' of European measures and the programme is co-financed by the FEOGA. The co-financing rates differ based on the region and measure concerned. The European Commission approves the programmes including a financing plan and a set of performance indicators. The programme is monitored and assessed by the Commission and the Member States with a joint system for rural development policy.

The 'European menu' includes the following options:

1. Methods of knowledge and information transfer (such as training and public awareness campaigns).
2. Consultation, farm management, and immediate support service for farmers.
3. Agricultural and food quality assurance systems (innovative approaches to farmer involvement in quality assurance systems).
4. Investment expenditures (on things like food processing, infrastructure, farm productivity and sustainability, and so on).
5. Restoring the potential for agricultural production lost due to disasters and catastrophic occurrences and implementing measures to prevent similar losses in the future.
6. Farm and company expansion (including assistance for new farmers and the establishment of non-agricultural firms in rural areas).
7. Reviving rural communities and providing essential services to them (high-speed internet, cultural events, tourism attractions, etc.).
8. Investing on the growth of forests and making them more sustainable (through reforestation and new forest creation).
9. Forming organisations and groups of producers.
10. Ensuring that environmentally and climate-friendly farming methods are maintained (agro-environment-climate measures) (which should be incorporated into rural development programmes).
11. Conversion or support payments for organic farmers.
12. The Water Framework Directive and the Natura 2000 system, and the related payments.
13. Compensation for regions with unique physical or social challenges.
14. Funding for animal welfare.
15. Conservation of forests, environmental services, and climate change compensation.
16. Encouraging cooperation between farmers and forestry operators and those involved in the food production chain (establishing centres and networks, operational groups of the European Innovation Partnership for Agricultural Productivity and Sustainability (EIP)).
17. Risk management toolkit including crop, livestock, and plant insurance; mutual funds for adverse climate events, animal and plant diseases, pest infestations, and environmental incidents; income stabilisation programmes" (European Parliament 2023).

About EUR 100 billion were set aside in the EU budget for rural development in the 2014-2020 multiannual financial framework, with another EUR 61 billion supplied by the Member States as national co-financing for such measures.

On January 1, 2018, the Omnibus Regulation took effect, drastically altering the pre-existing risk management framework. If a farmer's revenue drops by more than 20%, or if more than 20% of their annual average crop is lost, they may qualify for the sector-specific stabilisation tool.

Building on the Cork 2.0 Declaration on rural development (EU 2016), the EU released a new communication on the future of food and farming for the period of 2020-2027 on November 29th, 2017. The communication focused on the next generation of farmers and the importance of preserving natural resources and promoting sustainable development. Value chains in growing sectors including bio-economy, sustainable energy, the circular economy, and eco-tourism are highlighted as a new area of emphasis in this communication.

As part of the EU's cohesion policy, the regulations of the Leader programme have been incorporated into the cohesion policy framework, the FEOGA is no longer a structural fund, and the rate of co-financing from the Community budget has been reduced. The Farm to Fork and Biodiversity Strategy, as well as the European Green Deal, will all make significant use of agro-environmental and climatic strategies. While the Next Generation EU Fund will be increased to aid rural areas in making the necessary structural changes to achieve the objectives of the European Green Deal and the Digital Transition Pact, the overall budget for Pillar II has been cut by about 19% compared to the previous period (European Parliament 2023).

6. Notable features of RDPs

Adopted on December 23, 2020, the CAP transitional regulation lays out the rules for rural development expenditure in 2021-22. These rules are as follows:

1. Climate and environmental spending: Each RDP must allocate at least 30% of its budget to initiatives that address climate change and the environment.
2. Fostering local initiatives: At least 5% of RDP money must go towards initiatives using the LEADER / Community Led Local Development methodology.
3. Supporting smart villages: The smart villages programme seeks to offer a flexible toolkit to nurture, facilitate, and scale up innovation in rural areas, addressing the common difficulties residents confront in rural areas.
4. Financial tools: The EAFRD (European Commission) serves as a source for loans, microcredits, guarantees, and equity for financially viable projects fulfilling the EAFRD's aims.

A graphical illustration of the evolution of CAP was presented in Figure 1. Dark lines are the main CAP reforms introduced since 1962. Red lines represent the other changes during the implementation of CAP, basically indicating the rural development policies of the EU.

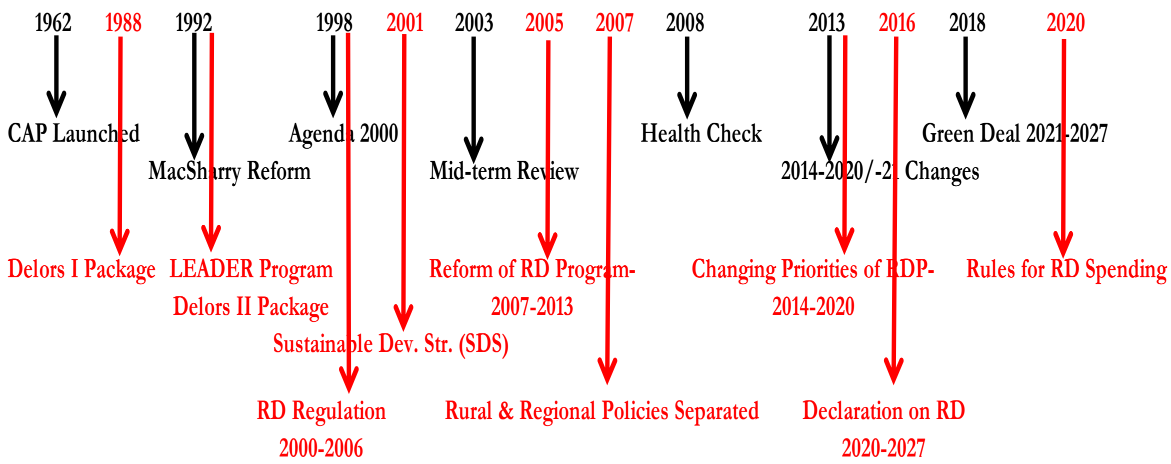

Figure 1- EU Agricultural Policy Evolution

7. Literature Review: Agent-Based Models (ABMs)

7.1. General characteristics of ABMs used for agricultural policy impact assessment

Modelling agricultural sector for policy impact assessment is becoming a real challenge due to both the sector's multi-functional characteristics and to the changing economic and institutional environment surrounding each country and regions. The multi-functionality covers economic, social and environmental dimensions. Parallel with these circumstances, policy objectives and instruments of the CAP have been shifting continuously from country/activity-based interventionist to farm-based decoupled payments in the last 50 years or so. Last couple decades also witnessed the changes in policy objectives that aim at preserving/improving environmental quality, increasing food safety/security and animal welfare standards and achieving more developed and viable rural areas.

From the above perspective, in the last decade a shift in modelling approaches used for policy impact assessment has been observed in the empirical literature towards farm-based approaches rather than country/region- and activity-based representative type models. Thus, it is foreseen that farm-based approaches (Hybrid modelling approaches that integrate various modelling platforms/capacities of different disciplines have been also increasing lately. These approaches can account for the economic, environmental, and social impacts at different spatial scales however parameterization and calibration of these modelling platforms might become the main challenge rather than policy modelling) will be capable of analysing the socio-economic and environmental impacts of agricultural policies at a much more disaggregated level. Figure 2 provides a summary of the factors behind the shift in modelling approaches which increased the importance of farm-based policy outcomes rather than representative findings.

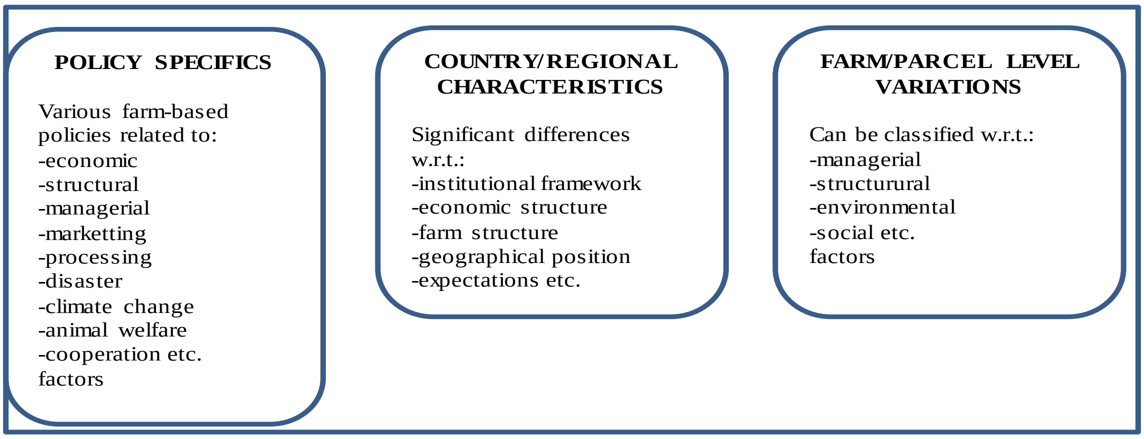

Figure 2- Factors that Led Modellers towards the Agent-Based Approach

Use of agent-based models for agricultural policy analyses is quite new and number of studies is increasing in the last decade. Modellers often choose to build these models from scratch to best fit to their modelling objectives. Hence these models may be referred to as objective-tailored. The individual elements of the approach are farms and a bottom-up strategy is followed focusing on farm behaviour. This strategy allows for modelling local and global properties by using multiple levels of hierarchical organization to represent for example villages besides the households (Kremmydas 2012; Axelrod & Tesfatsion 2012).

Therefore, probably the most striking feature of the approach appears as its capacity to model farm heterogeneity and farm interactions. The heterogeneity might be sourced by demographic characteristics of the farm, social environment of the farmer, ownership and managerial type of the farm, farm structure and environmental/climatic/geographical conditions surrounding the farm which might affect farms' decision-making process (Kremmydas et al. 2018). This flexibility that make farm characteristics endogenous allows this approach to model human–environment interactions and land use, land cover and landscape change which might be the second and third striking features of the approach.

Billari et al. (2006) highlights four advantages of agent-based models in comparison to representative type models. First, in ABMs modelling feedback relations between farms are relatively easy. Second, risk behaviour of the agents can be modelled and third, not fully rational farm behaviour can be modelled. Finally, constructing and solving problems non-tractable by non-linear systems and/or systems with a large number of interacting agents is possible. Axtell (2000) introduces a fifth advantage which is the capacity of ABMs in modelling problems far from any type of equilibrium; time, space and social networks.

Besides these advantages ABMs have some disadvantages as well. Robustness of the ABMs is weak compared to conventional mathematical models as initial conditions of the simulation are highly decisive on the solutions. The "black box" criticism arises for ABMs as well, referring to the difficulty in representing the assumptions and algorithms related to the modelling in a standardized and comprehensible manner (Kremmydas 2012). Finally, the data requirement and consistency of the required data for linking human-environment/climate-farm problem might be quite demanding.

8. A Comparison among ABMs with respect to their Modelling Capacity

This review focuses on how certain characteristics of agricultural farm holdings differ and are incorporated in agent-based models as farm holdings are the main agent/subject of the agricultural sector and as modelling the decision-making process of the agents is the main aim. Several criteria have been identified as keys to compare various agent-based models and these criteria are demonstrated with the help of a figure that centres on the farm.

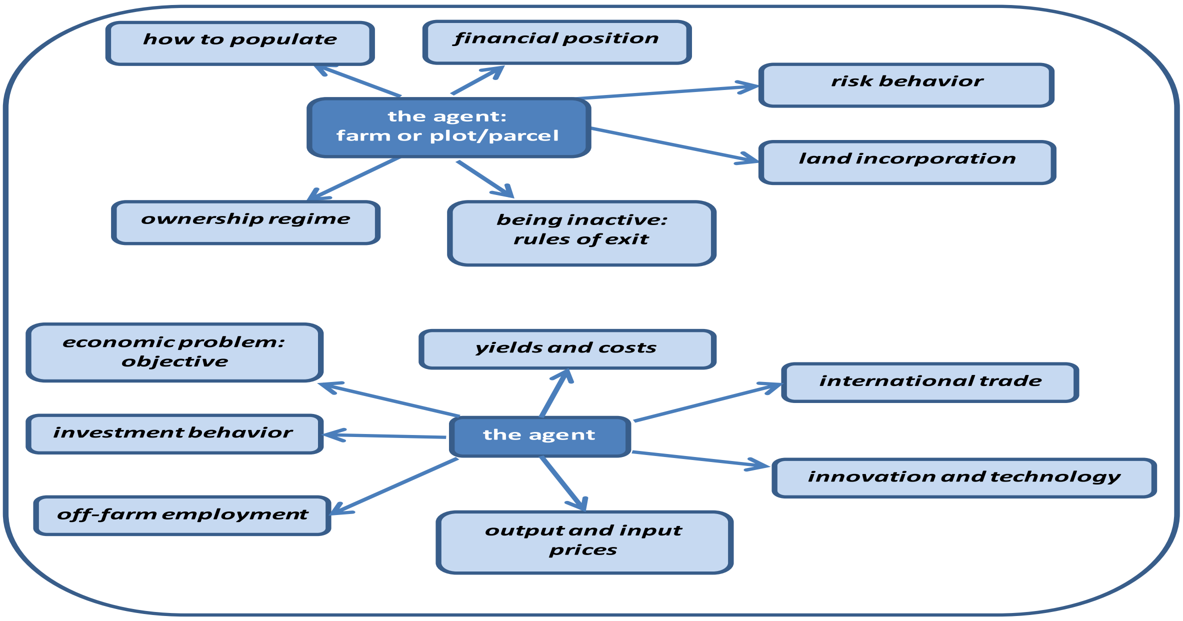

Figure 3- Comparison Criteria

The agent: farm or plot/parcel. A plot/parcel might be composed of more than one soil type and they might be exposed to different biophysical conditions. Therefore, if plot/parcel is taken as the main modelling unit (agent); geographical, climatic and biophysical conditions can be better reflected in the model whereas if farm is the agent, modelling exercise can turn into a real challenge as farms are composed of more than one plot/parcel. On the other hand, a farm (and farmer) is faced with certain economic, demographic and social conditions, institutional constraints and policies. Therefore, if the farm is the agent; then managerial, economic, social, demographic conditions can be better reflected in the model whereas if plot/parcel is the agent, incorporation of those conditions could be very difficult or impossible.

Farm ownership regime. The farm can be owned and used by the owner/farmer or might be fully or partly rented out for other farmers due to certain economic, financial, institutional and demographic factors and therefore might go to downsizing. Similarly, a farm owner or an off-farm business may rent from other farmers as well, under certain conditions to upsize the owned or non-owned agricultural land. Setting and modelling the up- and down-sizing rules is a distinguishing feature among ABMs.

Existence of inactive farms and rules of exit. ABM platforms might allow mobility of financial and productive resources between farm and off-farm opportunities. The conditions that lead to this resource reallocation might be either due to financial/economic reasons or demographic conditions such as nonexistence of successors or both. In other words, how to allow active/inactive farms to become inactive/farms is an important question. In addition, related to this, how the fallow, set-aside and idle land is handled also a notable point as “land” is the main productive factor.

Incorporation of land market. Having endogenous land market raises various questions. The models might or might not allow for renting/leasing behaviour or selling/buying or both. For each activity institutional and economic rules have to be set and integrated to the modelling algorithms. These rules might include neighbourhood and tenant rights/priorities, physical distance, profitability and regulations related to trade agricultural land. Both activities can operate through auctions and/or endogenous land prices could be determined algebraically solving land demand and supply equilibrium. Having endogenous land market is also important to model interactions among farms.

Populating with agents. Populating the agents can be achieved through real, virtual or synthetic methods. A synthetic farm is retrieved through using farm-specific databases. Therefore, each farm type (by characteristics) represented in the database can be used by weighting it in relation to the territory it belongs. Real farm information/data can also be used in ABMs. However, based on availability of the farm characteristics, the heterogeneity might turn into a real challenge in modelling farm behaviour. Populating agents by real or synthetic methods might become an important decision problem depending on whether the land data belongs to plots/parcels or farms. Virtual farms are obtained from real farms (over virtual regions) and this might help to reduce the heterogeneity problem observed in modelling farm behaviour with real farm data.

Financial position of the farm. Modelling farm management is quite significant in determining farms’ decision towards continuing/leaving farm activity. Setting financial rules for short- and long-run existence is not only about defining profitability/bankruptcy but also about how to model it in a dynamic fashion by allowing investment and borrowing from finance institutions. The other alternative is apparently modelling farm only by cost/profit accounting which might be a short-sighted decision. On the other hand, modelling financial position of the farm might be quite difficult if the modelling entity is the plot/parcel rather than the farm.

Risk behaviour of the farm. Risks can be defined in terms of various economic, social and environmental conditions. However, in most of the times risks are reflected through their direct and indirect impacts on agricultural markets and farm management. One option to model risk is integrating it through price determination process which represents market risks for farmers. The other is integrating it through financial disposition of the farm which represents risks involved in farm management problem.

Economic problem of the farm. The main economic problem of the farm can be modelled depending on how the farm behaviour is set up in the research context. In most cases the ABMs use cost minimization and/or profit maximization as the main objective function to solve. However, in some models, maximization of farmers' utility and/or income may constitute the main problem.

Investment behaviour of the farm. Explicit modelling of investment is a distinguishing feature among ABMs. Whether an ABM allows for agricultural and/or non-agricultural investment behaviour actually is quite decisive on farms' short- and long-run financial position and profitability and it is also a part of farms' current production problem. This fact also affects farms' current resource use and cost structure.

Off-farm employment. Off-farm employment opportunity may become important in two different contexts and based on how the ABMs approach to this possibility creates the difference among ABMs. Firstly, if the main problem of the farm is income maximization then preferably modelling off-farm employment opportunities for the household members should be allowed in the ABM. Farmer's utility maximization problem also may take into account the off-farm incomes. Secondly, off-farm employment opportunities may trigger farms to exit from agricultural activity depending on the alternative income.

Incorporation of international trade. Majority of the ABMs do not model international trade endogenously. Therefore, exports and imports become exogenous to the model, if these are to be used for accounting aggregate excess supply and demand. In some ABMs telecoupling (Millington et al. 2017) methodology is employed to make international trade endogenous which is actually a hybrid approach. With this methodology exports and imports can be modelled explicitly but at aggregate levels and depending on the importance and specifics of the products, a net trade approach or bilateral-Armington approach can be adopted.

Output and input prices. Output and input markets can become totally or partially endogenous in the ABMs. In the output markets, in most cases the supply side is endogenous and demand side is exogenous to the system. If this is the approach, output prices are formulated as a function of some margins and policy parameters. If both demand and supply side are endogenous then prices are solved as an outcome of equilibrium condition. However, finding equilibrium price at farm level is not practical and therefore obtaining market or aggregate level equilibrium prices is more preferable. Another option to find output prices could be as outcome of optimization problem which gives shadow prices. In this case the convergence/divergence between shadow and actual market prices have to observed before using those. In some models, prices are fully exogenous. Input markets cover all chemicals, feeds, seeds, manure, mechanization, irrigation, land and labour. The land is handled in land market and explained separately in this paper. For labour, decision to assume exogenous labour supply is given depending on the level of unemployment, labour market regulations such as minimum wage. Otherwise both labour demand and supply can be endogenous in the system. Manure (To tackle with climate change the CAP of the EU regulates manure amount per hectare with a maximum limit which in return becomes a factor that may trigger land demand. Therefore, the modelling platforms' capability to model the relationship between land demand and manure regulation becomes a distinguishing factor) is obtained as a by-product in most models which focus both on livestock and crops. In some cases, manure is both constraint on objective function and cost in the profit function. Modelling of all types of chemicals, feeds and seeds are open to the possible options explained for output markets. Therefore, obtaining shadow prices for all inputs including labour could be an option. Mechanization and irrigation are actually part of the production technology and in most cases, these are incorporated by constant parameters. We need to mention that mechanization in some model is also a part of investment.

In addition to the above modelling features there are some other specifics that distinguish ABMs from each other. The regional focus and agricultural content are two of those specifics. Some ABMs cover forestry products besides crop and livestock production activities and all these activities are part of the decision process modelled in the optimization function. Related to models' agricultural coverage, some ABMs allow for mixed activities at farm (agent) base, while in some other farms allow for single crop only. How to incorporate innovation and technology is another distinguishing feature and, in most cases, these are introduced as a simplifying feature of mixed integer programming used to solve optimization problem. Otherwise, no innovation and fixed technology are assumed. Policy modelling capacity is another factor that creates the difference among ABMs. Some models are tailored for analysing specific policy instruments. However, the emergence of agriculture (policy) focused ABMs is actually triggered by the Second Pillar of the CAP particularly as farm-based policies in various contexts and farm-based outcomes gain importance. One last feature that distinguishes ABM platforms is about how yields and costs are incorporated. Both can be fixed or variable, but the decision is also related to how innovation and technology are incorporated and whether input markets are endogenous or exogenous to the system. In addition, the decision on modelling unit (plot/parcel or farm) might also affect the approach to handle costs and yield. However, it should be kept in mind that using ABM approach at the first place is about modelling farm heterogeneity which might be an outcome of various economic, social, demographic and farm structural characteristics that include changing yield and cost structure.

Next section reviews 10 selected ABM modelling platforms. The content of the review depends on available documented and published material. Therefore, the review is carried out by focusing on the platform-specific features/information that could be found for majority of the ABMs under consideration. These features include main decision rule of the agents, whether the platforms allow for farm exit and rules of exit, how they approach to land market, possibility of the off-farm employment and determination of output and input prices (see Table 2). However, in addition to these features that are common to most of the found model documentations, some other model-specific features are also reviewed. The policy modelling capacity and/or policy instruments covered in the selected ABMs are not given as their "modelling procedures" in most of the cases are implicit.

In the literature there are some agent-based models which put particular focus on modelling climate change, environmental problems, water use or sometimes some social aspects such as migration. Reviewing these modelling platforms is not the priority in this paper. In fact, in the selected ABM platforms in this review, the main focus is the agricultural sector. Similarly, some studies use agent-based approach but at some extent these platforms introduce "a representative behaviour" such as at regional (Johnson et al. 2008), activity (Schmid & Sinabell 2006), farm level (Jayet et al. 2007), farm typology (Louhichi et al. 2010) etc. levels. These studies are also excluded from the review in this paper. Hybrid models which bring modelling platforms of different disciplines together such as bio-economic, bio-physical models are not also included for two reasons. First, sometimes these definitions are not definitive enough to pinpoint the utilized approaches in different components of the platform. Second, what is hybrid or not is actually a question itself.

Table 2- Review Criteria: Distinguishing Features of Selected Agent-based Modelling Platforms*

Modelling Platforms	*Modelling unit (agent); farm or plot/parcel*	*Decision rule*	*Exit; rules of exit*	*Labour market; off-farm employment*	*Output and input prices; expectations*
AGRIPOLIS	Farm	Household income max.	Allowed, financial/economic age	Endogenous; allowed	Endogenous; adaptive; agent level
REGMAS	Farm	Household income max.	Allowed, financial/economic	Endogenous; allowed	Exogenous
MP-MAS	Farm	Household income max.	Allowed, financial/economic age	Endogenous; not allowed	Exogenous
SWISSLAND	Farm	Household income max.	Allowed, age	Endogenous; allowed	Endogenous; adaptive; agent level
ADAM	Parcel	Profit max. over land allocation	Allowed, age	Exogenous; not allowed	Exogenous
LARMA	Farm	Profit max. over land allocation	Allowed, financial/economic	Exogenous; not allowed	Exogenous
PALM	Farm	Profit max. over land allocation.	Not allowed	Exogenous; not allowed	Endogenous
BAZZANA & Zhang (2022)	Farm	Maximizing farmer well-being over food security	Not allowed	Endogenous; allowed	Endogenous; activity level
MAES & PASSEL (2014)	Farm	Profit max.	Allowed, age	Exogenous	Exogenous
GLOBIOM	Farm	Profit max. over land allocation	Not allowed	Not allowed	Endogenous; activity level

8.1. Decision rules of the agents

The decision rules in AGRIPOLIS, REGMAS, MP-MAS and SWISSLAND modelling platforms are quite similar to each other. In all these platforms the agent is farm and basing on neoclassical production theory each farm-family household is assumed to maximize her income. Income is obtained as a combination of production activities and investment choice, given with respect to a set of resource constraints which means the maximized income is actually gained by family members both from on- and off-farm sources. Mixed-integer programming is used to formulate the above-mentioned behavioural model and optimization problem bring together farm factor endowments, production activities, investment possibilities, and other restrictions and circumstances. While in REGMAS the maximization problem is solved to generate results over multiple years, in others the solution is given for the production period/financial year. In MP-MAS the objective function can also be defined as multi-dimensional utility function that includes income and consumption.

In ADAM, LARMA, PALM and GLOBIOM modelling platforms, the main driver behind optimization problem is the change in land use and land allocation. Farms, as the agents, maximize their profit under certain internal (farm-based) and external (economic, social, environmental, political) properties. The distinguishing feature of PALM and LARMA is that the former has a biophysical component originally designed to simulate the flow of resources in rural communities while the latter has a market component that relies on neoclassical assumptions. The main feature of ADAM is that the solution of the model decides whether a new farm will be created, whether a farmer continues, stops its activities, or takes over an individual parcel or an entire farm. In GLOBIOM the objective is to allocate the land among agricultural and forest products to maximize the sum of producer and consumer surplus with respect to above-mentioned properties, as well as demand and technological conditions. A difference from all the above platforms is that GLOBIOM is recursive dynamic and creates projections for future.

Maes & Passel's (2014) modelling platform takes a different approach than the aforementioned ones by using three distinct objective functions. Agents make decisions based on the level of financial risk they are willing to accept and the availability of financing in order to maximise the farm's profit. The first objective function is profit maximisation, and like the previous platforms, it is confined by the agent's ability to choose among alternatives and the availability of loans. Maximising the total value of the farm, including its liquid and fixed assets as well as its agricultural land, is the second objective function, which has a longer-term focus. These farmers aim to establish a farm that will consistently provide sizable annual earnings. The third criterion takes into account the perfect layout of a farm. When compared to other platforms, Bazzana & Zhang (2022) takes a novel strategy, prioritising the food security of farmers as a key indicator of their success.

8.2. Farm exit and rules of exit

The agent in AGRIPOLIS and REGMAS decides whether to exit or stay in the sector based on expected returns for the next year. If the farm agent's equity capital is zero (the farm is illiquid) or if off-farm income of the farm-owned production factors (land, family labour, and working capital) is higher than farm income then it becomes rational for the agent to exit. In AGRIPOLIS, exit decision can be also given if the farm agent has reached a certain age and there are no successors to take over. However, even if there are successors, their off-farm generated income should be lower than farm income otherwise they are assumed not to take over. Opportunity costs of farm labour are quite decisive. In MP-MAS the agent exits if the bankruptcy cannot be avoided. Based on the physical and economic outcomes of the production/investment decisions given in the first step, the agent either sell assets to retain solvency and continue farming or leaves the agricultural sector. Successors' take over in MP-MAS in case household members die, retire or give birth is a desired feature. The agent is willing to forgo own-income if a major investment or expansion of the farm is necessary to employ their successors. In SWISSLAND platform, agents reaching a certain age threshold (qualifying to get direct income support) leave the farm business to potential successors (if there are) and the successors take over if the farm income is above the average level of income in the region. In ADAM, a similar process to SWISSLAND is implemented except that no age threshold is used and farm profitability is the key criteria. The exit/stay decision of the agent in LARMA platform is given based on whether the level of calculated working capital in each production cycle covers implantation and rental costs. In Maes & Passel (2014), succession to family members is a crucial step even if the agent evolves to an elderly farm without much growth, new investment, high efficiency or new innovations. The activity only stops when the owner passes away.

8.3. Off-farm employment

In AGRIPOLIS and SWISSLAND platforms, the labour market is modelled endogenously (or it is partly endogenous) and both allows for off-farm employment. However, the approaches used to model labour market in each platform is quite different. In AGRIPOLIS, labour supply is composed of three different types. First group of labour is sourced by farms (farm family labour), the second group can be hired for agricultural purposes on fixed term contracts or on hourly basis. The last group is composed of the labour offered by the farm to market for employment either in non-professional agriculture in off-farm opportunities. Total labour supply is determined in the mixed-integer programme as variable and fixed labour activities. The SWISSLAND platform forecasts the use of family labour, external labour and off-farm work by using a two-phase procedure. The first phase estimates the agents' most likely labour-adjustment strategies by using Bayesian Network and the second phase determines the optimal labour-input strategies by using cluster analysis. The results of cluster analysis are used to set up the Bayesian Network and parameterise all observed labour-adjustment strategies in the single-farm optimisation model. In Maes & Passel (2014) labour market is totally exogenous. In Bazzana & Zhang (2022) farms may hire outside workers if the optimal amount of labour required is higher than the farm family labour but the model allows this only if there is enough available agricultural income. The model allows for the opposite case as well where the household provides labour force to other farms to generate income. The wage level in the economy is assumed to be equal across farmers and labour can be hired within the village border.

8.4. Land market

In AGRIPOLIS platform land owned by farm agent is either landowners or external, non-farming landowners where the latter are not explicitly modelled but they can rent their land to farm agents. Land sales/purchases is not allowed. Land is distinguished as arable land, grassland and non-agricultural land and in each group quality is assumed to be homogeneous. All types are also assumed to be either managed land or abandoned land. All managed land is either owned or rented by farm agents. Bilateral interaction among agents in the land market is not allowed and the interaction occurs through sequential auctions in land market. Rental land is sourced either by agents withdrawn from the sector or by terminated rental contracts or both. A two-step auction process is modelled. Once free plots are released first, each farm agent produces a bid for a particular plot of land, basing the bid on marginal income from additional plot of land (shadow price for land, the number of adjacent farm plots, and the distance-dependent transportation costs between the farmstead and the plot). Second, the highest bidder agent is given the plot by the auctioneer. The space in AGRIPOLIS is represented by a set of equally sized cells/plots differentiated with respect to type of soil, type of ownership, state of the plot, size of the plot and transportation costs to the respective farm managing the plot.

In contrast to AGRIPOLIS, where space is represented by plots that are modelled with respect to soil type, in REGMAS, space is represented by plots that are modelled explicitly (using real land-use information). While the land market mechanism (auction) allocates vacant lots to agents, the REGMAS platform does not provide land sales/purchases or bilateral farm agent interaction in the land market. To ensure that all fixed and variable transaction expenses and overhead are covered, real estate agents assign a shadow price (the optimal solution to a profit-maximizing mixed integer programme) to each available rental unit. Distance from the rentable plots is used to limit the number of bidders in REGMAS (greater transport costs mean less likely it is that a certain farm will present a winning bid-to afford a better economic performance). The property is rented to the highest bidder. The land market is managed in the MP-MAS platform in a method quite similar to that of the REGMAS. If the shadow price for land is less than the actual average land price, land sales/purchases are prohibited and a renting decision is made. The land is rented to the highest bidder, and the bidder with the lowest internal transport cost (shortest distance) wins. SWISSLAND takes a different tack by not implementing a clear land market. Land swaps between neighbouring municipalities and within established neighbourhood patterns (farm sites) are first permitted. The second phase is to place the agents at the farms within the cities. In the third stage, the land lease from the "exiting agents" to the remaining agents is modelled, parcel by parcel. If a farmer on the SWISSLAND platform does not have a clear economic heir or if a potential heir decides against taking over the farm, the farmer is free to leave the industry. A plot's income increase is a major factor in the leasing decision made by an agent. After optimising for the new land, each agent rents it out to their nearest neighbour who stands to make the most money from the change. If a plot's adjoining agents are unable to turn a profit, the scheme is abandoned.

The ADAM platform is developed to model land use change and drivers behind the change. The modelling is done at parcel level to capture farms' abandonment or growth. The change in land use can be an outcome of certain conditions. Parcels are released if no new owner can be found, because the parcel is too far away or if no successors are left. Conversion of agricultural lands to residential houses can be another case. Changing cultivated crops on arable land basing on expected yields for the area and crop prices is another factor and finally converting the land to another type of agricultural land use is set as the last condition. Priority in getting the parcels is given to farmers from the same farming type as the previous owner or to a farmer who can easily convert the parcel to a desired agricultural land use. In Maes & Passel (2014) platform, simply any agent may enter bids for either the purchase or the sale of land with a requested price and sale/purchase bids are combined in the double auction mechanism to establish a negotiated transaction price. The other modelling ABM platform that focuses on land use change is the GLOBIOM. Space in the GLOBIOM platform categorises plots/parcels into groups with similar topography. Cropland, grassland, short rotation plantations, managed forests, unmanaged forests, and other natural vegetation land are the six types of land cover (the other three types of land cover (other agricultural land, wetlands, and not relevant) are held constant at their initial level and are not modelled). The predicted profitability (conversion cost is also considered in producer optimisation behaviour) drives the platform's modelling of land conversion among the first four land cover types. There are constraints on land conversion, such as the land's biophysical appropriateness and its production potential. At the local level, land use change is analysed on a per-hectare basis according to a conversion ruled by a matrix of land use conversion options (region-specific) between land use types and associated conversion costs (Havlik et al. 2018).

The LARMA platform is specifically a land rental market model -without allowing for sales/purchases- with a highly unique endogenous formation of land rental price. There are two agent types involved in agricultural activities: farmers who either operate owned and/or leased farms, and who rent out their land. The agents' land allocation strategies, risk aversion behaviour and financial characteristics differ among them. As similar to other platforms no bilateral interaction among agents take place rather the land market mechanism -called the manager- does the required calculations and re-allocation. The platform determines land prices through a series of model steps. First the agent-farmer updates the area that is needed (whether the farmer maintain or expand or release some/all of the previously farmed area) basing on expected status of climate conditions, output prices, input costs. This first step is actually identifying the demand for and supply of land in the market. In the second step prices that agents are willing to pay (expanding land) or get for land (releasing land) are endogenously and dynamically determined depending on agents' working capital and risk behaviour. Finally, a market clearing price is calculated by considering the willingness to pay (WTP) and willingness to accept (WTA) prices.

Table 3- Land Market Specifics of Selected Agent-based Modelling Platforms

	AGRIPOLIS	***REGMAS***	***MP-MAS***	***SWISSLAND***	***ADAM***	***LARMA***	***GLOBIOM***
Land cover/use change	land cover	land cover	land cover	land cover	land use	land cover	both land cover/use
Land ownership	both farmer and non-farmer land owners	farmer land owners	farmer land owners	not important	farmer land owners	farmer land owners	farmer land owners
Land sales/purchases	not allowed	not allowed	not allowed	not allowed	not allowed	not allowed	not allowed
Land renting/hiring	Allowed	allowed	allowed	allowed	allowed	allowed	not allowed
Land type/quality	arable, grassland, non-agri. land / homogenous in each group	mixed/heterogeneous in each group	mixed/heterogeneous in each group	product based/both organic and conventional	barns, grassland, greenhouses, permanent crops, or arable land	field crops/ homogeneous	cropland, grassland, short rotation plantation, managed and unmanaged forests, natural vegetation, others
Bilateral interaction/Land price	only through 2 step auction/land shadow price	only through auction; bidders are restricted by distance/land shadow price	only through auction; bidders are restricted by distance/land shadow price	neighbour with max. profit can rent land	priority given to same or similar farmer type	endogenous land market through WTP and WTA mechanism	not allowed
Space representation/quality	equal sized plots/heterogeneous	equal sized plots/homogenous	equal sized plots/homogenous	not important	unequal sized parcels/heterogeneous	unequal sized/ homogeneous	equal sized plots/heterogeneous
Exit/rules of exit	allowed/financial-economic, age	allowed/financial-economic	allowed/financial-economic, age	allowed/age	allowed/age	allowed/financial-economic	not allowed

8.5. Output and input prices

In ABM platforms both the current and future prices are in the focus of interest. While current prices can be determined endogenously or exogenously, future prices are formulated as a result of some sort of expectation function. In AGRIPOLIS for example, markets for products, capital, and labour, are coordinated via a price function with an exogenously given price elasticity and a price trend. The optimization problem in the platform produces the vector of shadow prices which are interpreted as the actual prices. But for future the prices are expected to stay constant. Therefore, dynamic effects of market and demand developments are neglected. The agents follow adaptive expectations (myopic behaviour) while planning decisions. They foresee all prices as a weighted geometric average of actual and expected prices. In SWISSLAND platform domestic prices are determined endogenously by interaction of demand and supply at activity level and expectations are derived from the previous year's prices. Domestic prices are specified as a function of world prices, exchange rates, transport costs, and country-specific policies that affect prices. Each year, prices are multiplied by the previous year's annual relative price trends, which are calculated endogenously in the demand module. Input prices, except for feed, are exogenous and are based on historic trends. In REGMAS, MP-MAS and Maes & Passel (2014) platforms current prices are exogenous and some expectation formula is used for getting future prices in REGMAS and MP-MAS platforms. Both in Bazzana & Zhang (2022) and GLOBIOM modelling platforms prices are endogenously determined for each activity level. While in the former there are price evolution coefficient that derive the current product prices, in the latter market equilibrium conditions provide the activity level prices.

Some of the more general characteristics of the above-explained platforms are briefly presented in the following paragraphs. In AGRIPOLIS agents distinguish between standard production (both livestock and crops) activities, auxiliary activities, investment activities, and the decision to continue farming. Production factors used in activities are land, buildings, machinery, liquid capital, labour of different types and capacities. Land rental activities, production quotas, and manure disposal rights are included in the auxiliary activities. Farm agents are allowed to take long-term and/or short-term credit and unused liquid assets are invested at the assumed savings rate. Technological change is not explicitly modelled however production technologies are assumed to progress over time and with every new investment unit production costs are assumed to decrease (cost-saving technology which can only become an outcome if larger machinery and larger field sizes are combined together). Production costs are formed by expectations of agents. Agents in REGMAS are involved in operations that have both short-term (annual) costs and long-term (investment) benefits. Although investments are limited to whole numbers, a particular asset can come in a variety of sizes. This gives rise to scale-effects in the model. However, scale effects (land/farm size), investment, and technology implications can be represented in systems that use mixed integer programming. Farmers' resource endowment, activity gross margins (produced endogenously through investment decisions, newly rented plots, or exogenously through market price changes and policy support), and other environmental factors are the primary focus of REGMAS's modelling efforts.

Similar to REGMAS, in MP-MAS platform main concern is to understand how agricultural technology, market dynamics, environmental change and policy intervention affects a heterogeneous population of farm households and the related agro-ecological resources. The platform combines biophysical production functions for irrigation and fertilization with constrained optimization models. Agents are engaged with crop production, grassland use, animal production and biogas production. The model has a long-term perspective and dynamic approach under which the decisions are given by considering sunk costs and lack of liquidity that might create possibility for farmers to trade land or give up farming. The SWISSLAND utilizes a recursive dynamic partial-equilibrium, multiple-commodity approach to create solutions for 10 to 15 years. Agents are involved mostly with livestock activities but products are assumed to be homogenous among agents/farms although the heterogeneity is introduced by farm characteristics. The platform solves reduced-form behavioural equations for production, consumption, and trade.

Internal and external factors are modelled in ADAM to predict how agents/farms will make decisions on changes to agricultural land use. Each farm consists of a number of individual parcels, and each of those farms focuses on a single primary farming method. Agents in PALM consider ecological, social, and economic factors while making land-use decisions. The household agents' choices lead to actions, which may alter water, carbon, and nitrogen fluxes over the landscape. There is also a physiological aspect to it. Different farmers have different responses because of the consistent decision-making technique used in the multidimensional preference space. The model presented in Bazzana & Zhang (2022) posits that agents/farmers are bounded rational and follow simple rules of behaviour due to the imperfect and asymmetric information context in which they operate. The disparities in human, physical, and social capital are the root cause of this information gap. With no input substitution possibilities and the ability to employ irrigation, a production function of the Leontief type is developed.

In specifically, Maes & Passel (2014) model the effects of structural change on agricultural agents' decisions to switch between different types of animal stocks, investments, and land. Single-farm and multi-farm operations are also supported by the modelling framework. Exogenous models are used for inputs like capital, labour, fertilisers, investments, and output markets, whereas inputs like land, manure, and animals are modelled endogenously. Live animal markets factor in transactions with processing plants. The costs are the result of econometric estimation, with the current state of technology held constant. Land, livestock, and agricultural investments are eligible for bank financing. GLOBIOM is a partial-equilibrium platform that focuses on land-based sectors including agriculture (both crops and livestock), forestry, biofuels and timber markets. The platform analyses the impacts of climate change mitigation and adaptation policies. The model is solved recursively dynamic and can provide projections up to 2100. Parameterization of the alternative Leontief type production functions in GLOBIOM is partially carried out by biophysical models integrated to the platform. In addition, GLOBIOM endogenously represents mitigation technologies including technological and structural mitigation options. The platform also models bilateral trade flows between individual regions assuming all products are homogenous across regions.

9. Conclusions

There is always a trade-off when it comes to choosing a method in impact analysis. The advantages of the chosen method often become the disadvantages of the non-chosen ones and the opposite is also true. Although these facts are valid, we can still say that recently there has been shift from the systems approach (as defined in the above) to the agent-based approach in impact analysis. We can talk about four major factors driving this shift as:

1. Policies implemented under the CAP have increasingly focused on farm and rural development in Pillar II, and the heterogeneous nature of farms and the economic interactions among farms have become more important.
2. Based on the first factor mentioned above, the farm-based policy outcomes rather than sector/country (region)-wide effects become more important. A fact that supports this is that the changing economic and institutional structures of the countries differentiate the responses on the basis of the farm.
3. In general, the environmental and sustainability (in the environmental, social and economic context) implications of policies have become more important. These implications also vary depending on the location of the farms rather than the countries.

4. Advance in data (i.e., geo-referenced, CORINE) and analysis tools (statistics and machine learning) can be considered another driving factors to shift modelling approach.

Challenging Issues

A significant challenge for agricultural/rural policy impact assessment studies/methodologies arises in determining the analysis level. The assessment platform preferably should represent the heterogeneity of the farms and consider the economic interactions among them while both input and output market adjustments are allowed in the same platform. The challenge here is that modelling farm behaviour does not always necessitate endogenous output/input markets and trying to achieve both could be cumbersome.

Another challenge could be the time horizon adopted in the analysis platforms which actually determines the “mathematical formulation of the farm problem”. In some cases a short-term perspective is adopted and farm behaviour is optimized with respect to economic conditions, whereas the platform might embrace a long-term perspective in which the optimization is based on changing financial position of the farm.

Third challenge is the inclusion of environmental factors/components into the modelling platforms. Environmental factors can be examined in a very wide scope (soil, water, biodiversity, landscape, air, climate change etc.) and this scope may differ according to country/region/farm location. At this stage excluding environmental factors from the modelling platforms is out of discussion since agricultural sustainability is one of the main objectives of the changing CAP. It is one problem to find the necessary data at the analysis level, and is another problem to parameterize and calibrate the modelling platforms with these environmental modules.

Finally, the adjustment between primary and secondary data (spatial inconsistency); between the level of social, economic and environmental data is another challenge. As the modelling platforms is expanded with various environmental components and with other output and input use data, adjustment problems become costly in terms of time and effort. The increasing availability of spatial data seems to be a solution however it calls for big data tools. Advance in “machine learning technic” including its integration with AI will facilitate to finding solution to calibration issues in ABM.

This literature review identifies the trade-off elements that may arise when using the agent-based modelling approach for impact analysis of agricultural and rural development policies. Based on the information revealed by the survey, a few directions can be made for researchers working on the subject. In this type of analyses, it is necessary to determine what the research question addresses and who are the end-users. The answer to these questions would determine the impact measurement scale of the analysis and hence will reveal if there is a need for an agent-based model or not. On the other hand, it is also a priority to correctly identify the question to which the answer is sought, and thus to correctly identify the explicit and implicit objectives of the changing policies. The most comprehensive and detailed modelling and analysis does not necessarily mean that it is the best approach. All or most aspects of an analysis can be handled in a single modelling platform such as with an integrated assessment platforms that integrate several modules. However, complexity always comes with various technical difficulties. An alternative approach would be to search for answers to the questions both in a highly disaggregated structure, such as agent-based models, and in an aggregated structure with representative characteristics. Then, analysing the consistency between the findings of the two approaches would be a rather powerful and relatively technically easier problem to solve.

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