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An agent-based model of farmer behaviour to explain the limited adaptability of Flemish agriculture

Dries Maes[1] and Steven Van Passel[1,2]

Abstract:

Transition projects have been implemented for Flemish agriculture since 2003, but these did not enable a transformation of the agricultural sector. This paper looks at pre-transition scenarios that have been collectively designed by stakeholders of the agricultural sector in 2002. These foresaw decreases in the regional animal stocks in Flanders. However, the real evolution of the sector did not reveal such a decrease. It is assumed that the individual adaptive behaviour of farmers can explain the unexpected stability of the Flemish agricultural sector. A detailed agent-based model has been built to replicate the past evolution, accounting for structural diversity of farmers, heterogeneity in behaviour, and natural resource constraints. The results indicate that different forms of rigidity in the individual behaviour of farmers slow down the adaptation of the agricultural sector. Future transition scenarios should account for these elements in order not to overestimate the speed of change in the sector.

Keywords:

adaptation, behavioural diversity, agent-based model, agricultural transition

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[1] Centre for Environmental Science, Hasselt University, Martelarenlaan 42, 3500 Hasselt, Belgium, dries.maes@uhasselt.be

[2] Department of Engineering Management, University of Antwerp, Prinsstraat 13, 2000 Antwerpen, Belgium

1. Introduction

The agricultural sector plays a pivotal role in a transition to a more sustainable society. Changes in agriculture are induced by a rising interest in sustainable agricultural practices, by shifts in international trade and by external markets trends for qualitative products and biobased materials. The growing uptake of sustainable practices follows the increasing demand for organic materials of all kinds, fresh crops, agricultural waste streams and new cultures. But despite these forces, the overall adaptation of the agricultural sector remains slow. In order to speed up the adaptation of the sector, several projects were implemented in the Flemish agricultural sector. In 2001, a principle text was published outlining regional aspects of sustainability in agriculture (Reheul et al., 2001). The objective of this text was to start the discussion on the definition and implementation of sustainable agricultural practices. In 2001, the non-governmental organisation DP21 or "Dierlijke productie in the 21ste eeuw" (Animal products in the 21st century) was created. DP21 started a dialogue between farmers, agro-industrial sector federations and authorities, and conducted a large pre-transition project to define future scenarios for animal husbandry and animal products in Flanders. This vision exercise grew through intensive interaction with over hundred stakeholders in agriculture and the food industry between 2001 and 2003. The scenarios each described a different potential path for the future development of the animal husbandry sector in Flanders. Following general trends, three central scenarios were elaborated in stories, taking multiple social and economic aspects into account. The project raised the awareness within the sector of the future challenges of agriculture and the importance of scenarios in this respect (Magiels, 2003, 2004). The three central scenarios were elaborated to cover widely diverging future trajectories for the sector:

- The race: This scenario assumes a low economic growth, limited consumer spending power, strict environmental regulations and an international fully freed trade for agricultural products. Farms respond individually, by increasing specialisation, efficiency and scale. In this scenario, family farms gradually disappear, and large individual farms specialise in order to remain competitive against foreign imported food products.
- The European forum: This scenario assumes limitation to free trade in order to improve environmental and social aspects of European agriculture. New export opportunities arise due to the EU enlargement and the collaboration between agriculture and agrifood actors intensifies. The farmers react more in cooperation, with emergence of niche productions and high-quality products.
- The global bazaar: This scenario assumes a consumer concerned about quality and willing to pay for additional environmental values. International free trade allows the rapid growth of international consortia. Farmers respond individually with highly specialised niche production and flexible cooperation with other actors in the food chain. The market becomes highly dynamic with large international consortia, challenged in niche products and niche markets with small versatile highly-specialised producers.

Table 1 shows the estimated sector impact for each scenario. The corresponding market conditions span future possibilities from low consumer interest in quality to high spending power, from low international competition to fierce extra-European import, etc. A remarkable outcome of the sector discussions was that despite the large variations in market conditions, some general tendencies were outlined that were replicated for each scenario. The most important tendency in this respect was the reduction of animal stock, to be expected over the coming years. In each scenario, animal stocks were expected to decline. This indicated the acknowledgement of the structural overproduction of animal products at the start of the 21st century, and the sector faced the challenge to reduce this structural overproduction.

Table 1: Particular consequences for the different vision scenarios

	The race	The European forum	The global bazaar
Number of farms	Large farms remain, family-businesses disappear, specialisation.	Reduction with approximately 25%, mix of smaller and larger farms, specialisation.	Reduction with approximately 30%
Jobs	Large reduction	Reduction tempered by increased demand for landscape management.	Moderate reduction.
Animal stock	Cattle for beef – 70% Dairy cows – 35% Pigs – 50 % Chickens – 30-50%	Pigs – 60% Chickens – 60 %	Cattle for beef – 50% Dairy cows : stable Pigs – 50 % Chickens - 50%
Export	Reduction. Sales restricted to local and European markets.	Reduction. Local market is growing. Larger export potential for quality products.	Sales mostly local. Interregional sales with collaborative efforts of farmers and authorities.

In a consecutive project, two participatory transition trajectories were started (i) on animal welfare, and (ii) on coherence in visions and actions for a future agricultural and food system (Claes et al., 2008). The scenario project of DP21 has also contributed to further research in sustainable agriculture. Building on this development, a Flemish policy research centre for sustainable agriculture (Stedula) was created (Nevens et al., 2008). Stedula continued the participatory approach for vision creation in a transition thinking setting and developed multiple sustainability measurement methods (Meul et al., 2008; Van Passel et al., 2007). Further research led to a holistic system analysis of the ongoing transitions in agriculture (VMM, 2012). These highlighted the links between niche-development in different scenarios and crucial issues that accelerate or hamper the emergence of more sustainable agricultural practices.

At this point in time, the effects of these activities remain small. Despite the strong stakeholder involvement, the transition projects did not enable a corresponding transformation of the agricultural sector. The developed ideas and visions became common knowledge in the sector, but the actual evolution of the agricultural sector does not seem to take its lessons into account. Animal stocks did not decrease and the production levels of animal products remained relatively stable, especially for dairy products and pork. This contradiction between the scenarios and the actual evolution is puzzling. The scenarios resulted from structured discussions with diverse stakeholders, and represent an acceptable idea of the future sector evolution for most stakeholders. Moreover, reduction of production levels was foreseen, regardless of the precise market conditions, by combinations of farmers, scientific and practical sector experts, and policy makers. It is therefore important to investigate more closely the insights that supported these scenarios, and to compare those to the actual sector evolution.

A principle starting point of the scenarios was the description of overarching market conditions for the sector, such as extra-European trade, quality standards, consumer spending power, etc. Following trends in these conditions, the impact on an adapting agricultural sector was outlined. The implicit assumption here is that changing price conditions both for inputs and outputs, will direct the choices of the farmer. Or, market incentives exert their influence on every individual farmer in a similar way, and incite those farmers to adapt their farm structure into a more suitable configuration.

But adaptation of the agricultural sector requires a capacity to adapt of the individual farmer. The stakeholders assumed this gradual and individual adaptation of farmers to follow market prices, but there are several elements that may slow down or hamper this adaptive process:

- Sunk costs and transaction costs. Farmers need to maximise the yield of their assets, in order to recover sunk costs and to reimburse investments, before large changes can be made. Even when the farmer invests, these changes at farm level do not immediately yield their optimal return. This learning period is an additional transaction cost and is a barrier for swift adaptation (Lohano and King, 2009).

- Strategic persistence. The envisioned adaptation measures required a change in farm strategy: specialisation in one type of animal product or leaving animal products and focussing on crops. Both changes are fundamental at the farm level. It is therefore possible that farmers do not change in relation with negative market conditions during one year. Market conditions have to remain negative during several years, before farmers decide to implement fundamental structural changes (Audia et al., 2000; Bailey et al., 2009).
- Behaviour diversity. Empirical research that details interactions and decisions of farmers, shows a very complex decision framework. This has led to clustering behaviour patterns of farmers confronted with rural policy changes (Shucksmith and Herrmann, 2002). In the case of land use change decisions, role playing games have clarified the multiple decision drivers and criteria (Lamarque et al., 2013). The results indicate how general scenarios of climate change can have very different results in terms of land use change, not only depending on local characteristics of the land and adaptability of the farmers, but also due to diversity in decision rules. This diversity in decision rules leads to uneven and unpredictable adaptation patterns at sector level.

The hypothesis of this paper is that these three elements of individual behaviour of farmers can partly explain the unexpected and apparent stability of the Flemish agricultural sector. This paper investigates the role of individual behaviour of farmers during the last decade, and analyses why the actual evolution of production levels differs markedly from the predicted evolution of the transition scenarios. We look at the role of adaptation capacity of the individual farmer, at transaction costs, and at diversity in decision rules.

In order to replicate the internal dynamics of the agricultural sector in Flanders, an agent-based model (ABM) has been built, accounting for a detailed behaviour model, structural diversity of farmers, heterogeneity in decision rules, and natural resource constraints. This model is based on empirical data at the farm level, and mimics the sector production from 2001 to 2011. This type of modelling is complementary to the results of scenario workshops in transition projects (Halbe et al., 2015). The aim is to approximate the historical evolution as closely as possible. Within transition projects, this approach is relatively rare. As such transition management is an emerging discipline, and there is often not sufficient historical data to replicate the dynamics during a managed transition retroactively. This paper looks in particular at the intuitive insight of the combined stakeholders of the sector during the visioning exercises between 2001 and 2003, and compares it with the actual evolutions to see where these insights diverge from reality.

Similar projects have been executed in order to analyse economic dynamics during technological evolutions. Malerba et al. (2001; 2002) pioneered this approach by replicating the structure of the pharmaceutical and computer industry, and derived essential requirements for the demand market, R&D structure and patterns of competition in order to allow the actual evolution to take place. These "history-friendly" models have since then been applied to other sectors, including the semi-conductor industry (Malerba et al., 2008), dynamic random access memory industry (Kim and Lee, 2003), and Local Area Networking industry (Fontana and Zirulia, 2015).

Within the scope of societal transitions, examples of studies that replicate past evolutions in order to analyse the underlying dynamics are scarce. A principle application to reconcile historical data within a transition analysis has been presented by Schilperoord et al. (2008). More detailed models have been applied to look at historical shifts in naval transportation and in the electricity sector

(Yücel, 2010). Applications to simulate transitions differ from history-friendly models because one has to focus during a transition more on nuanced rules for individual behaviour and social interaction, rather than on the economic structure of the markets and innovative companies. And specifically for farming systems, the inclusion of personal behaviour has been identified as a prerequisite (Woodward et al., 2008). Holtz and Pahl-Wostl (2012) used this approach, and showed the importance of elaborate behaviour models for farm agents to explain empirically observed land use changes.

The rest of the paper is structured as follows. Section 2 describes the essential methodological choices, and compares these with related projects reported in literature. Section 3 reports and discusses the simulation results. Section 4 concludes.

2. Methodological choices and model architecture

2.1. Agent-based models with detailed agent behaviour

The simulation is based on an evolutionary agent-based model (ABM) of the Flemish agricultural sector. Evolutionary approaches are capable of integrating essential features of transitions, such as complexity, multiple levels, adaptation, co-dynamics, emergence and heterogeneity. Evolutionary economics has since long focused on economic change and its underlying dynamics (Dosi and Nelson, 1994). Variety and diversity are of particular importance in evolutionary descriptions of the economic process. Evolutionary economics incorporate a variety of economic actors, combined with an innovative reproduction process fuelling this variety, and selection mechanisms reducing it. The approach stresses bounded rationality of economic actors, and realism in the analysis of economic behaviour (Nelson and Winter, 2002). This led to new theories of endogenous growth, fuelled by innovation and economic self-transformation (Metcalfe, 2005), and the creation of new sectors (Saviotti and Pyka, 2004). Evolutionary economics shows a sufficiently large potential, allowing this approach to be applied to investigate industrial and societal transitions. Safarzynska et al. (2012) demonstrate that evolutionary thinking and modelling are very well suited to enrich research in sustainability transitions. The evolutionary methods can be helpful to render more precise the definitions of transition concepts, and they are able to model and quantify tentative and qualitative transition scenarios. Moreover, Faber and Frenken (2009) demonstrate that the combination of evolutionary and environmental economics can be particularly fruitful.

Agent-based models (ABM) are founded on groups of autonomous agents that have individual behaviours, technical characteristics, and communication possibilities. These are particularly suited for the simulation of economic evolution (Pyka and Fagiolo, 2007; Tesfatsion, 2003). An ABM model is built from the bottom up, and simulates economies as decentralised, complex and adaptive systems, without imposing market equilibrium or a functional form at higher levels (Basu and Pryor, 1997). ABM have been able to integrate both the natural resource constraints and social dynamics. Especially the field of agent-based agricultural economics has shown several successful applications. The first models in this field have been created by Balmann (1997), studying structural economic change in an abstract landscape. Further developments have elaborated this model to study impacts of policy changes in different regions in Europe (Happe et al., 2004; Happe et al., 2006; Sahrbacher et al., 2005). Freeman et al. (2013) review the effect of land markets on spatial distribution of farmers, and residential developers.

The simulated behaviour of the agents requires sufficient detail. The inclusion of farms, including family farms, brings about a wide range of behaviours of economic actors, given the diversity of motivations and behaviour rules observed in farms' decision making (Viaggi et al., 2011). This diversity is required to keep the sector as a whole sufficiently flexible (Darnhofer et al., 2010). Empirical investigations of Land Use Change show that patterns of land abandonment, restoration or reforestation, reveal different types of behaviour, linked with the individual characteristics of the farm agents (Bakker and van Doorn, 2009). In principle, behavioural heterogeneity is possible (Tesfatsion and Judd, 2006). However the application of behaviour diversity in ABM is mostly reserved for diversity in consumer decisions, and less for simulation of diversity in behaviour of economic actors (Chappin and Afman, 2013; Sopha et al., 2013).

An (2012) reviews behaviour models in coupled human and natural agent-based models. The overview shows a large variety in principle decisions and practical elaborations to build behaviour models for human agents. Several studies choose for a process-based decision, and adopt individual profit or utility optimisation, subjected to practical constraints (Schreinemachers et al., 2006). These solutions can also be influenced by individual environmental concerns (Zheng et al., 2013). Other solutions adopt insight from psychological and social research, and base the decision patterns for instance on the theory of planned behaviour (Kaufmann et al., 2009). In order to approximate real decision heuristics, several projects let go entirely of process-based decision algorithms, and conduct field research with questionnaires and role-playing games to deduct empirical decision rules (Barreteau and Smajgl, 2014; Bohensky et al., 2007; Lamarque et al., 2013; Smajgl and Bohensky, 2013). The potential for detailed and diversified behaviour models is large, and the research experience on this subject is growing fast. However, the most detailed and empirical-based behaviour model is not always the most suitable solution (An, 2012). Projects that adopt very detailed behaviour patterns are especially focussed on the effects of these behaviours on their environment. Simpler behaviour models are required whenever the agents are embedded in larger model structures. The behaviour is crucial in defining the evolutionary trajectories of the agents, and simpler models allow then to keep the overview of the dynamics. The modelled solution thus has to balance between the request for detailed and realistic behaviour heuristics on the one hand, and simplified and transparent behaviour heuristics on the other. The implementation of behaviour diversity provides a useful solution for this point. Each of the different behaviour types can be based on simple heuristics. But the combination of the behaviour types allows the model to display a much wider range of evolutionary pathways.

The model is calibrated to empirical data at sector level. Empirical calibration of evolutionary models has been gaining attention lately (Fagiolo et al., 2007), and several approaches are available (Boero and Squazzoni, 2005). Still, it has been noted as a critical problem in applications of empirical ABM's and solid methods are required to guarantee the credibility of the results (Robinson et al., 2007). Standard controls take two steps. The first step calibrates the input data of the model on realistic data sets and benchmarks. The second step compares the output with empirical data for the output and determines the validity of the model. A specific and pragmatic calibration method, the Werker-Brenner method, adds a third step (Werker and Brenner, 2004). The method uses the specificities of evolutionary models, exhibiting often numerous degrees of freedom. The Werker-Brenner approach labels itself as 'critical pragmatist' in the sense that the model is not required to deliver one correct solution. The more pragmatic approach is to allow for several realistic solutions that are able to explain the same phenomenon. Several acceptable sets of input data are determined that return solutions in line with the calibration constraints. The third step is thus to investigate the underlying dynamics, similarities and differences between the inputs sets. These patterns show underlying principles common to all acceptable data sets. This approach narrows the sets of possible entry data down to more realistic figures, and this improves robustness of the model (Russo et al., 2006). This approach is applied in this case.

2.2. The farm as the primary agent

The simulation combines thousands of single farms that produce, sell, and adapt year after year. A farm is a complex undertaking, and its production is influenced by land characteristics, by investments and investment history, by the options for co-production of different outputs, and by the capabilities of the farm manager. Not all these characteristics and influences can be integrated in sufficient detail. In this case, the focus is directed towards changes in livestock production, and more generally towards the investigation of structural change in agriculture. Structural change has been investigated as shifts between different types of producers (Baumol et al., 1985) or shifts in labour allocation per sector (Ngai and Pissarides, 2007). Generally, structural change can be regarded as shifts in productive assets at the level of an economic sector.

The definition of the farm agent thus includes different types of productive assets. The modelled behaviour has to clarify the farm agent's decisions with respect to these diverse farm assets. The main answer to this requirement is the inclusion of different types of animal stocks, investments and land types for each individual farm agent. The farm agent can therefore specialise on one type of production, or he can choose to combine multiple stocks and create a mixed farm.

Mixed farms are an important part of the Belgian agriculture. Multiple economic studies focus on specialised farms (Berentsen, 2003; Meul et al., 2007; Nevens et al., 2006; Van Passel et al., 2007; Van Passel et al., 2009). But the Belgian agriculture contains different forms of mixed farming. This combination of different animal products and crops can be historical, but can also be strategic in response to economic adversity or low productivity (Meert et al., 2005). Mixed farms keep different production options open, allowing for more evolutionary pathways than specialised farms.

The chosen farm model allows for a simultaneous production of crops and animals in four categories (i) Forage : cultivation of plants destined for animal nutrition, (ii) Pastures and grasslands, (iii) Horticulture and (iv) Crops : all other types of crops. The animal products are grouped in three broad categories : (i) Pig products : The output of this category consists mainly of live pigs, (ii) Dairy products : This output does contain raw milk, but also live reform cows for sale, (iii) Cattle products: All other live cattle are grouped in this category. Every farm agent is represented by an individual accounting with specific assets for each production category. These assets cover land, animal stocks and investments in machinery and building. The production of the grassland category can only be used internally to feed cattle. The production of the six other categories (three crop and three animal categories) can either be used internally or can be sold. This leads to six potential types of revenue for each farm. Specialised farms will focus on one category only. Mixed farms can combine different revenue streams. The supplementary information provides the details of the accounting structure and relations between its elements. Farm agents operates with annual cycles, as illustrated in Figure 1.

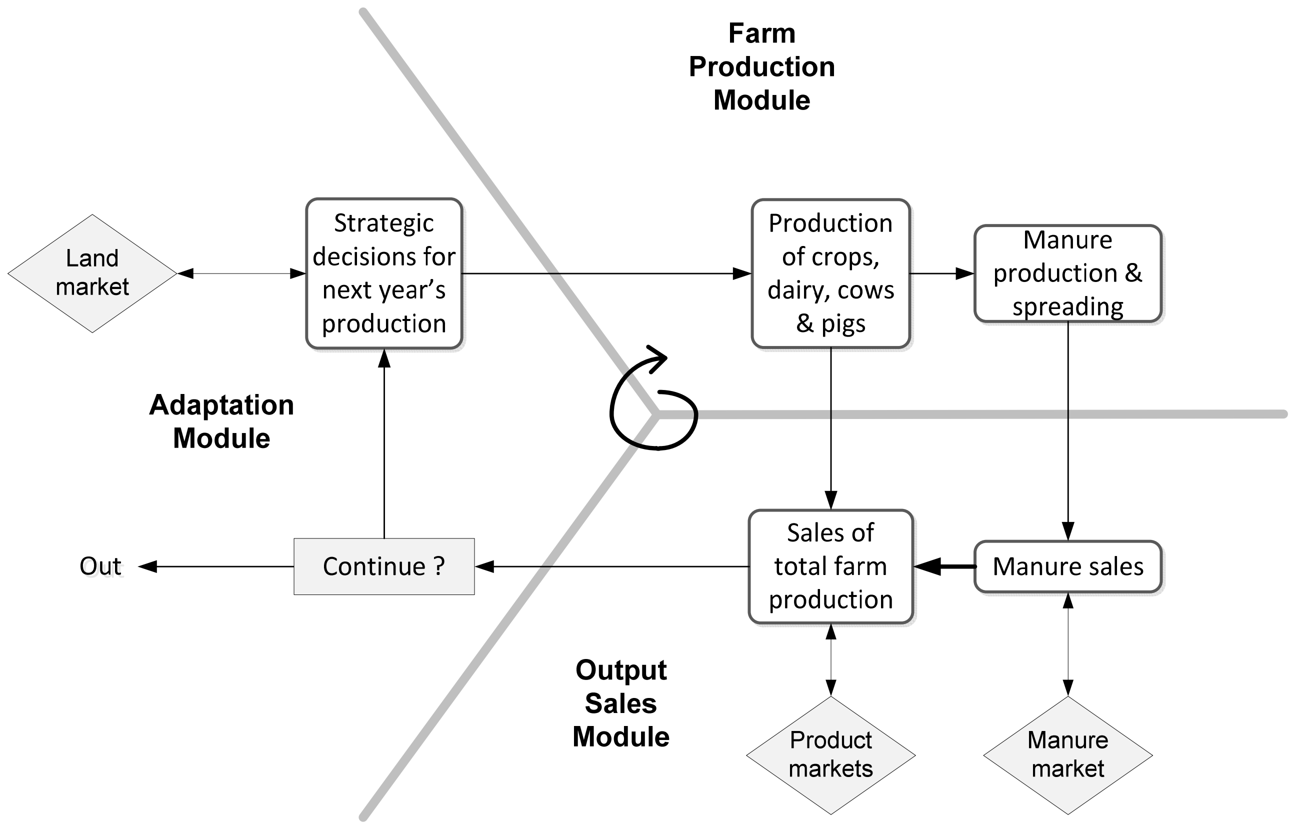

Figure 1: Annual cycles for the farm agents in the model

The annual process is divided in three modules: (i) After the initialisation of the model for the first year, the agent starts producing. Whenever possible, the manure is first spread on the fields of the farm itself. The remaining manure has to be sold on the manure market. (ii) The second module handles the sales of output products and manure. After the sales, the total annual turnover can be calculated and farm agents decide whether they want to continue farming or not. Reasons to cease activity are bankruptcy, or death of the farm agent. (iii) If the farm agent continues, he adapts his farm structure to the new market situations, and optimises assets for next year. After the rearrangements, the farm agent starts the next year.

2.3. Detailed adaptation steps

The third module contains all elements of decision-making and adaptation. This module is constructed to include the variables that describe the behaviour patterns that have to be calibrated in order to clarify their role during the last decade. As defined in section 1, these variables are the sunk costs, the transaction costs, behaviour diversity, and strategic persistence. The first variable, the sunk costs, is included by the detailed accounting for each individual farm agent. Every agent contains a history of investments and loans, and their recovery is required for the survival of the farm agent. The second variable, transaction costs, are included for every change in animal stock. The transaction cost is considered as an additional cost for change, proportionate to the investment cost of the change, separately for each of the three animal types. The exact value of this transaction cost has to be determined by calibration. The third variable, the influence of behaviour diversity, is integrated by allowing five different behaviour types, as explained in the next section. The final variable, strategic persistence, is approximated by singling out radical changes in farm structures as strategic decisions. The adaptation and rearrangement module separates decisions in two distinct groups: strategic and incremental decisions. The strategic decisions concern the decision to specialise in one animal type only, or to abandon animals and to focus on crops. Strategic decisions are not taken every year, and their frequency is matched with empirical data.

The adaptation part of the farm agent is structured in four steps, each grouping related decisions, as illustrated in Figure 2.

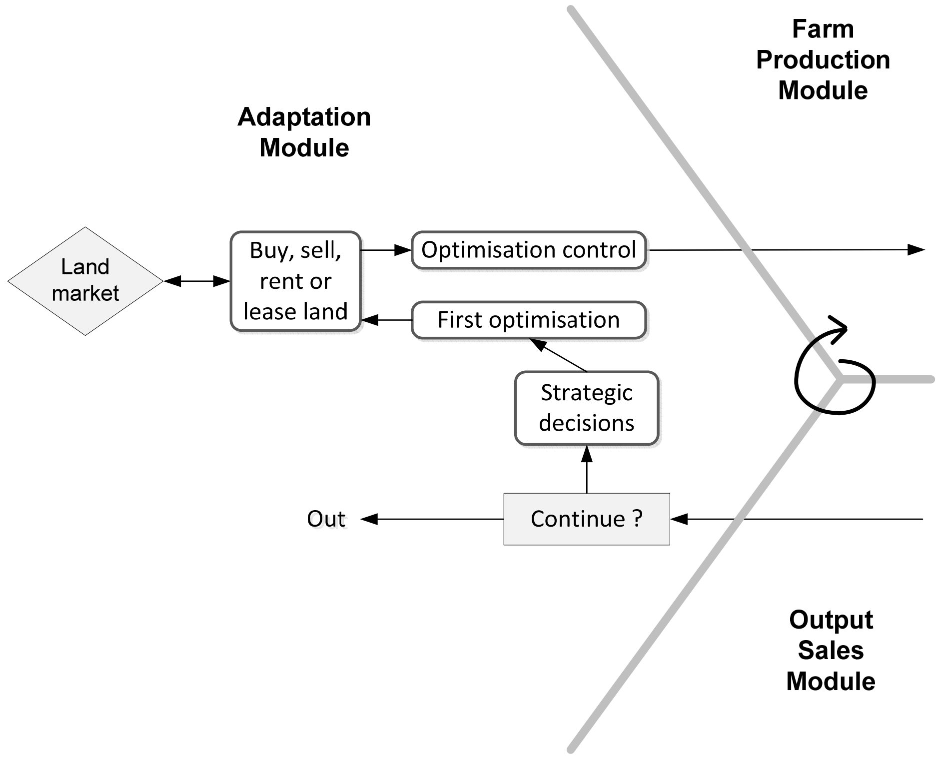

Figure 2: Different steps within the annual adaptation process

The first step of the decision process is the overall strategic decision, allowing the farmer to review the types of animals on his farm. This means that the agent can decide whether or not to continue raising a certain type of animal. The agent can also decide to invest in a technological innovation to improve production efficiency.

In the second step, the farm agent can change the size of his animal stocks, his acreage and the crop allocations. These are changes of a much less radical nature. The farm agent optimises the production assets by incremental de- or investments and allocates different crops to the remaining available acreage. The farm agent can adjust the amount of livestock with a maximum of ± 20%. Increases in animal stock are accompanied by investments for additional stables and machinery, and the farmer has to respect a minimum surface of grassland per cow at all times of 4 livestock units per ha.

Step three captures the process of the land market. For the individual farm agent, the land market is an unpredictable process. The farm agent may propose bids or offers, but he cannot be sure to sell or buy his land at the requested price. Because of this uncertainty, the farm agent reviews in a fourth step his optimisation plans after the results of the transactions on the land market and adapts his asset allocations according to the results of the exchanges on the land market. Step four follows by adjusting in a similar way as step two.

The first step of the strategic decisions cannot be taken every year by each farm agent. In reality there are several reasons that induce a farmer not to change his strategy every year. First of all, large strategic changes require willingness to change. Secondly, large changes are disruptive at farm level. They reduce the options for future production and render some past investments obsolete. Finally, there can also be a form of persistence or stubbornness that explains why farmers continue production with an existing configuration rather than ‘giving up’ one type of animal. The model integrates this lack of adaptability. The overall population adaptiveness is defined as the percentage of the farmers that review their strategy during the course of one year. The determination of this variable through calibration brings insight into the speed of change for radical modifications at farm level.

2.4. Diversity of behaviour

Diversity is a key feature in evolutionary analyses. Following the variety of farmers in Flanders, the implementation of technical diversity leads to a large range of technical variables, combinations and characteristics in the model. The implementation of behavioural diversity adds an additional level of differentiation between the agents, leading to a multiplication of combinations. This large combinatorial freedom could signify in practice that the model is very hard to build empirically. But the application of diversity in both technical and behavioural characteristics is feasible because one can rely on the coherence between the two aspects. This coherence leads to the construction procedure. When one considers certain behaviour to be continuous, it will influence the lay-out and structure of the farm over the long term. Mixed farms will not be held by farmers pursuing maximum production efficiency, or large farms require a certain willingness to take risks from the farmer. The model implements behavioural diversity, constructed according to the procedure of Smajgl et al. (2011). This method builds two parallel classifications: according to the technical characteristics of the farm, and according to the behaviour characteristics of the decision taker at the farm. The technical characteristics include farm size, type of activity, animal stock size, capital structure, profitability, and age of the farmer. The behavioural diversity is integrated by forming different classes of farmer behaviour. Through recursive optimisation of the classes, groups of farmers are constructed that combine each a technical type and a behaviour class. This recursive process defines clusters and requires continuous feedback from external experts with practical experience on decision rules at farm level. In each case, the method integrates empirical datasets and qualitative information to build the full model (Valbuena et al., 2008).

The behaviour classes have been distinguished through discussion with experts. In this case, scientific experts and experts from the innovation unit at the Farmers' Union contributed to the discussions. At first, the discussions determined different behaviour classes, based on practical questions of farm modification: "When a plot of land is available for sale, how do different farmer types react ?", "When pig prices drop dramatically, how do different farmer types react?". This leads to a first distinction of behaviour classes and their respective motivations and objectives. In a second step, the relation with the technical characteristics is refined: "This type of farmer who is always interested in innovative technological solutions, what does his farm look like ?". This two-step investigation has been applied iteratively until the behaviour classes and their respective technical descriptions were acceptable for all experts.

Finally, five different types of farms have been determined. These represent roughly five common behaviour heuristics for Flemish farmers: (i) growing family farms, (ii) stable family farms, (iii) innovator farms, (iv) elderly farmers and (v) industrial farms. The links between the different types are illustrated in Figure 3. Every behaviour type is related to technical farm characteristics, as described in Table 2.

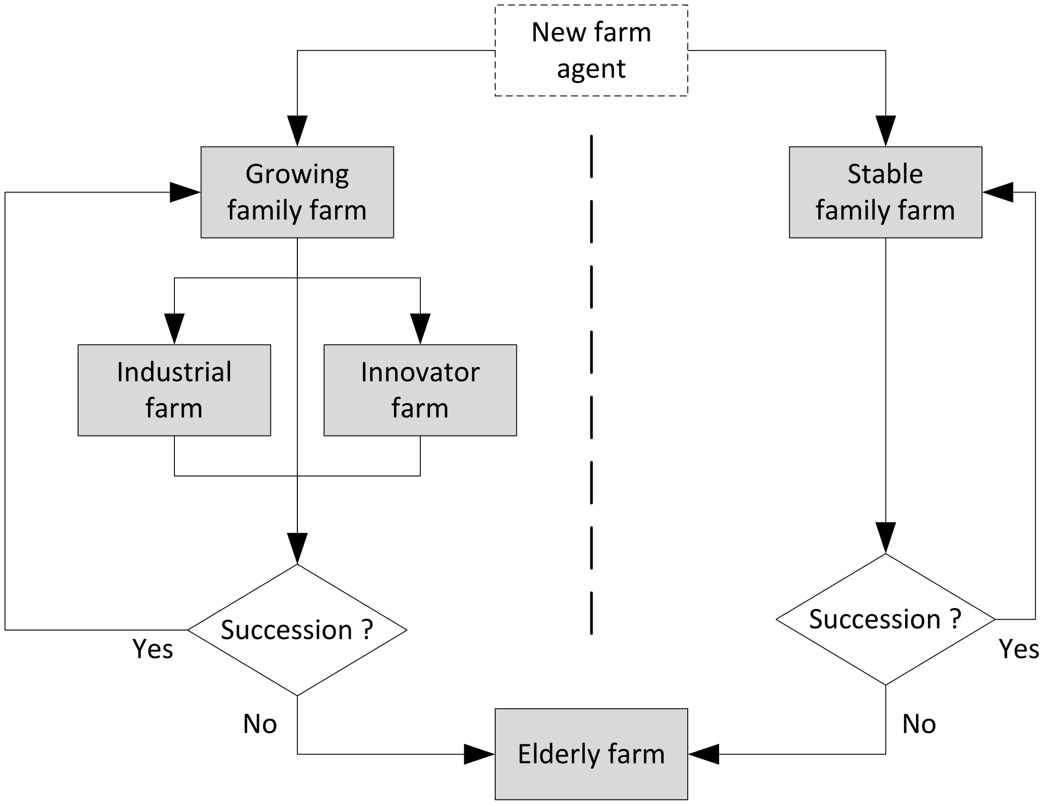

Figure 3: The links between the different behaviour types

At the start the farm agent can be defined as a growing family farm, or as a stable family farm. Stable family farms are based on one family pursuing a stable surface of land and stock of animals. The main objective of these farmers is to obtain a stable farm configuration, while increasing ownership of the land under cultivation and achieving a growing income and farm value. The farmer does not optimise the value or the income of the farm. The farmer defines an ideal farm containing a specific acreage, and specific quantities of animals. He pursues this structure over the years, and every step that can be financed to bring his actual farm closer to the ideal, is executed. Investments to increase efficiency are implemented when affordable.

Growing family farms on the other hand, have a very different behaviour. These farms are also created from one family with a growing surface of land and stock of animals. The main objective of these farmers is to grow steadily. Growth of production can be achieved both by acquisition of production assets as by implementing innovative technologies for increased production efficiency. Through multiple adaptations, the growing family farm can become an innovator farm or an industrial farm.

The innovator farm has already achieved a high production efficiency, and adopts a long-term strategy based on high specialisation and innovation. Growth is pursued, but it is no longer the primary objective. Investments in efficiency increase and in niche specialisation are preferred. The farmers of innovator farms are over 45 years old, allowing them to achieve sufficient experience and background to invest in multiple innovations. These farms achieve the highest production efficiencies. The type is most commonly associated with specialised pig and dairy farms, less with cattle farmers. The industrial farms on the other hand, are less specialised, but larger than innovator farms. Industrial farms are managed as industrial plants. The farms maximises the total value of the farm in the long run. The strategy is based on economies of scale, and leads to intensive growth of the farm. These are the largest farms but do not require specialisation.

Finally, at the end of the lifetime of the farmer, the farm has to find a successor, or he is to evolve into an elderly farm. Succession is a crucial step in the history of family farms. This is increasingly the case, as farms grow larger in size, to a point where it is difficult to start a new farm without any capital or assets available from a predecessor (Calus and Van Huylenbroeck, 2010). However, the current rate of farms that find a successor on time is low. Farms without a successor can present zero growth or decrease in total farm assets (Calus et al., 2008). But in the case when no successor is present, elderly farmers do not retire. Elderly farmers stay active after their pension age, and continue farming without further adapting their farm structure. So the typology of elderly farms consists of farmers that remain active, and don't find a successor. Currently, a succession rate of 41% is implemented in the model, in line with the real situation (Calus et al., 2008). Any farm that fails to find a successor on time becomes an elderly farm when the farmer's age reaches 65 years. The elderly farmers live up the farm's assets, maintain the land in ownership and do not invest any longer. The activity only stops when the owner dies. Starting from 65 years old, each agent has an increasing chance of dying, up to a chance of 100% at the age of 85. Besides the high age of the farmer, these farms also present low efficiencies and high stability of activities or even decreasing activities.

So the behaviour typology can be divided in two very different pathways, one based on stable family farms, the other on growing family farms that can potentially evolve towards industrial or innovator farms. Both types turn to elderly farms at the end of their life. The difference between the two pathways is especially a difference of adaptability. The growing family farm is responding to market prices by adapting his production assets. Growing farms can also decide to specialise their production and to discard one type of animals. This characteristic is shared with the innovator and industrial farms. On the other hand, the stable family farms remain focused on their ideal farm structure. Stable family farms do not adjust their production according to market prices. At most they delay investments because of insufficient liquid assets. The stable family farms represent a very stubborn and fixed behaviour. The other farm types represent a very flexible and adaptive behaviour. The percentage of stable family farms in the total farm population is therefore an important factor for the overall adaptability of the agricultural sector. This percentage has to be determined through calibration.

2.5. Farmers' objectives

Each year, the agent will adapt his situation in order to maximise his fitness (Holland and Miller, 1991). The annual adaptation of the farm agent is driven by an objective function or fitness measurement. Multiple models use an objective function based on various forms of profit-optimisation. In these models, every farmer decides on his strategy and assets while optimising his annual profit. Profit-optimisation has been applied before in agricultural agent-based models, but rarely in the strict neoclassical sense. Several adaptations to this basic decision model have been applied to bring the behaviour closer to reality. The Agripolis model (Happe et al., 2004; Happe et al., 2006) utilise a farm income maximisation decision module. This maximisation is based on limited information and personal prediction of future output prices. Similar constrained and bounded rational optimisation of annual farm income is found in agricultural models such as MP-MAS (Berger and Schreinemachers, 2006; Schreinemachers and Berger, 2011) or CATCHSCAPE (Becu et al., 2002; Becu et al., 2003), the latter combining optimisation with linear programming. In this project, farmers follow the price predictions are formed by averaging the prices the farmer received for this output during the last three years. This is narrow foresight, similar to projects described above.

However because behavioural diversity is used in this model, two different objective functions are used as well: one function pursuing maximum farm value, and a second function pursuing an ideal farm configuration.

In the first case, the farm agent decides on the optimal quantity of land, animals and animal types for a maximum farm value next year. Annual profit maximisation is a very short-term planning horizon for the farm agent. In order to incorporate a focus with a longer time-frame, farm agents maximise the entire value of the farm rather than solely their profit. This entire value includes liquid and fixed assets and agricultural land. This type of farmers does not pursue the largest profit for next year, but they pursue the creation of a large and rich farm, yielding important annual profits each year.

The second objective function is not based on a value, but on an ideal farm structure. Maximisation implies that the agent disposes of a range of choices. For instance, the choice of a mixed farmer to stop raising pigs and to specialise on dairy farming instead, can be part of the decision process. But this is not a valid choice for 'stable family farms'. This type of farmers is passionate about their specific farm type or about the animals they raise. Entirely driven by personal preferences and conviction, this type of farm can for instance prefer pigs. Despite the fact that crop farming presents larger marginal benefits, this farm will continue to raise pigs. There are no alternatives considered during a maximisation process. Their objective is the creation of an 'ideal' farm configuration and size, based on personal preferences of animals and crops. The 'ideal' farm configuration is entirely personal and different for each stable family farm. It consists of a certain acreage under full ownership, and a specific stock of animals. Every affordable step that can bring the farm closer to the ideal, is implemented. When achieved, the farmer stops the farm growth and invests only in efficiency.

In this model, the objective maximisation of each farm agent is constrained by the availability of loans and by the level of financial risk the farm agent is willing to take. New investments in land, animals, farms or installations may require loans. Banks will not restrict the maximum amount of the loan based on the future business plan, but based on the value of the land of the farm that the farmer can give as a guarantee. The maximum loan that a farm agent can obtain is therefore the value of the owned agricultural land, reduced by existing loans.

However, the farm agent will not always take the maximal available loan. This depends also on the financial risk the agent is willing to take. The financial risk of the farm agent is defined as the ratio of liabilities over owned assets. Every farmer disposes of a unique maximum level of risk he is willing to take. This maximum financial risk level RF is age-dependant. The fixed level RF_0 is exponentially distributed among the agents with mean 0.246, corresponding to risk levels in 2008. With growing age, the risk preference of farmers decreases and falls to zero at the age of 65: $RF = RF_0\left(1 - e^{\frac{x-65}{10}}\right)$. This financial risk limitation introduces the age dependence in the behaviour of the farm agent.

Table 2 : Translation of the behaviour into modelled rules

Name	Evolutionary traits	Technical characteristics	Optimisation objectives	Optimisation constraints
Industrial farms	These farms set out from the start to behave strategically as industrial firms.	Farm owner is older than 45 years. Farm size exceeds 350 LSU. Farm is not specialised in one animal type.	The farm maximises the value of the firm.	Growth is constrained by a maximal financial risk of 60%.
Innovator	These farms start as family farms. When the farm achieves sufficient experience, efficiency and specialisation, it can become an innovator.	The farm owner is older than 45 year, and is specialised in one animal type. The farm production efficiency exceeds 110% for dairy farms, 135% for cattle farms, and 150% for pig farms.	The farm maximises a double objective, maximum farm value and maximum production efficiency.	Growth is constrained by a maximal financial risk dependent on the owner's preference. And the total labour burden should remain smaller than 20 times the farm household size.
Growing family farms	Farms start as growing or as stable family farms. Only growing farms are interested in an evolution towards industrial or innovator configurations.	The farm owner is younger than 65 years, or has a successor. There is no other technical restriction for this type of farms. Farm types are randomly designed growing or stable family farms at the creation of the farm agent.	The farm maximises the total value of the farm, composed of liquid assets, and fixed assets including land.	Growth is constrained by a maximal financial risk dependent on the owner's preference. And the total labour burden should remain smaller than the farm household size plus one.
Stable family farms	Farms start as growing or as stable family farms. These Stable family farms remain in this category unless they fail to find a successor in time.		The farm pursues a size of land and livestock, determined on beforehand as ideal. Whenever land is available or financial reserves allow it, these farmers grow their assets until they reach their ideal size.	Purchase of new assets is constrained by a maximal financial risk dependent on the owner's preference. And the total labour burden should remain smaller than the farm household size plus one.
Elderly farmers	All farms that do not find a successor in time become elderly farms.	The farm owner is older than 65 years, and has no successor.	The farm doesn't change investments any more, nor does it invest in efficiency improvements. The same activity is maintained with slowly declining efficiency.	
Remarks: Farms that are facing bankruptcy due to negative cash flows, revert to cash maximisation as a short term survival strategy. When the danger of bankruptcy is averted, they return to their standard optimisation procedure.				

3. Results and discussion

In order to determine the main behaviour variables, the Werker-Brenner calibration method is applied. At first, the initial situation is adjusted to represent the diverse technical and production characteristics of the Flemish agricultural sector in 2000. This initial set-up fixes the starting variables for all productive assets of the farm agent population, and the distribution of the productive assets is the same as for the real farmer's population in 2000. The construction of this set is illustrated in the supplementary information. In a second step, randomly varied sets of the calibration variables are created and the model is calculated for each set. The variables that need to be determined through calibration are:

(i) the adaptation capacity of the farmers' community. This is the proportion of farmers that take a strategic decision during the course of one year

(ii) the annual availability of land: not every farm agent disposes of the necessary acreage next to his farm in the case of farm growth. The land availability is the proportion of farm agents that finds accessible land available for sale or rent during the course of one year.

(iii) the transaction costs,

(iv) the proportion of growing family farms compared to the number of stable family farms.

In this Monte Carlo approach, 67.500 simulation runs have been executed. The chosen results show the closest correspondence with the historical evolution in the period 2000-2011. The scenario chosen for the simulation is 'the race'. This scenario assumes continuous low prices and low restrictions of extra-European import, and resembles closest the actual evolution of the market conditions during the past decade.

Not all of the calibration variables exert a similar influence on the evolution of the model. An essential role remains for the proportion of growing family farms compared to the proportion of stable family farms. This can be clarified by highlighting the large differences between the two. The growing family farms are very reactive to their environment and to the price signals they receive. They are also the basis for the emergence of larger and more innovative farms. The stable family farms however, are mostly driven by internal motivations and constrained by personal limits on size and labour. A high proportion of growing family farms yields an evolution that is highly reactive to the price evolution. Consequently, a high proportion of stable family farms yields an evolution driven by changes in acreage and by the age pyramid of the farmers.

The exercise has been done for a varying proportion of growing versus stable family farms. The optimal values for the corresponding parameters are reported in Table 3. Figure 4 shows the simulated evolution when no stable farm agents are included in the initial population. This simulation shows that even the closest approximation cannot replicate the actual production levels between 2000 and 2011. When all farmers are farm-value optimisers, they tend to disinvest and move away from livestock husbandry. The strategic persistence in this case is very high. The optimal value for the adaptation capacity is set at 3%. This means in practice that an average farmer considers a strategic change of his farm only once every 33 years. In other terms, the optimal solution in this case allows only for gradual adaptation. This is not a coherent result in principle and not a good approximation of reality. A sector that is entirely composed of profit-maximising farmers cannot replicate the past evolution, even if their individual adaptation is severely restrained.

The results from the model applying diversified behaviour are closer to reality. The three best approximations are illustrated in Figure 5. The evolution for pigs and dairy can be approximated closely. With an increasing proportion of stable family farms, the transaction costs diminish, the sector adaptability has a tendency to increase, as well as the land availability. As indicated in Table

2, the best approximation, with 60% stable family farms, stays each year within a range of 5% of the historical dairy and pig production, and within a 10% range of the cattle production. In this set-up the strategic persistence of the farmers is very low. An adaptation capacity of about 60% is optimal. This corresponds to a farmer reconsidering his farm's strategy every 20 months on average. This gives a clear split between highly flexible and adaptive growing family farmers, and persistent stable family farmers.

At the highest proportions of stable farmers, 75% and 90%, the rigidity in adaptability and in the land markets can be reduced. However, transaction costs start to rise again. This time, the transaction costs are required to dissuade the stable farm agents from growing too quickly. All simulations with these high proportions of stable farmers consistently overestimate the live cattle production in Flanders. This shows that the assumption of a complete sector of stable farmers is not realistic either.

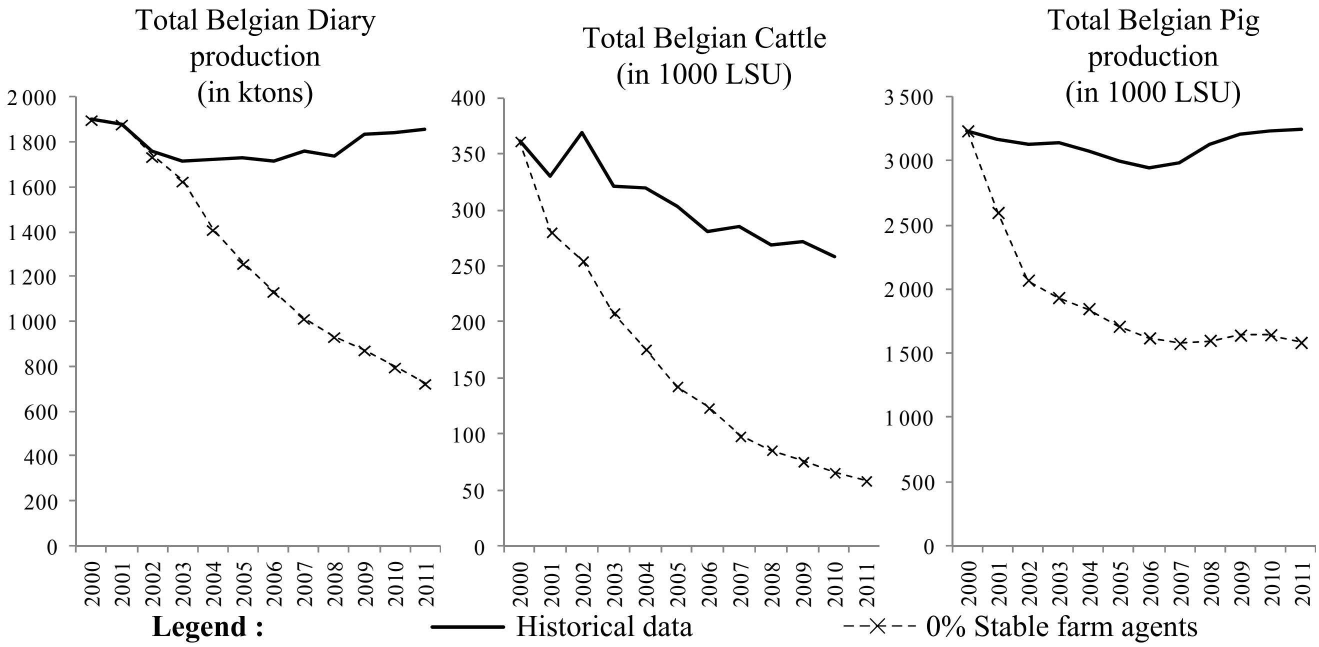

Figure 4: Evolution of regional production without Stable farm agents

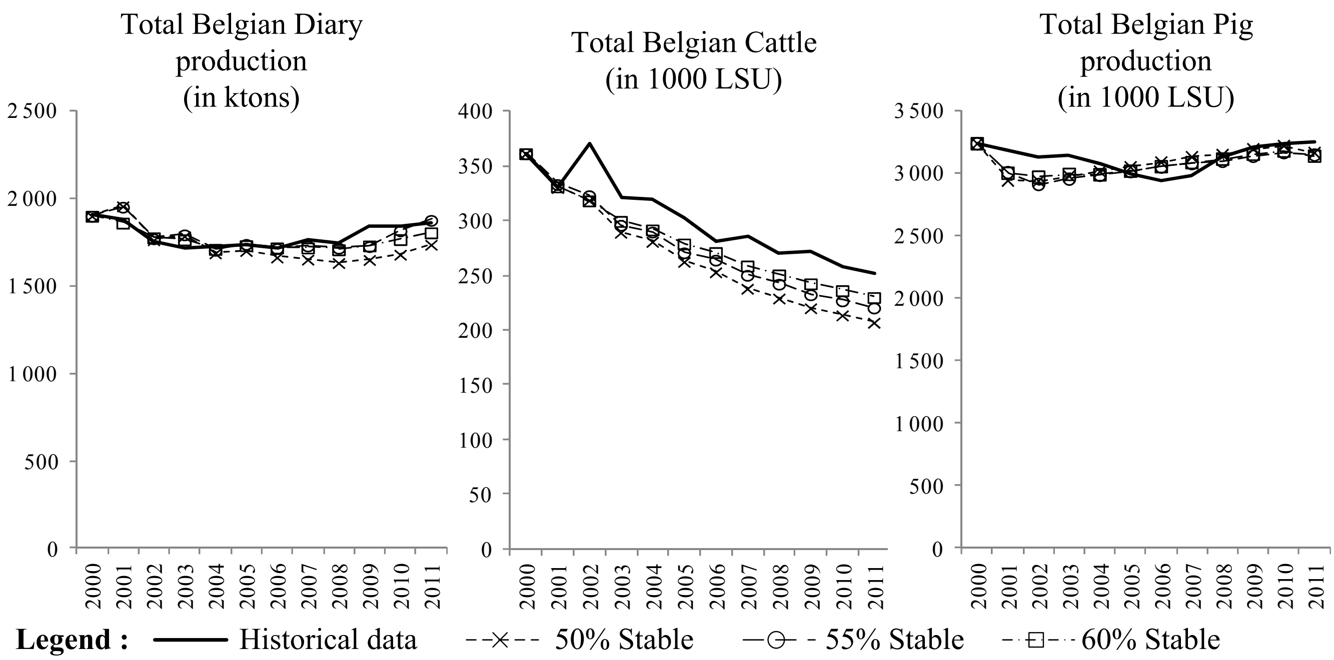

Figure 5: Evolution of regional production with different proportions of Stable farm agents

Table 3 : Optimal parameter sets to simulate the actual production

Proportion of stable family farms	0%	15%	30%	45%	50%	55%	60%	75%	90%
Adaptation capacity[1]	3%	5%	10%	55%	55%	60%	60%	60%	40%
Land availability[2]	2%	2%	10%	20%	30%	35%	30%	30%	10%
Transaction costs[3]									
Dairy	20	20	-	-	-	-	20	-	-
Other cattle	20	20	-	-	-	40	40	30	30
Pigs	40	40	80	5	40	40	40	15	15
Approximation quality[4]	23.7%	18.8%	11.6%	9.3%	6.5%	4.7%	3.9%	11.3%	20.3%

[1]: The adaptation capacity is the proportion of farm agents that execute the strategic decision process per year.
[2]: The Land availability is the proportion of farm agents that has land available for purchase or for rent in his neighbourhood per year.
[3]: The transaction costs are defined as an additional cost when change is undertaken, of x times the price of the added animals. This transaction cost is accounted for in addition to the much larger extra capital investments to take care of the increased animal stock.
[4]: The average relative differences with the real macroeconomic productions is used as a measure of approximation quality for the scenario.

The common patterns between these parameter sets are the resistance to change in the agricultural sector. With low proportions of stable farms, there is rigidity in the market and in the learning processes. With a low proportion of stable farmers, between 0% and 30%, rigidity has to be imposed by the market. Higher transaction costs, low adaptability and rigid land markets are required to match the real evolution. With growing proportions of stable family farms, the rigidity in the market and in learning can be reduced significantly. In these last cases, the rigidity resides in the behaviour of the farm agents themselves. Stable family farms are modelled to remain on an evolutionary track that they determine themselves at the start of their activity.

The assumption of immediate change is related to several other suppositions. It implicitly assumes that farmers have multiple alternatives to choose from and that they also consider these choices annually. It should be noted that the detailed farm model at the basis of the individual farm agent already structures a lot of the options. Being based on empirical data, each farm agent decides how actual change in acreage and livestock can contribute to the farm income, constrained by the actual labour that the family can provide, by existing sunk costs and loans, by availability of new loans, and by practical availability of land in the neighbourhood of the farm. The available options are already restrained to the practical available options. If all farmers would choose between these options based on profit-maximisation, the sector production would decline fast. This is not supported by the actual evolution of animal production.

It should be noted that models of the farm agent's behaviour are not linked to an actual reason of the farmer's motives. For instance, stable family farms focus their personal evolution on a predetermined ideal farm structure. But this simulating approach does not imply a reason for this behaviour. Actually, several different reasons can result in the same behaviour pattern. One potential situation that is modelled by the stable farmer behaviour pattern, is the case of an idealistic farmer. This idealistic farmer builds his personal ideal farm over time and is content with a lower profitability than average, as long as he can proceed towards his personal ideal farm. In this sense, it can be expected that the idealistic farmer sees the trend of evolving towards his ideal as very positive. However, the same behaviour can be possible for farmers who are stuck or restricted. Due to a lack of knowledge and skills, lack of examples and alternatives, or poor understanding of his personal situation, the farmer who is stuck maintains the farm in his specific configuration. This farmer has very limited options. This also means that this type of restricted farmer sees the trend of evolving to his ideal farming structure not at all as a good evolution. Both types are covered by the behaviour type of 'stable family farms'. In general, the diversified behaviour model distinguishes between adaptive and non-adaptive farm agents, without detailing the personal reasons for this behaviour. More detailed behaviour models will require this type of modelling to be coupled with detailed field investigations of actual decision patterns, and their related motives.

The primary directions of change for a farmer in this set-up are in- or decrease of the farm size in terms of acreage and livestock, or specialisation in one type of animal product or in crops. There are of course different directions and strategies a farmer can pursue that do not involve these changes. A transformation of the farm towards organic farming for instance implies a strategic change that is not covered by the options in the model. This study looks at the past evolution in the agricultural sector, and during this period organic animal products remained a very small niche evolution. In 2011, only 0.23% of the cattle and 0.03% of the pigs in Flanders were organic (DLV, 2015). It has thus been decided not to include this type of diversification in the agent construction.

The future scenarios established by the project of DP21, estimated a significant decrease in livestock. The general market conditions for "The Race" has been followed, and this scenario foresaw intuitively a reduction of the regional animal stock within 20 years to -35%, -70%, and -50% for dairy cows, cattle and pigs respectively, starting from 2005. The real evolution indicates that this reduction is not happening. The long-term scenarios of the transition projects severely underestimated the sector rigidity and it's principle objectives. The simulation of the sector shows that a large proportion of the farmers needs to be inflexible in their business decisions, in order to explain the relatively stable production levels. The sector was aware of the overproduction during the DP21 exercises, but this situation did not change during the past decade. Following relatively stable production levels, the prices for animals and raw milk remained also at low levels, whereas higher prices were needed to maintain the sector's profitability. This sector rigidity may be related to the lack of adaptability of individual farmers, or individual objectives diverging from profit-maximisation, the result is still that the overall profitability of animal production remains very low. The sector rigidity following the behaviour of individual farmers does not lead to improved market situations for these farmers.

The inclusion of diversity in behaviour opens new possibilities for policies or interventions. Different policies can appeal to different types of farmers with diverging strategic objectives. When a significant proportion of farmers is not inclined to change its farm structure in response to market prices, then policies to change market prices will only have a limited effect. Alternative policies, that aim for stable but reduced farming activity might then have more impact. A similar consideration can be made for transition projects that incorporate the agricultural sector. Transition arenas and discussion groups gather a lot of expertise on agricultural trends and characteristics. But the speed of adaptation in the sector should not be overestimated. And diversified transition pathways should be constructed for different types of farmers. This has large consequences for related transitions, such as the emergence of the bioeconomy, or more sustainable consumption patterns. Their successful emergence depends on the evolution in the agricultural sector as well.

4. Conclusions

This paper looks at three elements of rigidity in individual farmer's behaviour and links this with the adaptive capacity of the agricultural sector. A detailed agent-based model has been built, accounting for structural diversity of farmers, heterogeneity in behaviour, and natural resource constraints. Five different behaviour patterns are distinguished, and the actual evolution between 2000 and 2011 is simulated in order to determine the distribution of behavioural patterns. The behaviour types can be distinguished in two groups. The first group based on the growing family farms, is responsive to markets and growth-oriented. The second group, based on the stable family farms, is self-centred and focussed on an individual ideal farm structure.

The model is used to replicate the actual sector evolution between 2000 and 2011. The evolution of the past decade indicates that the sector displays a very rigid behaviour. The best approximation of these production levels are obtained when both groups are present in the farm agent population. A population comprising only growth-oriented farmers leads to a swift decline in production capacities and animal stocks. A farm agent population of only stable farmers, leads to a model overestimating the total cattle production during the last decade. The combination of both groups makes it possible to replicate the sector dynamics more closely. The growth-oriented farmers display high flexibility, reviewing their strategic orientation at least every two years. The self-centred stable farmers make up the largest part of the population, leading to a very rigid sector. Future transition scenarios should consider these elements of rigidity, because these variables indicate the adaptive capacity of the sector as a whole.

This model is in Belgium the first application to combine diversified behaviour and agent-based farm modelling. For this case, separate categories of adaptive and non-adaptive farmer types have been implemented. The results show that the diversity in behaviour rules is necessary to explain the production levels of the sector over time. The inclusion of rigid behaviour also adds another dimension to the discussion of future adaptation in agriculture. The influence of other factors to explain rigidity, such as transaction costs or barriers in the land markets, is reduced when a proportion of the population does not display profit-optimising behaviour.

The current application can only present the first step in an iterative refinement of the model through questionnaires, participatory techniques or mediated modelling. The present shortcomings include the simplicity of behaviour rules and rough distinction between adaptive and non-adaptive farmer types. Further detailed analysis of behavioural typologies and decision strategies can help to gain a better understanding of the evolution of Flemish agriculture over the last years. This research will also give important information on the adaptive speed of the sector in future transitions related with the agricultural sector.

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