A dynamic perspective to farming system resilience and its trade-offs

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Paper prepared for presentation at the 173rd EAAE Seminar
"Sustainable and resilient farming systems in the European Union"

September 26-27, 2019
Institute of Agricultural Economics, Romanian Academy
Bucharest, Romania

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Abstract

Resilience management of farming systems in Europe requires building understanding of the underlying drivers of systems' adaptive capacity. In this paper we argue that looking at systems from a dynamic perspective offers a valuable addition for developing such understanding. We characterize a dynamic perspective through three elements: 1) the notion that the relationships between the different components of a system (that is, the structure of a system) affect its behaviour over time; 2) an assessment of system performance (robustness, adaptation, transformation) based on the behaviour of system outcomes over time; and 3) the explicit representation of control variables that shape how other variables, particularly outcomes, respond to shocks and stressors. We implement a dynamic perspective by building a system dynamics model that aggregates complex processes driving beef production systems in France and thus facilitates a discussion about resilience and its drivers. Model analyses reveal, for example, trade-offs between resilience to climate change and resilience to fluctuations in commodity markets. The results also highlight the presence of conflicting objectives between crop farming and livestock farming.

Keywords: resilience, beef production, dynamic systems, farming systems, climate change

JEL Code: Q - Agricultural and Natural Resource Economics; Environmental and Ecological Economics

1. Introduction

Farming systems in Europe are experiencing changes in the technological, demographic, environmental and economic landscape (Knickel et al., 2016, Saifi and Drake, 2008). In this context, resilience becomes a compelling concept for researchers and policymakers aiming for long-term sustainable systems (Meuwissen et al. 2019; Rey, Holman & Knox, 2017; McCalman et al., 2016). Resilience is understood as a system's capacity to withstand changes in the environment while preserving the same structure and continuing to provide the key outcome functions expected of it (Folke, 2006; Walker et al., 2002; Walker, Holling, Carpenter, & Kinzig, 2004).

Resilience management is the active modification of a system with the explicit aim to improve its capacity to absorb and adapt to change (Nettier et al, 2017; Fath, B. D., Dean, C. A., & Katzmair, 2015; Walker et al., 2002). These capacities depend on the way the system has been organised and, therefore, resilience management is interested in understanding such organisation and identifying more effective ways for structuring the system.

According to Walker et al. (2002: 14), the aims of resilience management are a) to prevent a system from transitioning into undesirable configurations in the face of external shocks and b) to cultivate the conditions that facilitate system adaptability following a massive change. Undesirable configurations can be operationalised as the set of conditions and relations within the system that prevent it from providing its main outcomes. For instance, in the case of farming systems, undesirable configurations are those that prevent them from providing: sufficient, affordable and good quality food; sustainable revenues for farmers; or enough jobs in their communities.

The second aim proposed by Walker et al. (2002: 14) suggests that a resilience management process is not a normative process but a structured and systematic framework that allows stakeholders to adapt to challenges in the environment (Nettier et al, 2017; Duru, Therond, & Fares, 2015; Holling & Gunderson, 2002). In this paper we work towards this aim by focusing on means to analyse and communicate the mechanisms driving resilience of farming systems (Sieber, Biesbroek& de Block, 2018; Biesbroek, et al., 2014).

For this purpose, we illustrate how using a dynamic perspective can inform our understanding of the system structure and the mechanisms driving the system responses to external shocks. Next we present the analysis and insights gained from using system dynamics models to explore the resilience of beef production systems in France. To do this, this paper proceeds as follows. First, we describe what we mean by a dynamic perspective, particularly in the context of resilience. Then we describe the beef production system in France and focus on the structures driving the behaviour of important functions of this production system. These structures are later used to interpret the results from the system dynamics model and to cast light on drivers of resilience and trade-offs.

2. A dynamic perspective on resilience

Building resilience requires understanding of social, economic and environmental aspects of farming systems (De Bruijn et al., 2014; Berkes, 2009). This implies that the system should be studied as a whole and the processes and subsystems within the system viewed as interdependent (Biesbroek, Dupuis & Wellstead, 2017; Bruijn et al., 2017; Walker et al., 2002). Elements of the system traditionally considered in isolation are often part of interlinked complex structures that condition the system outcomes (Schut et al., 2014a; Schut et al., 2014b; Spielman et al., 2009).

The complexity of farming systems arises from the large number of interactions between many actors (e.g. farmers, retailers, workers, local governments, national governments, etc.) (Biesbroek, Dupuis & Wellstead, 2017; Schut et al., 2014) and farming systems' interdependencies with socio-technical and socio-ecological systems (Giller et al.,2008; Schut et al., 2014, Olsson et al., 2014). This complex network of interactions and interdependences introduces time delays between cause and effect. This reduces decidability and makes it difficult for decision-makers to anticipate system responses to shocks and changes (Davidson, 2010; Brand & Jack, 2007; Axelrod & Cohen, 2000).

One possibility for dealing with such complex systems is to use analytical constructs that help to make sense of the real world and operationalise the concept of resilience. While there are many such constructs that can be used (see for example: Michellier et al. 2016; Dolega & Celińska-Janowicz, 2015; Biesbroek, et al., 2014; Ostrom, 2009; Mayunga, 2007; Manyena, 2006), in this paper we propose to analyse resilience using a dynamic perspective on system behaviour (Bodin & Tengö, 2012; Folke et al., 2010; Young et al. 2006).

A dynamic perspective on systems is an analytical lens that explains systems' behaviour as a result of their underlying structure. In particular, a dynamic perspective looks at how the relationships between the different components of systems affect their behaviour over time. In simple terms, a dynamic perspective focuses on: a) **aggregated relations among systems' components** (Bodin & Tengö, 2012), b) **systems' outcomes as indicators of their performance** (Herrera, 2017) and c) control variables as drivers of systems' behaviour (Walker et al., 2012).

Using this analytical lens, European farming systems can be seen a collection of organisations (farms, NGO, government bodies, markets, etc.) interacting with each other across different regions and sectors. These organisations are linked by a complex network of interactions that conditions their performance and their response to shocks in the environment. While the complexity of these interactions make difficult to analyse the detailed behaviour of each individual organisation (detail complexity of the system), it is helpful to focus on the relationships between aggregated parts of the system and how these interactions evolve over time.

Resilience can be an overwhelming concept that is difficult to analyse due to its openness and vagueness. To overcome these challenges, we propose to use a dynamic perspective to operationalise systems' resilience through the behaviour of their outcomes and their response to shocks (Bruijn et al., 2017; Walker et al., 2004). Whereas each outcome is likely to exhibit its own particular response, for simplicity, these responses can be clustered into three big groups:

a) building robustness: creating the overall conditions that allow the system to withstand the shocks from the environment without significant changes in the behaviour of its outcomes. Building robustness often requires building infrastructure, building capabilities, creating institutions or establishing procedures for providing a first response to extreme weather conditions (e.g. creating food banks).

b) increasing stakeholders' adapting capacity: fostering stakeholders' ability to manage the system and to responde to changes in the environment. These strategies often focus on making critical thresholds and tipping points more difficult to reach by making the access and distribution of key resources more flexible across different sectors within the system (Walker et al., 2004). For instance, decentralised governance, stakeholder networks and opportunities for innovation are often seen as critical strategies for adaptation (Biggs et al., 2012).

c) preparing for managing transformation: if the system transforms to create a new fundamental new system (Walker et al., 2004), stakeholders might be deprived of fundamental services provided by the previous system. Preparing for transformation requires to explore cross-scale interactions with other systems for building redundancy. For instance, the survival of local farmers might be ensured by securing their access to national resources in case the local system collapses. In this case, farmers might be relocated to other regions or might develop complementary skills for getting into different jobs.

Finally, another important concept in the resilience literature is the notion of '**control' or 'slow' variables** (Ludwig et al. 1978, Holling 1986, Carpenter and Turner 2000). Often described as slow because they need time to change (be depleted or accumulated), control variables are differentiated from other variables because they shape how other variables, particularly outcomes, respond to external drivers. For example, soil organic matter is a control variable because, as described by Walker et al. (2012), it shapes how crop production responds to variations in rainfall (external driver) during the growing season.

By focusing on how control variables change over time it is possible to understand why systems respond differently to shocks from external variables (changes in the environment). Shocks to the system might have an impact on control variables but won't produce significant change in the outcomes of the system if the resources remain within certain thresholds. As the shocks increase in magnitude or frequency, control variables move closer to the threshold and fluctuations in the outcomes of the system become more pronounced. These fluctuations are the result of the internal dynamics of the system and the action of feedback loops within the system (Walker et al. ,2012, Carpenter and Brock 2008, Scheffer et al. 2009). Once key resources reach their thresholds, the strength of these feedback loops shifts and the system moves towards a different, and potentially undesired, configuration that exhibits different behaviours.

In the remainder of this paper, we illustrate how these three constructs (dynamic perspective, outcomes focus and control variables) can be used to understand, analyse and explain resilience of beef farming systems in France. We do so with the assistance of a highly aggregated conceptual system dynamics model built by using historical data, case studies described in the literature (e.g. Lien et al., 2007 study in Norway and Eakin and Wehbe, 2009 studies in Latin America) and insights from the research conducted in the SURE-Farm project. While the model structure is generic to many livestock and mixed crops-livestock systems, in this paper we focus on beef cattle systems in France. Having a simplified model is advantageous in this case because it allows us to expand on the explanation of the analysis performed. Nonetheless, the results of the analysis presented need to be understood as illustrative examples of the type of insights that can be achieved using more complex and detailed models.

3. A conceptual model for livestock farming systems

Farming is one of France's most important industries. The country is self-sufficient in food supplies, from cereal crops, to beef, pork and poultry to fruit and vegetables. Beef production is of particular economic importance since meat production is the biggest agri-food business in the country (Eurostat, 2016).

Figure 1 portrays the basic structure of the livestock farming system. This structure is a simplified diagram compared to the actual system dynamics model. In Figure 1 the ‘livestock units’ stock represents the total amount of cattle held by the farmers in the region in livestock units. The amount of livestock units is depleted by the ‘slaughtering LU’ outflow and replenished and increased by the ‘Replacement and additional LU’ inflow. The revenues from selling the meat are used to pay dividends to the shareholders of the farm whom, if the return on their equity is higher than the return offered in the market, decide to replenish and increase the LU (R1-Profits driving growth on livestock in Figure 1).

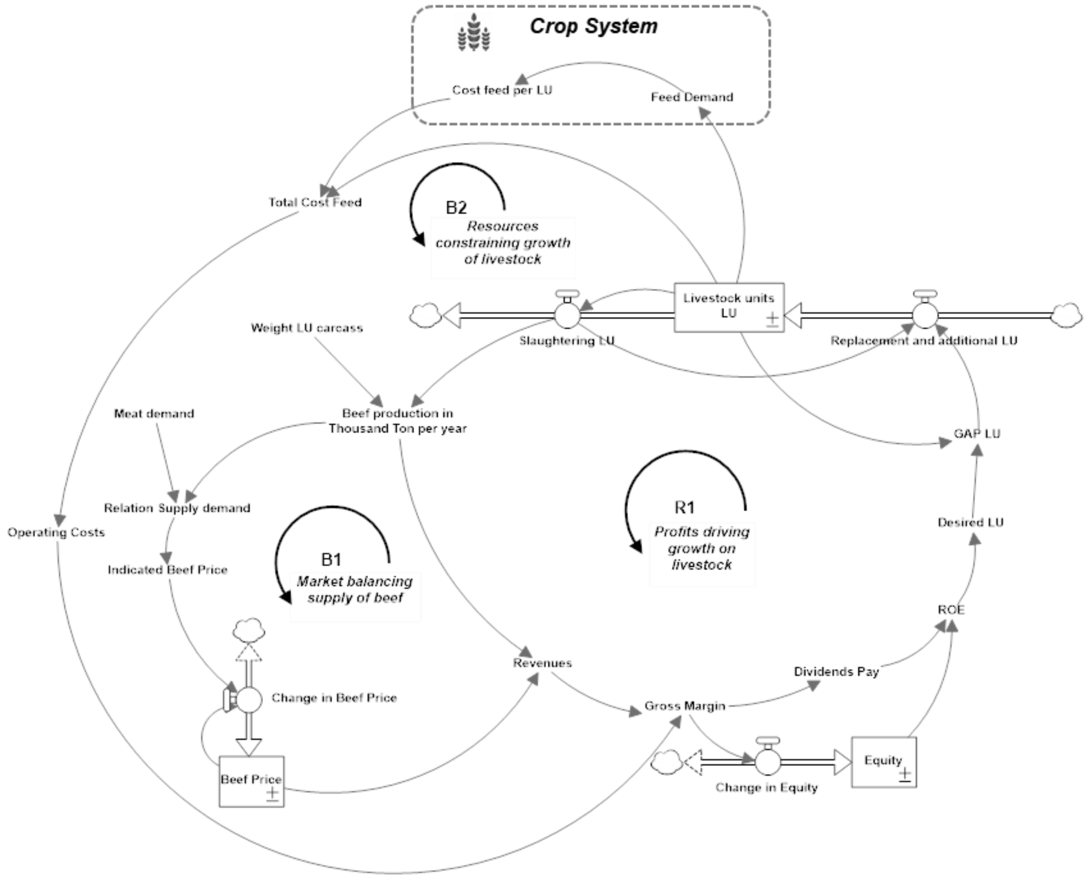


Figure 1: Illustrative structure of the beef production system

The 'Replacement and additional LU' also depends on the selling price for the meat. The meat selling price is assumed to be elastic to the relation between supply and demand. Hence, the size of the beef production system is constrained by the rate at which the markets (local and international) change (see B1 Market balancing supply of beef). Similarly, the size of the beef production system is constrained by the resources available for production (e.g. land, fodder, and workforce). In the diagram these constraints are represented by the cost of acquiring such resources. Costs increase as the resources become scarcer (see B2 Resources constraining growth of livestock).

3.1. Introducing the impact of climate change

The change in weather patterns is a visible global phenomenon (IPCC, 2013). There is substantial evidence showing that climate conditions are quickly changing around the globe as result of a sustained increase in the global mean temperature (Wheeler & von Braun, 2013). Food systems are intrinsically sensitive to changes in the weather and highly vulnerable to climate change (Campbell et al., 2016; Ericksen, 2008; Vermeulen et al., 2012; Wheeler & von Braun, 2013). The magnitude and type of climate change effects on food systems will vary with the location.

In general, climate change is likely to have a direct effect on the environmental drivers in ways that will diminish the capability of food systems to support food production. For instance, the increase of floods and weather variability is expected to result in a net reduction in crop yields (Schmidhuber & Tubiello, 2007; Wheeler & von Braun, 2013). In livestock systems, the effects of climate change are both direct and indirect. Directly, the increase in mean temperatures resulting from climate change will have an impact on the animals themselves. Indirectly, the climate change effects on production of crops and increased exposure to pests and pathogens will increase operating costs and make it difficult for animals to gain weight (Silanikove & Koluman, 2015). For simplification purposes, we aggregated the effect of climate change into two effects: effects on crop yield and effects on grassland yield. The effects on grassland yield increase the price of fodder and thus the operating costs of the beef production system (see Figure 2).

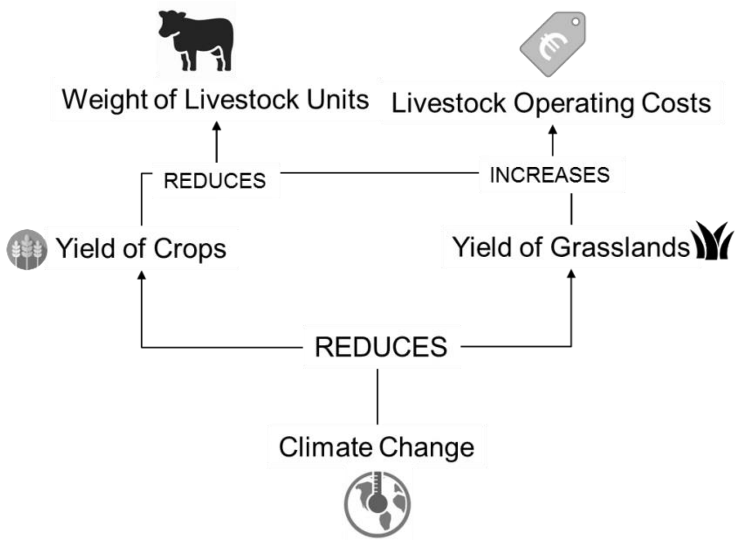


Figure 2: Effect of climate change on beef production

To introduce these indirect effects, additional structure is needed in the model. Figure 3 portrays the basic structure of a crop system producing forage and feed crops as well as crops for human consumption. As before, the structure shown in Figure 3 is a simplified diagram compared to the actual model, but illustrates the main dynamics analysed.

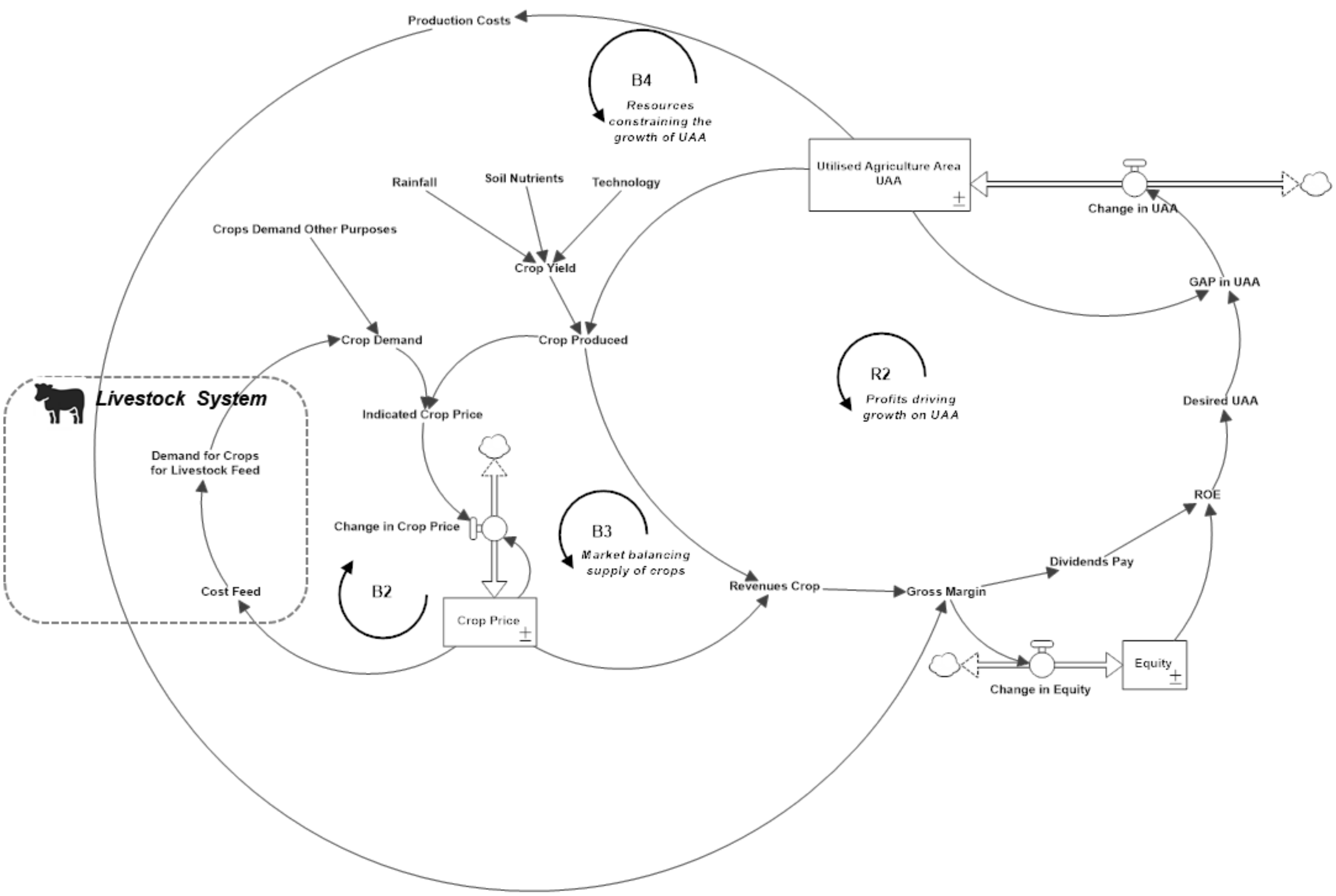


Figure 3: Illustrative structure of the crop production system

The amount of crops produced depends on the amount of utilised agricultural area (UAA) and the average yield per UAA. Similar to beef production, higher crop production results in higher revenues and incentives to investment in more UAA as well as to increase the size and number of farms (see R2-Profits driving growth on UAA). Like in the beef production system, the investment in UAA is constrained by the demand (see B3-Market balancing supply of crops) and the resources available (see B4-Resources constraining the growth of UAA). Since there is only a limited amount of land suitable for agriculture available, as the UAA increases, the quality of the land used is likely to be less suitable for crop production due to deficiencies in soil nutrients, landscape and water access. However, the model assumes these deficiencies could be resolved by spending more on fertilisers, irrigation and other operating costs, hence the more UAA the higher is the operation cost but we have assumed yields can still be kept at similar levels.

4. Results and analysis

The outputs of the simulation model operationalise farming systems' performance through the outcomes and functions they provide to the region. For our research we use a selection of indicators suggested by the SURE-Farm resilience framework (Meuwissen et al.,2019). In particular we look at the capacity of the beef production system to: i) deliver healthy and affordable food products and ii) ensure its economic viability. To do so, we use the proxy variables listed in Table 1 as quantifiable ways to assess how the system performs.

Table 1: Proxy variables used to assess outcome functions

Outcome functions	**Proxy variable**
i) Delivery of healthy and affordable food products	Beef production
ii) Economic viability	Price per carcass paid to producer

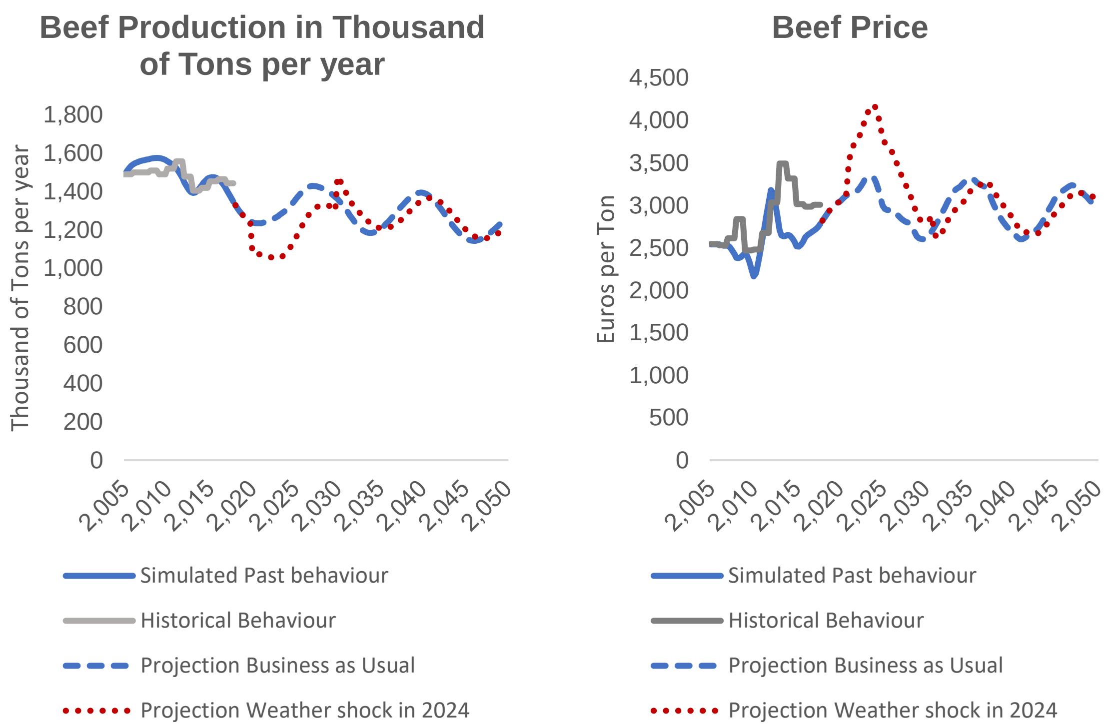
To analyse the resilience of the French beef cattle systems to climate change we used the model to simulate the response of the variables in Table 1 to more challenging weather conditions. For analysis purposes we considered that changes in weather conditions and an increase in pests could broadly manifest in two ways:

a) shocks in weather conditions that will temporarily reduce crop yield

b) and an increase in weather variably that leads to fluctuations in crop yield

For our analysis we considered two shocks, a moderate shock reducing crop yield by 20% and an extreme shock reducing crop yield by 50%. For simulating weather variability we assumed random variations between 10% and -50% on crop yield constantly for the simulated time horizon.

a) System response to a moderate shock



b) System response to an extreme shock

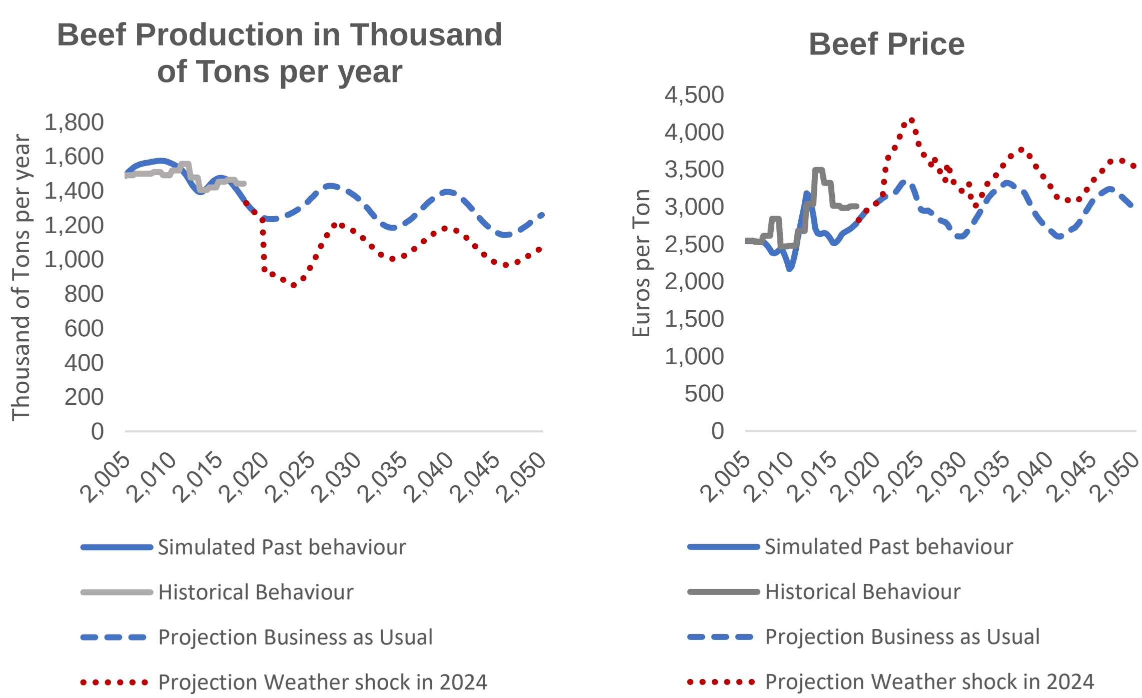


Figure 4: Beef production and beef price response to a a) moderate shock and b) extreme shock in weather conditions in 2024

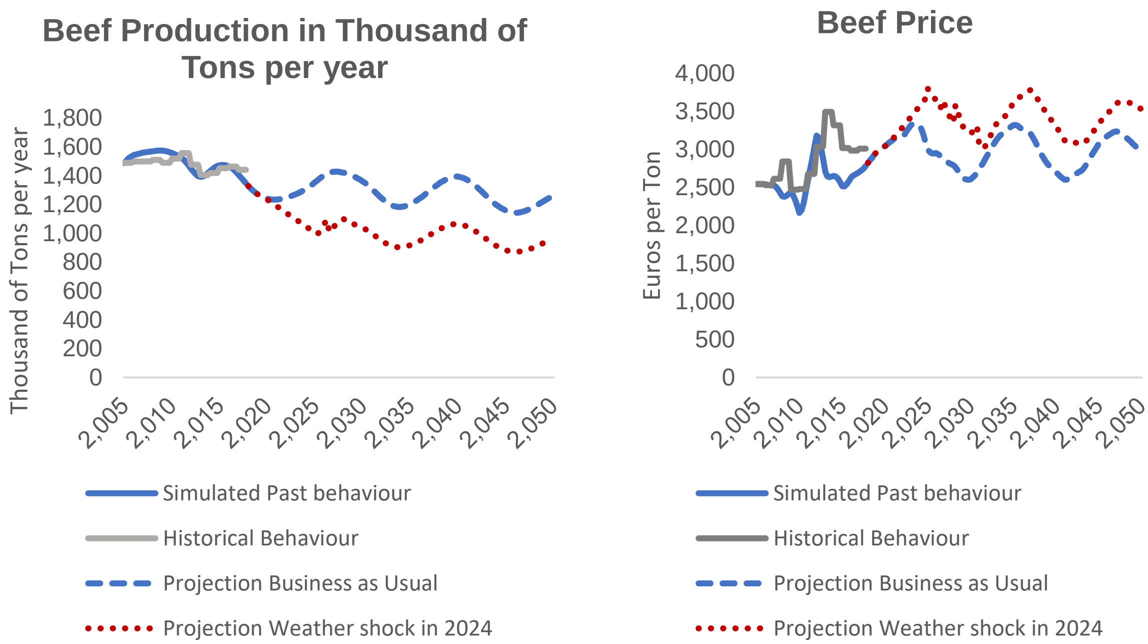
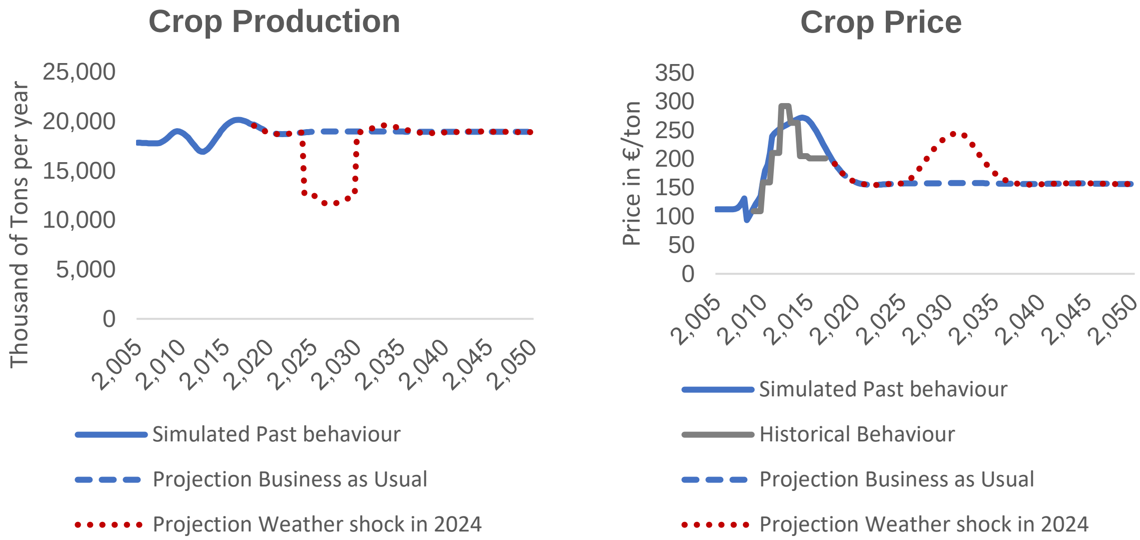


Figure 5: Beef production and beef price response to an increase in weather variability.

Figures 4 and 5 can be used to communicate the difference between adaptation and transformation. If the variation in the weather is moderate, the simulated results shown in Figure 4a suggests the system will miss perform for a relatively short period of time but the system will eventually be able to bounce back. This type of response is described in the resilience literature as 'adaptation' (Walker et al., 2004) and its mechanisms can be better understood by looking at the underlying structure of the system (Sieber, Biesbroek& de Block, 2018; Biesbroek, et al., 2014).

As discussed before, climate change effects reduce crop yield and increase the production costs of the beef cattle industry. In the short term, the disbalance between crop supply and demand increases crop prices and encourages an increase in UAA (see Figure 6). More UAA results in higher crop production which in turn reduces production costs for livestock farmers. This temporal reduction in production costs gives farmers the opportunity to recover after years of receiving lower margins (see Figure 6).

a) System response to a moderate shock



b) System response to an extreme shock

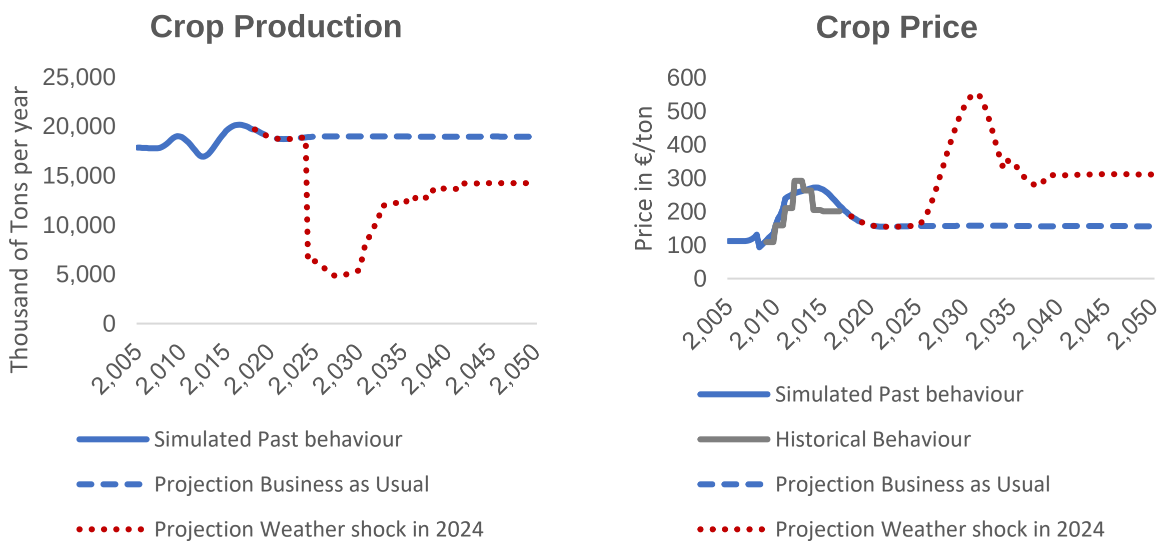


Figure 6: Crop system response to a a) moderate shock and b) extreme shock in the weather conditions in 2024

Alternatively, if the weather variations are too intense and or occur too often, the simulated results suggest that the system will move towards a new equilibrium state (Figures 4b, 5a, 5b). This type of response is known in the resilience literature as 'transformation' and the mechanisms driving this response in the system can also be understood by looking at the system structure. In these cases the adjustments described above in price are not enough to balance the system because the equity needed during the periods of poor performance makes it economically unattractive to remain in business (see for example Figure 7). As the impact of climate change in farmers finances is too big to bear with, farming systems are likely to respond by shrinking to more efficient sizes and could potentially disappear.

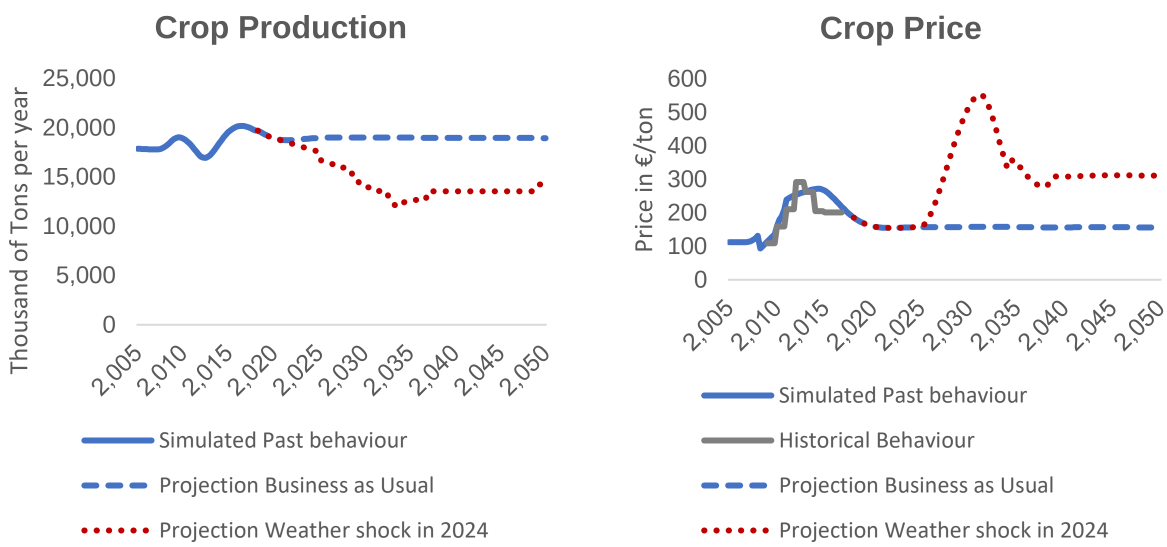


Figure 7: Crop system response to an increase on weather variability

4.1. Exploring trade-offs: Imports vs local production

As illustrated in Figure 2, climate change has a direct effect on crop yields through water scarcity and the increase of pests and an indirect effect on the demand for crops through the reduction of forage available from grasslands. Both reduction of yields and increase in dependency on forage and feed crops result in higher costs than otherwise for livestock producers. However, they have the opposite effect on crop producers who see a reduction in their throughput but an increase in their price. The long-term response of crop farmers is then governed by the elasticity of the markets and heavily influenced by market openness to foreign crops and logistic constraints.

Figure 8 shows the response of the crop production and the beef production to a shock in weather conditions when a) local crops cannot be easily substituted by foreign crops (e.g. because quotas or tariffs are in place) and b) local crops are easily replaced by foreign ones. As shown in Figure 8, openness to markets increases resilience of beef production but reduces resilience of crop production. Moreover, in the long-term, beef production becomes more dependent on foreign supplies, which potentially decreases its resilience to market disturbances by making the system more vulnerable to changes in commodity prices.

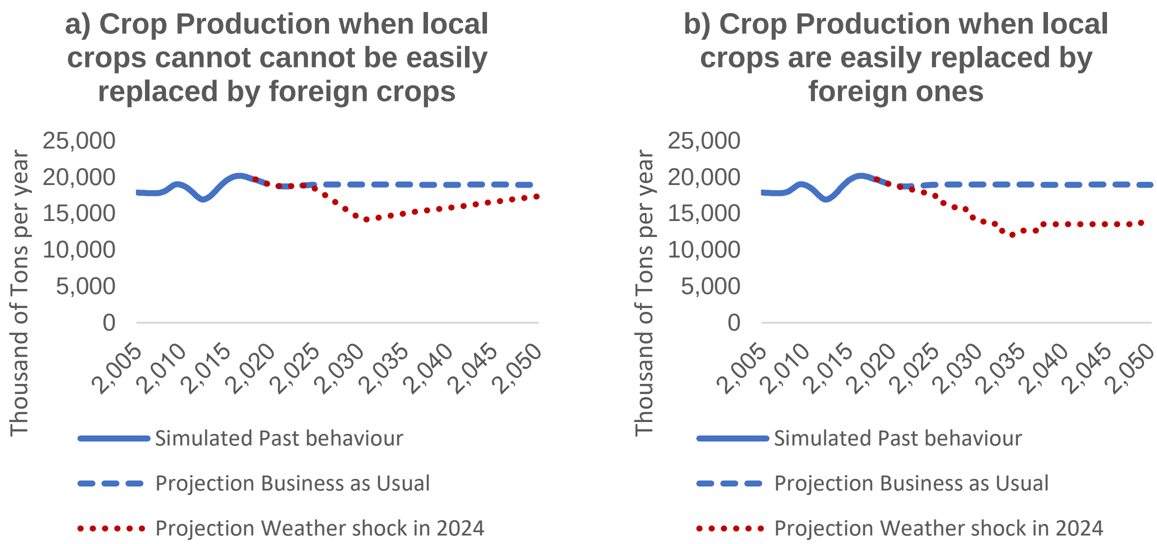


Figure 8: Crop system response to an increase in weather variability when a) local crops cannot be easily substituted by foreign crops and b) local crops are easily replaced by foreign ones

4.2. Exploring potential strategies: access to credit and insurance

As discussed above, one of the drivers of the transformation response is the increased requirement of equity to compensate for missing revenues during the periods when yields are low. An alternative to ease the financial drain on farmers and shareholders is to ensure that farms have access to credit during the periods when climate change is inflicting more pressure on their accounts. Access to credit, long term debt and the costs of borrowing can be included in the model by adding additional structure like the one illustrated in Figure 9.

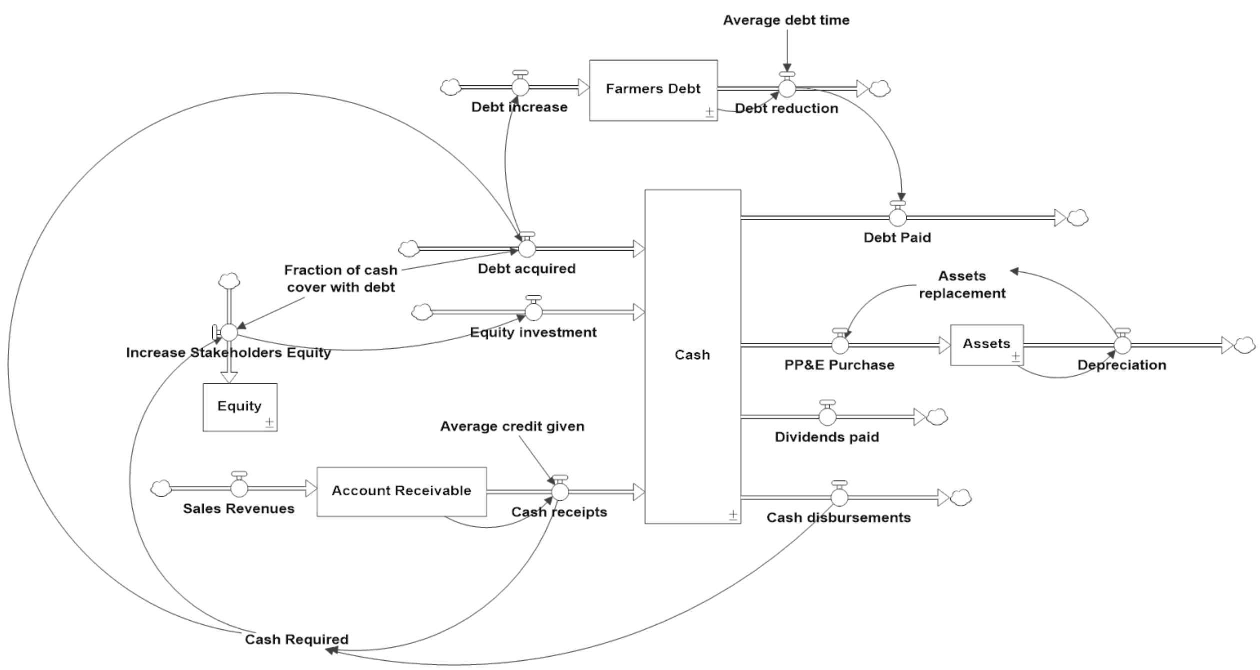


Figure 9: Illustrative structure of a financial subsystem within farming system

For simplicity, short-term and long-term borrowing have been combined and the interest rate has been kept constant. Figure 10 shows simulated responses of both beef production and crop production to climate change effects.

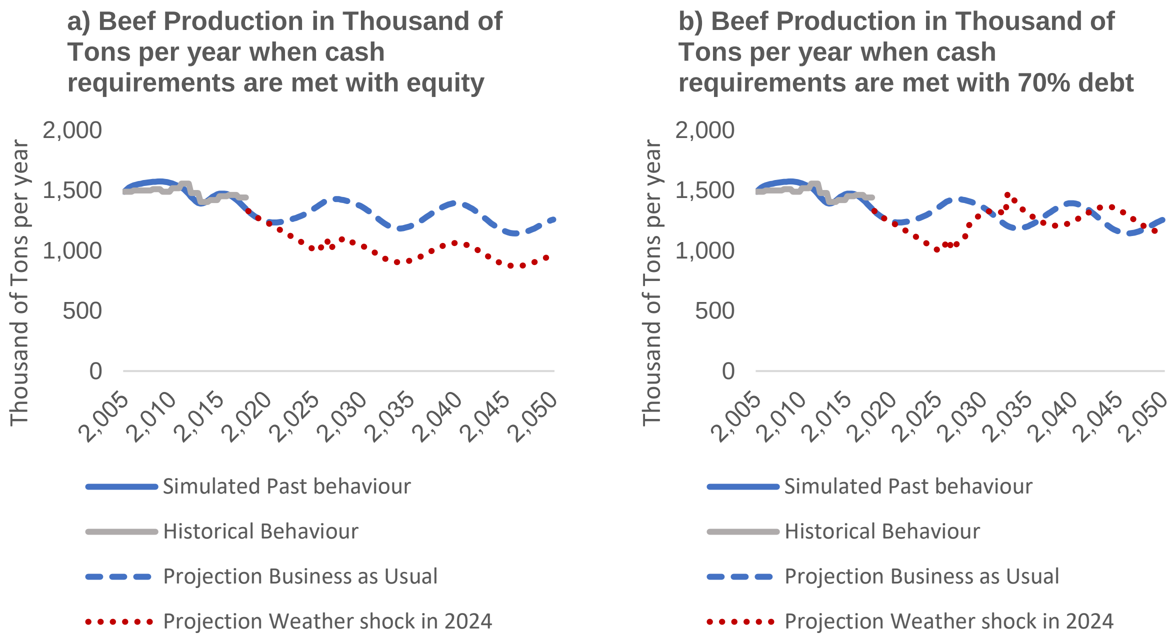


Figure 10: Beef production and beef price response to a) a shock to the weather conditions in 2024 and b) an increase in weather variability, when 70% of cash requirements can be met with debt

The simulation shows that access to credit enhances adaptive capabilities by increasing farms' financial capacity to absorb disadvantageous weather conditions. Similar benefits could also be achieved by creating insurance programmes that cover, at least partially, the losses during periods marked by severe climate change effects (see Figure 10b). Government strategies that secure access to cash for crop producers, either through public or private credit or through insurance programmes, complemented with a strategy that guarantees open access to foreign crops could be an effective combination to build robustness in the livestock sector while maintaining local production.

Nonetheless, such combination of strategies will come with other unintended consequences. For instance, high debt-ratios will make crop producers more vulnerable to fluctuations in market conditions and eventually reduce their resilience not only to climate change but also to other stressors like bubbles in the stock market. Alternatively, a strategy that relies on insurance programmes might become prohibitively expensive if climate change events become a frequent occurrence.

5. Conclusions and further research

Fostering security of supplies, stability of price and financial viability of European farms in times of climate change is vital for the economic wellbeing of rural regions. Hence, although complex and challenging, resilience management of farming systems is a pressing task that needs to be undertaken. We argue in this paper that the aim of such task is not, or at least not only, to implement projects addressing particular issues but to develop a systematic process for enhancing understanding and building adapting capacity.

In this paper we make a case for supporting the resilience management process with a dynamic perspective. The results show that there are at least three clear benefits from using this approach. **First**, by adopting a dynamic perspective it is possible to aggregate complex system processes into their main dynamics and foster understanding about the underlying mechanisms driving system behavior. The diagrams and simulation results presented in this paper illustrate how theoretical and empirical knowledge can be translated into mathematical tools that facilitate a discussion about resilience and its drivers. By using system dynamics models and diagrams it is possible to communicate these complex dynamics in a concise and comprehensive manner.

Second, the simplicity and transparency of the models used also ease the analysis and discussion of potential points for intervention and strategies that can enhance resilience. Whereas the simulation results produced by the model are not meant to offer an accurate prediction of future developments, the analysis we presented shows how simulation results can be used to explore the complex mechanisms fostering resilience. Understanding these mechanisms and basic dynamics will help researchers and policymakers to identify areas where further research and more detailed analyses are needed. For instance, stakeholders might explore in more detail, and considering a wider political and economic agenda, the benefits and challenges of focusing on local production against opening local markets to foreign crops.

Third, having a dynamic model helps to understand trade-offs between different types of resilience resulting from different strategies. As shown in this paper, looking at the simulation results and model structures makes evident some trade-offs between resilience to climate change and resilience to fluctuations in commodity markets. The results also highlight the presence of conflicting objectives between crop farming and livestock farming.

In the case presented in this paper, the boundaries of the model limit the results and insights gained to being explorative. We recognise that more research is necessary to identify other relevant dynamics in the model and to replace some exogenous variables (e.g. impact of climate change on crop yield) by endogenous mechanisms. This is ongoing work that will be developed further by looking in detail into the two case studies assessed by the SURE-Farm project and by incorporating strategies identified by the project in the analysis. However, the preliminary results presented in this paper give confidence that a dynamic perspective will yield relevant insights to resilience management of European farming systems.

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