TYPES OF INTERACTION BETWEEN ENVIRONMENT, RURAL ECONOMY, SOCIETY AND AGRICULTURE IN EUROPEAN REGIONS

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DIVERSITY AND RESILIENCE OF RURAL AREAS – REPORT

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THE ROLE OF AGRICULTURAL DIVERSITY IN RURAL SUSTAINABLE DEVELOPMENT: A DYNAMIC SYSTEMS APPROACH

(DIVERSITY AND RESILIENCE OF RURAL AREAS – REPORT)

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Contents

Figures

Tables

Abbreviations

Countries

AT	Austria
DE	Germany
ES	Spain
FR	France
HU	Hungary
IE	Republic of Ireland
IT	Italy
NO	Norway
PL	Poland
RO	Romania
UK	United Kingdom

0 INTRODUCTION

This report provides the modelling results and overall findings of WP3 of the TERESA agent-based model, which was developed in the 6th Framework Programme project, contract no SSPE-CT-2006-044400 (www.teresa-eu.info). The central question addressed in the present report is: How does diversity affect the dynamic system properties of agricultural supply chains in regions over time?

The methodology used to explore the relationship between diversity and the dynamic system properties is agent-based modelling (ABM). ABM is a modelling paradigm that specifically explores how individual elements within a system (in this case agricultural supply chain actors) affect and are affected by changes in the environment in which they operate. The aim of the TERESA model is to explore how interactions and interdependencies between different agricultural network structures and the rest of the rural economy affect rural sustainable development. The model consists of a range of agricultural supply chain actors, which characteristics are based on empirical information from different NUTS-3 regions in Europe. The results show how different behavioural rules lead to the evolution of different agricultural supply chain networks. Furthermore, this model can be used to explore the effects of future conditions on the performance and evolution of these agricultural supply chains. The analytical framework used to develop the ABM is described in an adjunct report named ‘Exploring dynamic system properties of agricultural supply chains in rural regions – An agent based model’. An operational description of the model can be found in the TERESA deliverable D.3.1 EXPLORING DYNAMIC SYSTEM PROPERTIES OF AGRICULTURAL SUPPLY CHAINS IN RURAL REGIONS (AGENT-BASED MODEL OF RURAL AREAS).

The report consists of the following sections. Section one starts with a theoretical discussion on the concepts diversity and dynamic system properties and how they are related to each other. The second part of the report discusses the application of these concepts to rural development and agricultural supply chains in particular. The third section discusses the methodology developed to explore the relationship between these different concepts empirically. The fourth section provides an overview of the modelling results from six case studies. The fifth section discusses the result and attempts to draw some generic conclusions from comparing the different case study results.

1 DIVERSITY, RESILIENCE AND ROBUSTNESS

This section provides a general discussion of different theoretical frameworks that consider the role of diversity and its implications for dynamic system properties of agricultural supply chains within rural regions.

1.1 Diversity

The history of the concept of diversity is strongly rooted in ecology and evolutionary thinking. Before the 1970s, the dominant view was that diversity enhances the stability of ecosystems. In other words, an ecosystem that only consist of a small number of different elements is more vulnerable to destructive oscillations and invasions (McCann 2000). Furthermore, diversity is related to heterogeneity, which is one of the building blocks of evolutionary theory; without heterogeneity there is no evolution. These ideas were first challenged by Robert May (May 1973), and later also by others who developed models showing that the number of species and the number of pathways were not the only determinants for stability within a system (McCann 2000). Two additional hypotheses have been offered. First, it is argued that diversity is not a driver for stability, but that stability depends on the ability for systems to contain elements, or functional groups, that are capable of differential responses (McCann 2000). Thus, it is not necessarily the number of species but which function each of these elements provides within the system. From this perspective, adding or removing one element might change the overall stability of the system regardless of the total number of elements within the system. Second, an important element is the structure with which elements are related. So instead of the number of species, it is their interactions that are important for stability (McCann 2007).

Since the 1970s, several other disciplines have started to look at the concept of diversity and its role in socio-economics, policy and physical systems (Carroll 1993; Grabher and Stark 1997; Britto 1998; Weisbuch 2000; Hannan 2005). Most of these studies assume that diversity increases the stability and adaptability of systems, although there is also evidence that diversity comes with a cost (inefficiencies, additional investments or obsolete capital).

The concept of diversity has also been taken up by some studies on the role of agriculture in rural regions. There are three different ways in which the concept of diversity is used: 1) diversity is used to refer to non-agricultural activities of farmers, 2) diversity is used to refer to the variety of economic activities within a region, whereby agriculture is seen as one of the possible economic activities and 3) the diversity of agricultural activities within a region. Each of these three uses are discussed shortly below.

The most common hypothesis is that a rural region with more diverse activities is more stable and resilient to potential shocks to the system, because alternative forms of income are available to the agricultural farmers. These alternative forms of income allow farmers to overcome periods of stress, which therefore improves the overall performance of the region as a whole. The most common use of the concept of diversity can be found the terminology of 'diversification', Diversification refers to farmers enhancing their household income from sources other than conventional farming production through diversifying their business activities (DEFRA 2007). This conceptualisation of diversification is particularly dominant in rural development perspectives where the role of farms is seen a potential multi-functional rural enterprises which serve a variety of markets contributing to sustainable rural development (Marsden 2003). However, there is no exact definition of what constitutes diversification activities. Some definitions include the hiring or letting of assets for non-agricultural purposes as diversification activities (DEFRA 2006),while others exclude them because they do not involve any entrepreneurial activity by the farmer. Furthermore, it is disputed whether part-time jobs outside the farm (either on other farms or in the secondary or tertiary sector) should be counted as diversification activity.

The concept of diversity is also used to describe the totality of economic activities within a region. From this perspective, a region that has multiple economic activities is assumed to be more stable against stresses that affect the performance of the agricultural sector. For example, a complete abolishment of agricultural subsidies could leave regions mainly dependant on agriculture as the main source of income very vulnerable.

The third use of the concept of diversity in studies on the role of agriculture in rural areas refers to agricultural activities itself. From this perspective, a region that has a diverse portfolio of agricultural activities is more stable to stresses than a region that is dominated by one particular agricultural product. For example, a region that is dominated by wine production would be more vulnerable to a grape virus than a region that has a diverse set of agricultural activities which includes horticulture, arable land and meat production. Furthermore, there is contradiction empirical evidence suggesting that there is a relationship between the diversity of agricultural supply chain structures (from conventional supply chains to structures that include organic farming, direct marketing or local processing) and stable rural development (Smith and Marsden 2004; Darnhofer 2005). This relationship is complex, because both forms of agricultural supply chain structures are adaptive and change over time (Seyfang 2006).

Because the main focus of this report is on the role of agriculture in rural regions it uses the third conceptualisation: the diversity of agricultural activities and agricultural supply chains within a region. It extends the definition of agricultural activities to include both product diversity and the diversity of the extended supply chains associated with agricultural products. Thus, instead of focusing on the diversity of land use within a region, this project looks at the diversity of the agricultural supply chain as a whole. By extending the focus, it becomes possible to explore how different agricultural supply chains structures might contribute to the resilience and stability of rural regions. As such, it attempts to incorporate the structural component, which plays a role in the relationship between diversity and resilience and stability (see the previous discussion of McCann 2007).

By extending the scope, it incorporates not only the existing supply chain structures, but also possible changes in the future, and how processors, wholesalers and retailers, normally classified under the secondary sector, are connected to each other and convert agricultural products into consumer goods. As such, the focus on agricultural supply chains rather than land use extends the scope of what is considered as elements contributing to rural development.

1.1.1 Measuring diversity

Despite an increasing amount of research on diversity, there is relatively little cross-disciplinary research on the general characterisations of diversity (Stirling 2007). Because of the lack of a common framework to analyse the role of diversity, it has so far been difficult to draw lessons from analyses in different domains.

In this report, we are using a framework to measure diversity developed by Stirling (2007), because it combines and encompasses most diversity measures used by other scholars. Stirling distinguishes between three basic properties of diversity:

- ➔ Variety: the number of different elements within a system. The basic assumption is that when variety increases within a system, the diversity of the system increases. In this particular case, variety refers to the number of different supply chains. In the model, a maximum of seven different supply chains can be considered.
- ➔ Balance: the contribution of the different elements to a system. The basic assumption is that the more balance between the elements within the system, the more diversity within the system. In this particular case, balance refers to the contribution of each agricultural supply chain to the total GVA provided. The total GVA is defined as the total sum of GVA provided by the agricultural supply chains under consideration.
- ➔ Disparity: how distinct the different elements are to each other. Again, the basic assumption is that the more separate the elements are, the greater the diversity. Different criteria can be used to measure the disparity between different elements ranging from the number of actors within each supply chain to the total level of knowledge required within the agricultural supply chains. Each criterion is normalised according to the GVA provided by the agricultural supply chain at the time of the comparison, which means that the comparison is on an 'unit of functionality' basis. This normalisation procedure is required to be able to compare the different supply chains, regardless of their size and the time of the comparison.

The heuristic for diversity is as follows:

$$\Delta = \sum_{ij(i \neq j)} \left(d_{ij}\right)^{\alpha} \cdot \left(p_i \cdot p_j\right)^{\beta}$$

Where Δ represents a diversity heuristic considering three elements; variety (Σ_{ij}), disparity between different elements (d_{ij}) and balance between the different elements ($p_i \cdot p_j$). The index *i* refers to the total number of elements N within the system, p_i is the contribution of the element to the system's function and d_{ij} is the disparity between element *i* and element *j*. The parameters α and β are parameters that can be used to reflect the relative importance of balance, variety and disparity when measuring diversity.

The way in which the contribution p_i is measured depends on the context in which diversity is measured. If diversity is important to create environmental stability, then p_i should be measured in terms of the contribution of element *I* to system should be diverse

There are several methods that can be used to compare the disparity between two or more agricultural supply chains on the basis of multiple criteria. These methods differ in the extent to which they regard the different criteria as being substitutable. Thus, these methods differ in the extent to which they allow a high score on one criterion to compensate for a low score on another criterion. The discussion on substitutability is particularly relevant in the domain of sustainable development, where measurements often involve economic, social and environmental criteria.

Two different methods have been employed to measure diversity; 1) an outranking method called ELECTRE III and 2) Multi Attribute Utility Theory (MAUT). Outranking compares supply chains on the basis of each individual criterion. Only if two supply chains are distinguishable on each criterion, the supply chains as a whole are treated as qualitative differently. MAUT also compares the different supply chains on the basis of individual criterion, but uses a weighted average over all criteria to determine the difference between the different supply chains, which means that MAUT allows for more substitution between criteria. The disparity is measured using the squared Euclidian distance between different supply chains as represented by their corresponding disparity attributes (Yoshizawa, Stirling et al. 2009). In other words, for each disparity attribute the distance is measured, squared and weighted according to the disparity's weight. The total distance is the square root over all the disparity measures (see the next formula).

$$d_{ij} = \sqrt{\sum_{c=1}^{n} \left(w_c^{disparity}\right)^2 \left(D_{ci} - D_{cj}\right)^2}$$

With w_c being the weight of disparity measure *c*, *n* is the range of disparity measures and D_{ci} being the value of disparity measure *c* for supply chain *i*.

The level of diversity of the agricultural supply chains in a region is measured at the end of each year because the model only measures GVA contributions of each supply chain at the end of the year. This method results in a quantitative measure of diversity for each evolutionary pathway from the year 2006 to 2025.

The diversity measure is calculated using the MAUT method because the disparity measure is not used to make a qualitative comparison between the contributions of the different supply chains to the sustainable development of the region (in terms of economic, environmental and social contributions), but instead to measure the observable differences between the different supply chains. As such, MAUT allows for expressing a greater difference between the different supply chains. Namely, the comparison is done on the basis of the criteria within the supply chains (allowing a 19 point difference) rather between the overall performances of the different supply chains (only allowing a 12 point (6x2) difference).

1.2 Dynamic system properties

As outlined in the previous section, there is a long history of research into the relationship between diversity and stability, whereby stability is defined as the system's ability to defy change. Outside of ecology, the concept of stability has been extended and is referred to as resilience: the ability of a system to return to an equilibrium after a perturbation or a non-equilibrium attractor (McCann 2000). The work on resilience continued to grow, most notably by Holling (1973; 2001), Holland (1995), Kay, Regier et al. (1999; 2000) and Kauffman (2000).

The concept of resilience has also been applied to socio-ecological systems (Folke, Carpenter et al. 2002), whereby the definition of resilience has been extended to include not only resistance to perturbations, but also the system's capacity to self-organise and the "degree to which a system is built to increase the capacity for learning and adaptation" (p. 5). However, the use of the term resilience in socio-ecological systems has proven to raise some challenges (Walker, Anderies et al. 2006). Socio-ecological systems are defined as systems in which people, society and ecosystems are interlinked, and as systems in which actions and/or changes in one sub-domain affect the behaviour and performance of other parts of the systems. The challenge in applying theories and ideas about resilience to socio-ecological systems is that such systems do not lend themselves for controlled experiments, in which it would be possible to changes some parameters and leave others constant. The research conducted so far have mainly been case studies, from which the overall conclusion is that a top-down approach for managing socio-ecological systems towards resilience is inappropriate (Anderies, Walker et al. 2006). Instead, it is argued that moving towards 'adaptive governance of resilient socio-ecological systems' would be advantageous (Walker, Anderies et al. 2006).

The concepts of resilience and stability have also entered the debate on sustainable development. Initially, the concept of diversity was only mentioned in the context of ecosystems and as an example of why environmental diversity should be preserved (Ayres 1993). However, more recently diversity, stability and resilience have entered the discussion more centrally and are referred to as essential characteristics for long-term sustainability of socio-economic systems (Arrow, Bolin et al. 1995; Limburg, O'Neill et al. 2002; Allenby and Fink 2005; Cabezas, Pawlowski et al. 2005; Fiksel 2006; Nelson, Adger et al. 2007).

Despite the rise in research applying the concept of resilience to socio-ecological systems and sustainability in general, there remain some important challenges. A recent symposium on the use of resilience in socio-ecological systems collected some of these critiques and issues (Leach 2008). First, the focus has been so far on the structure of systems rather than the actual value of the relationships between structures. Furthermore, the viewpoint of the actors operating within a system, and the variety of framings, narratives, imaginations and discourses possible to describe their issues need to be considered. Second, the term resilience is often used in an abstract way. Instead, it should be used with direct reference to the intentions, actions and strategies of the actors involved. As such, resilience becomes a normative concept which can form the basis for further critical discussion rather than an objective aim for the future. Associated with the latter concern is the issue of power and politics. Each socio-ecological system is embedded in a wider environment in which power and politics play an important role and create the framework within which alternative pathways are evaluated. These forces need to be considered and brought into the discussion of resilience.

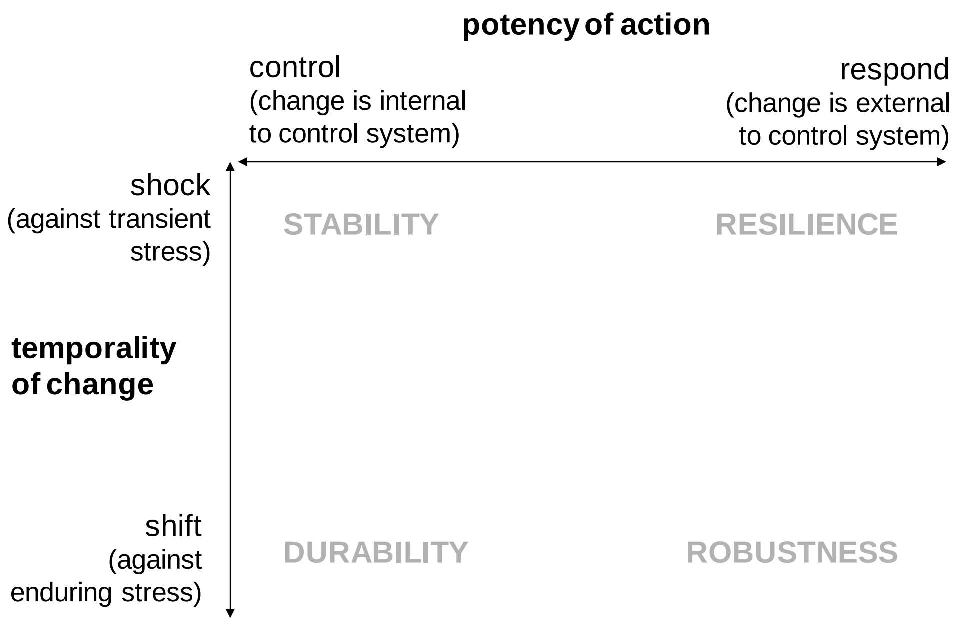
This report is not able to address all of the issues raised above. Instead, it focuses on one specific socio-ecological system, which is agriculture in rural regions. Different from most other work on applying the theories and ideas of resilience on socio-ecological systems, it uses an experimental platform in the form of an empirical agent-based model. An agent-based model, in contrast to case studies, allows for experiments and dynamic and quantitative analysis of the evolution of agricultural systems over long periods of times. The TERESA ABM is used to explore two topics in more detail. First, it explores the relationship between action, structure and the dynamic systems properties of agricultural systems. Second, it explores how different stresses might be conceptualised from a dynamic perspective and how this might influence the relationship between diversity and the dynamic system properties of socio-ecological systems. These two issues will be explored in more detail below.

The first issue raises questions on the relationship between actions and structure within socio-ecological systems. In most attempts to apply theories of resilience to socio-ecological systems, no distinction is made between the ‘function’ and the ‘structure’ of socio-economic systems (Scoones, Leach et al. 2007; Kempener 2008). In their definitions of resilience (see Kempener 2008 for an overview), researchers in the field of socio-ecological systems argue that systems should simultaneously maintain AND adapt their function in the face of disturbances without discussing when and what should be maintained and what should adapt. This is particularly relevant for socio-ecological systems in which actors are driven by perceptions about what the future holds. These perceptions or ideas might not be true (as the future is inherently unpredictable), but they do form the basis for their actions and as such might change the direction of these systems over time. Furthermore, the function of a system is assumed to be given, while the function of a socio-economic system depends on the framing; the subjective view of the person or organisation interested in the system (Scoones, Leach et al. 2007).

The second issue that is addressed in this report is the conceptualisation of stresses. In most work so far, stress is a predefined change to the system which is either known (in the case of historical case studies) or narrowly quantified and defined (in case of ecological experiments). However, in socio-ecological systems there is a variety of stresses possible and each stress might require different responses. Different authors have conceptualised these external events impacting on the system differently. On the one hand, some authors point to a temporary and sudden perturbations after which the external environment returns to its initial conditions (Arrow, Bolin et al. 1995; Holling 2001; Limburg, O'Neill et al. 2002), while others refer to external stresses as gradual but permanent change within the environment to which the system needs to adapt (Dovers and Handmer 1992; Folke, Carpenter et al. 2002; Nelson, Adger et al. 2007). This report will attempt to make the role of different stresses more explicit and explores their importance for the evolution of a system as a whole.

The report has adopted a framework developed by Stirling (2008) for exploring both issues. The framework pictures the different dynamic system properties discussed more explicitly. These are presented in the figure below.

Figure 1 Dynamic system properties of socio-ecological systems (adapted from Stirling 2008)



The framework displays two axes, whereby each axis describes a different characteristic of the system under investigation. The vertical axis describes the stress onto the system. Some systems might be prone to shocks, which are temporal disturbances to the system after which the initial conditions under which the system operates return. Examples of shocks to agricultural systems are a severe drought or a virus affecting a particular crop or animal. On the other hand, a system might face a shift. Under such conditions, the external environment in which a system operates changes permanently. This permanent change requires the system to adapt and to operate in a different way in order to deal with the change in its environment. Examples of shifts in agricultural systems are the introduction of a new technology, climate change or a permanent change in the availability of water to a region.

The characteristic of the stress is not the only dimension which is important to characterise the dynamic system properties of a socio-ecological system. As important is the response of the actors which operate within the system. The vertical axis shows different responses of actors within a socio-ecological system. On the one hand, actors can act in order to control the stress. There could be different reasons why they would act in such a way, namely because they truly believe that they have the capabilities to deal with the change to maintain the performance and function of their system over time. It could also be that the actors believe that they can control the stress although in reality they cannot. Finally, it is possible that actors pretend that they can control the stress and act accordingly, however in reality they cannot. Similarly, it is possible that actors believe, think or pretend that they can only respond to a stress. These two different ways of action, either controlling or responding to the stress, will lead to different configurations of the system and therefore different network evolutions, even if the stress in both situations would be the same.

Together these two axes can be used to explore different conceptualisations of resilience, each leading to different structures, institutions and development of the system over time. In the case where a socio-ecological system is prone to shocks and in which the actors believe, think or pretend that they can control these shocks, stable structures and institutions are favoured. An example in agricultural systems is the case where a region or country is struck by a virus. If the actors and institutions believe that they can prevent such shock the next time, they will put different measures and regulations in place to prevent the next epidemic and stabilise the system. In cases where is socio-ecological system faces shifts and actors believe, think or pretend that they are in control, structures and institutions are established that favour the durability of the system over longer periods of time that can cope with the changing conditions of its environment. An example of such case is the increasing age of farmers within rural regions and the consequences to the viability of farming. When actors attempt to control such situations, they will put in place measures, institutions and structures that will make the system durable towards these changing conditions. When socio-ecological systems face shocks which they can only respond to, for example flooding or severe droughts, structures and institutions are favoured which makes the system recover quickly and resume its original function. In this particular case, one can speak of resilience as it is used in ecosystems. Finally, in systems where actors can only respond to shifts, i.e. climate change, structure and institutions are favoured that make the system robust to any form of change in the future.

The framework is both analytical and reflexive. It allows for understanding why under particular circumstances a system will move towards stability, while in other circumstances the system will lean towards the development of structures and institutions that promote robustness. In this report, the framework is used to explore the relationship between action, structure and diversity in the context of shocks and shifts to the system. In particular, it explores three issues: 1) how do behaviours of actors in agricultural supply chains affect their dynamic system properties, 2) what is the relationship between diversity and the dynamic system properties of agriculture and 3) how does the function of the agricultural system affects its ability deal with stresses. Each of these three issues will be addressed within an experimental platform, which is based on empirical case studies of agricultural supply chains within rural regions.

The next three sub-sections discuss in more detail the different elements of our investigation. The first section briefly discusses the features of the agent-based model and how these are different from other modelling tools to explore the dynamic system properties of agriculture. The second section explores in more detail how the potency of action can be explored within the context of agriculture and the empirical agent-based model in particular. The third section discusses the temporality of change and its implications for agriculture in rural regions.

1.2.1 Agriculture in rural regions

Agriculture and regional development are central to policy making in the European Union. As such, many research groups within Europe and elsewhere have been developing quantitative modelling tools to explore the impact of policy changes and policy effectiveness with regard to agriculture and rural development. The three most common modelling paradigms are general equilibrium models, partial equilibrium models and micro-economic models. General equilibrium models include a comprehensive view of the whole economy and the flow of resources (materials, labour, finances) between the different sectors (although Walrasian CGEs are also used on a micro-level). Partial equilibrium models present a detailed representation of a single sector of the economy and micro-economic models present households, firms and investment decisions using micro data (Bartova, Gil et al. 2008). The latter approach mostly uses static data assuming no inter-temporal dependencies of decisions over time. More recently, these models have been used to look at the dynamic structural features within agriculture using longitudinal datasets to quantify the parameters in the model (Gardebroek and Oude Lansink 2008). A fourth and increasingly applied modelling paradigm is agent-based modelling (ABM). Unlike the more traditional models, ABM are simulations and as such do not provide a single solution. Instead, they explore how individual elements interact within a common environment and how these interactions affect the evolution of the system as a whole (Parker, Manson et al. 2003; Matthews, Gilbert et al. 2007).

This report uses the latter approach for the following reasons. First, a dynamic approach is required to observe how the consequences of stresses to an environment play out over a longer period of time. Second, to explore the effect of behaviours on the evolution of a system, it is pertinent that the model incorporates activities on a micro-level. Finally, in contrast to micro-econometric models, a modelling paradigm is needed that is able to cope with structural changes within the system. Micro-econometric models are based on historical longitudinal data, however stresses to the system might disrupt the structure of the system and therefore change the interactions, structure and behaviours of the agents. It is difficult to incorporate such structural changes within micro-econometric models. However, ABM are able to incorporate such changes due to their flexibility (Happe, Balmann et al. 2008).

The specific features of the ABM used for this report have been developed to incorporate several important features, which are:

1. There is no single decision making rule as is the case in most other ABM (where the common assumption is that farmers maximise household income). Instead, a portfolio of different decision rules is explored. The features of these decision rules and how they relate to the potency of action is discussed below.
2. The ABM includes farmers and all other agricultural supply chain actors within a region. As such, it includes not only the effect of farmer activities on the region, but also the economic, social and environmental effects of processors, wholesalers and retailers transforming and exchanging agricultural products within the region.
3. The agricultural supply chain structures are dynamic. Any of the supply chain actors, from farmers to processors, wholesalers and retailers, can decide to interact with different actors. As such, it allows for exploring the effects of structural changes on the dynamic system properties of the agricultural supply chains within the region.

The next two sections discuss how the ABM is used to explore the consequences of different potency of actions and different temporalities of change on the dynamic system properties of the agricultural supply chains within the region. The main focus is on the role of diversity within each of these potential states within a system.

1.2.2 Temporality of change

The vertical axis used to explore the dynamic system properties of agricultural systems represents the different stresses to which a system can be exposed to. Stresses can occur within the environment in which a socio-ecological system operates or they can affect actors or sub-elements of the system itself. From an analytical perspective, this distinction is not so important, because it is a function of the analyst’s system boundaries rather than a characteristic of the system itself. However, this distinction can be of importance when modelling the effects of stresses within quantitative modelling tools. Furthermore, this distinction between internal or external stresses can be important with regard to the potential actions of the actors involved. A second distinction, and the focus of this report, is whether the stress is temporarily or permanent. A shock is a stress which is temporary and after which the environment returns to its initial conditions (or initial dynamics). Secondly, there are shifts which transform particular parameters or dynamics indefinitely. Such shifts can occur suddenly (a characteristic of complex adaptive systems (Bak, Tang et al. 1988)) or gradually.

A shock affects the system differently than a shift. A shock disrupts the functioning of the system only temporarily, which means that the system needs to find a way to continue functioning until the disruption has ceased to exist. For example, a system might change its structure to accommodate the loss or dis-functioning of one or more of its elements. Alternative, a system might need alternative resources or customers to temporarily replace its 'normal' resources or customers. Secondly, the system needs to be able to return to its original (or most effective) functioning as soon as the shock has disappeared. These characteristics of the system, whether they reflect actors' actions or intrinsic characteristics of other elements, are distinctively different from those that are required in times of shifts. In a shift, the system needs to adapt to new circumstances and as such has to adjust the way in which it will be functioning in the future. Essentially, this means that the current system is not viable anymore and that the system has to redefine its functions and operations in the face of a changed environment. Structures might have to change, different or new elements might be required within the system or the system might have to start providing different functions in order to adapt to the new environment.

Both shocks and shifts can occur in agricultural systems and any stress can have different consequences to the system. In order to reduce the scope of this investigation, this report explores shocks and shifts to the energy and world food prices. Figure 1 and Figure 3 provides two examples of both shocks and shifts in food prices. Figure 2 shows the apple prices in different EU countries between 1991 and 2004. In some countries, the price of apples remains fairly stable (Italy and Austria, for example), but even there it is not uncommon to see fluctuations in prices up to 100% in consecutive years. In other countries, such as Greece, it shows that prices sometimes double within a 2-4 year time period after which the prices remain on this higher level. The former is an example of shocks in prices and the latter is an example of a shift. Figure 3 provides an example for fluctuations in rapeseed prices, whereby in Ireland a downward shift takes places as well as temporary shocks to the prices.

Figure 2 Changes in apple prices in different regions in the EU from 1991 to 2006 (FAO 2009)

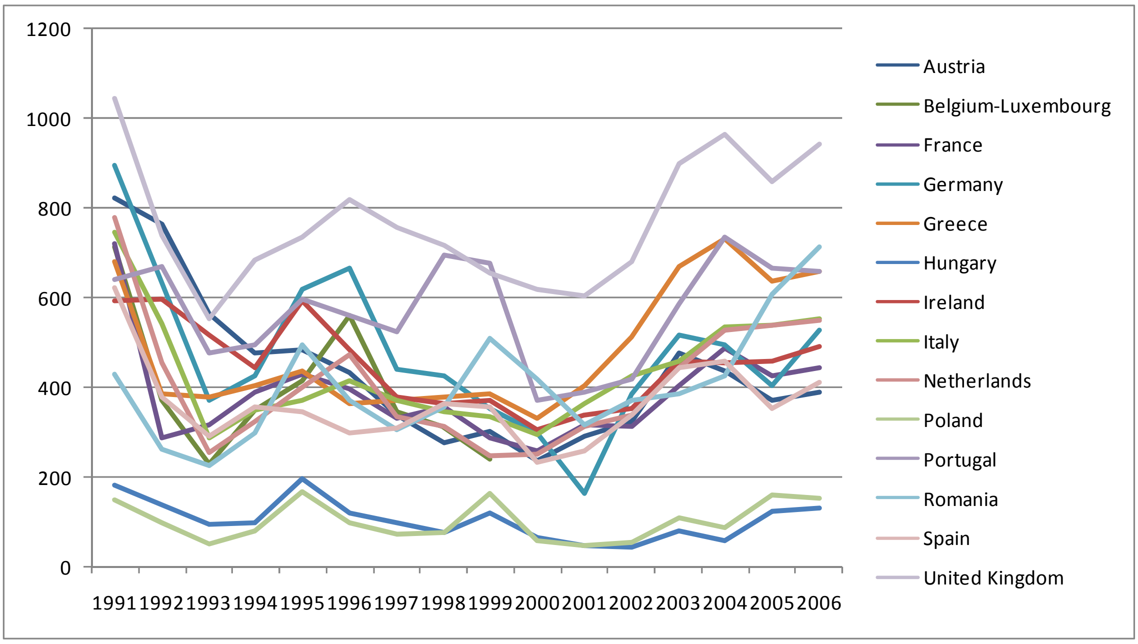
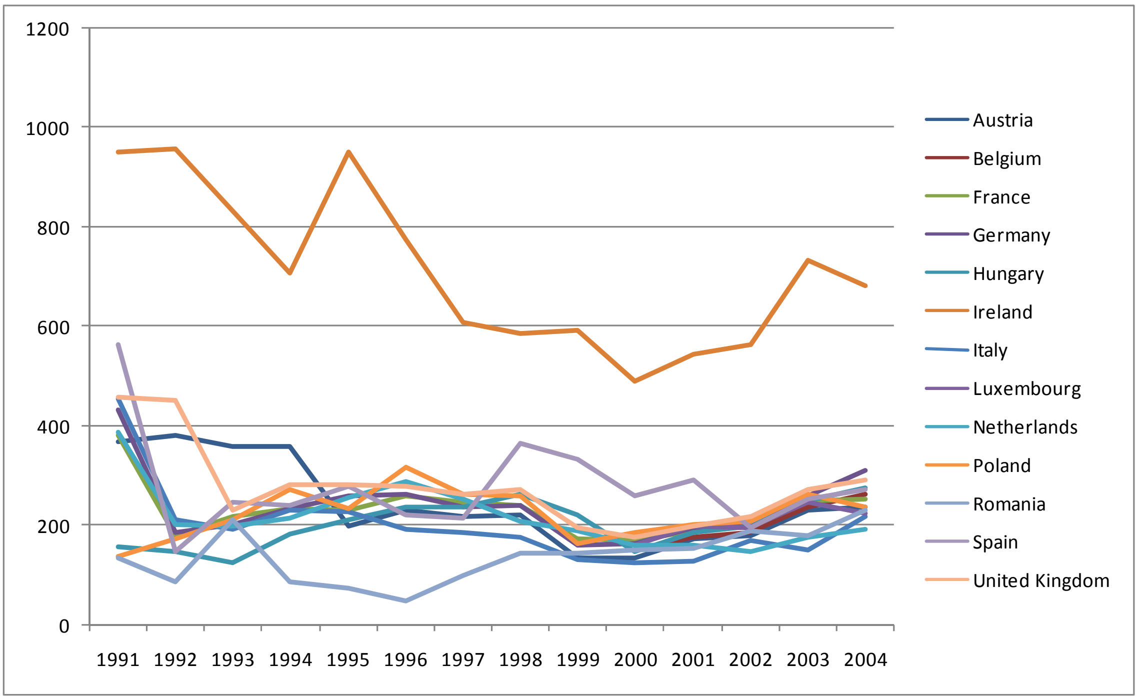


Figure 3 Changes in rapeseed prices in different regions in the EU from 1991 to 2004 (FAO 2009)



On the basis of these empirical examples, this analysis has chosen to explore the following shocks and shifts to world food prices in the case studies:

A shock to the world food prices consist of a doubling or halving of the price level over a period of two years, after which the price level returns to its initial price level and resumes its initial growth path.

A shift to the world food prices consists of a gradual doubling or halving of the price level over a period of five years, after which the price level remains on the new price level and resumes its initial growth path.

The second category of shocks and shifts take place in the energy prices, affecting not only gas, electricity and petrol prices, but also transport and fertiliser prices. During the last 30 years, there have been at least three examples (1973, 1980, 2007) where oil prices and subsequently energy prices have risen dramatically after which they returned to their original price levels (see Figure 4). More and more evidence suggests that in the next decades a fundamental shift might occur in the energy prices when peak oil becomes reality (Macalister and Monbiot 2008). A positive shock or shift in energy prices can have both, negative and positive consequences for the system depending on the actual function (performance) and structure at the time of the shock. Higher energy prices increase the price of production. This has a negative economic consequence for the producers of agricultural products, except if farmers and other supply chain actors are able to pass on these price rises to the customers in which case the effect is neutral. Furthermore, increasing energy prices make it more viable to produce energy crops. Finally, energy prices affect the transport of agricultural products making long-term transport less viable and promoting local use of products.

Figure 4 Crude oil spot prices between 1970 and 2007 (OECD 2009)

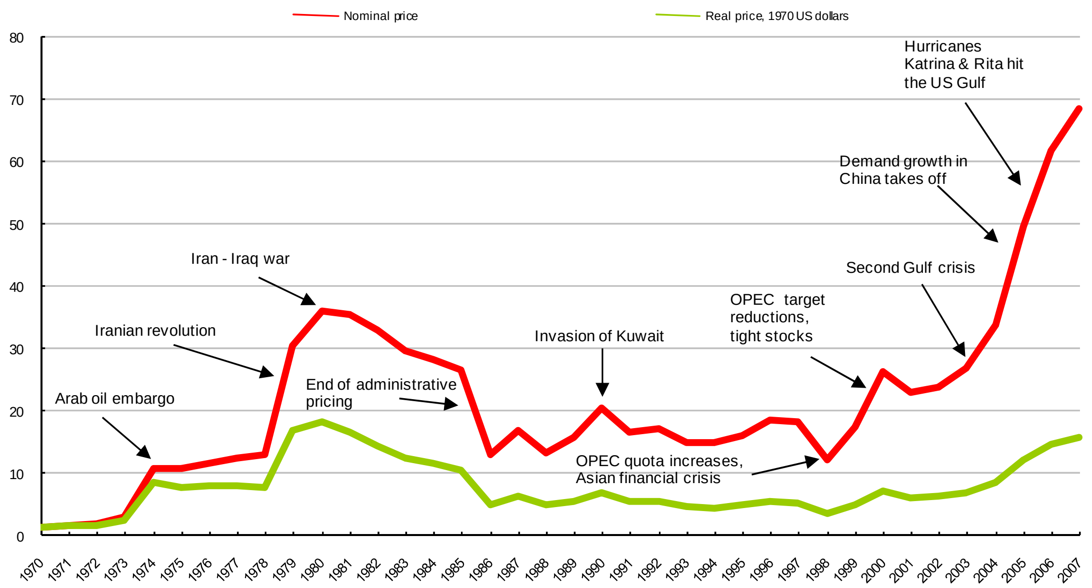


Figure 4 shows that large changes in the oil price levels are not uncommon with nominal prices tripling between 1974 and 1980 and even quadrupling between 2000 and 2007. On the basis of these empirical examples, this analysis has chosen to explore the following shocks and shifts to world energy prices in the case studies:

A shock to the energy prices consist of a tripling or 66% reduction of the price level over a period of two years, after which the price level returns to its initial price level and resumes its initial growth path.

A shift to the energy prices consists of a gradual tripling or 66% reduction of the price level over a period of five years, after which the price level remains on the new price level and resumes its initial growth path.

In this report, a shock in energy prices and world food prices will occur simultaneously, because both stresses are world-wide phenomena which are coupled and which cannot be controlled by local actors. Similarly, the shift will consist of a simultaneous change in both energy prices and world food prices.Figure 5 shows an example of the shocks. Figure 6 shows examples of a positive shock and a positive shift to the energy prices and world food prices within one simulation run. Both, the energy and world food prices grow with 5% per annum, which continues throughout the shock or shift. The difference is that the shock is temporarily and returns to its initial level (excluding the external price dynamics), while a shifts is gradual and permanent.

Figure 5 Shock introduced into the region in year 2012 with doubling world food prices and tripling energy prices.

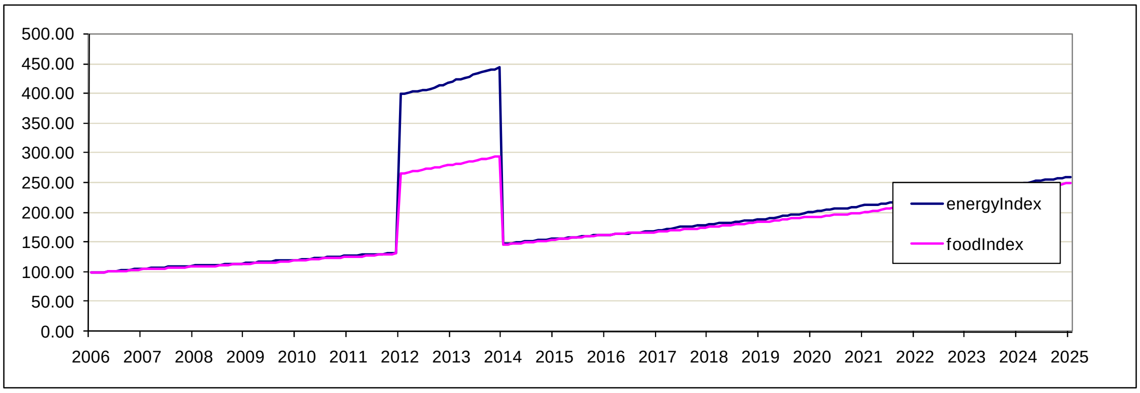
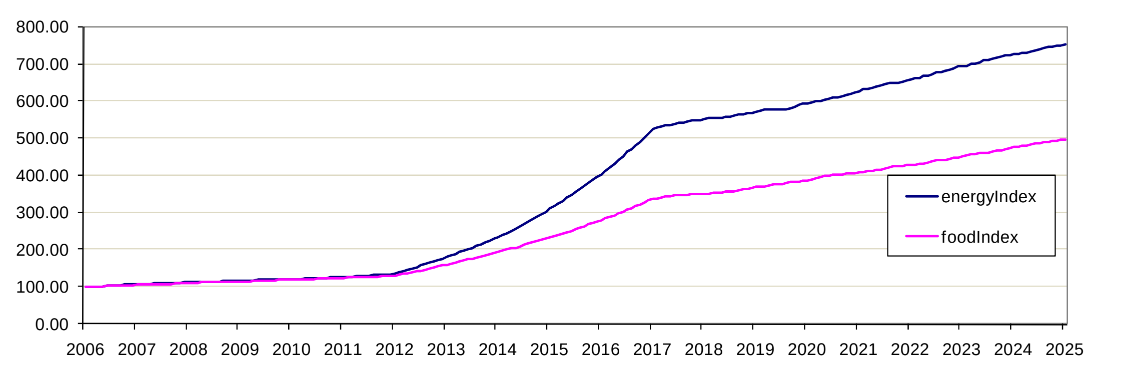


Figure 6 Shift introduced into the model in year 2012 with a gradient increase over five years in world food prices and energy prices.



Energy prices and world food prices are exogenous variables to the actors operating in a European rural region, so these variables cannot be controlled. Furthermore, it is difficult to envisage actors who would believe or pretend to control such variables at all. As such, the stresses investigated in this report are designed to explore different response actions and therefore the resilience and robustness of the system. The size, time and length of shocks or shifts can be adjusted to explore the consequences of these stresses at different point in time throughout the simulation.

1.2.3 Potency of action

With potency of action we mean the array of actions that actors within a region can undertake when faced with potential stresses to the system. The different actions possible and their consequences for the dynamic system properties of agricultural systems are expressed within the horizontal axis of Figure 1. The two extremes along the continuum are on the one hand actors that attempt to control the stress, and on the other hand actors that merely respond to stresses. Control actions attempt to block or reduce the stress. An agricultural example is the use of preventative antibiotics to reduce the chances that animals become sick. Response actions attempt to eliminate negative consequences of a stress by adjusting or adapting the structures in which they operate. Using a similar example, a response action could put in place a regulation that forbids the transport of animals across predefined borders when a disease has broken out. Both actions are ill-defined, however represent different extremes. In between, there are different combinations of actions possible, each representing a different way considering the agency of actors in directing the future performance of a system (something which is especially pertinent in socio-ecological systems).

It is also important to emphasise that the actions undertaken by actors might not be the right response towards the stress and that the intention of the action does not need to correlate with its actual effectiveness. Furthermore, there might be discrepancies between how different actors perceive the stress and the responses they regard as appropriate. Under these circumstances, the framework can be used as a reflexive tool to understand the perceptions, beliefs and actions of the actors involved.

In this report, we explore two stresses: changes in world food prices and changes in energy prices. Both stresses are external to the agricultural supply chains within the region, but affect their operation and performance. Since both stresses are outside the realm of any of the local supply chain actors and supply chain actors cannot, and cannot believe, to control such events, we only explore the relationship between 'responsive actions' and stresses. Thus, the framework used explores the relationship between different response actions within the system towards shocks and shifts and the resilience and robustness of the system as a whole. However, even in this subcategory there are a multitude of possible actions, and underlying intentions, possible, which makes it difficult to use this framework as a basis to produce predictive results for future policy consequences, especially quantitatively. Namely, it is impossible to model all potential actions because there are an unlimited number of potential stresses that could affect the performance and evolution of agricultural systems in rural regions and an almost unlimited amount of possible responses.

Therefore, one needs to narrow down the possible space of exploration by singling out one or two particular aspects of interest. We limit the scope of exploration in this report by focussing on a small number of responsive actions towards the external shocks and shifts: 1) farmers' can change their land use to accommodate for the shocks and shifts in world food and energy prices, 2) farmers' can decide to buy or sell land, and 3) supply chain actors' can decide to expand or reduce their respective processing, wholesale or retail capacity in the light of theses stresses. To explore the relationship between the perception of the actor and his or her corresponding action, different decision rule modules are explored. Each decision rule module is derived from different categories of psychological theories (see Jager 2000) and represents a different perception of the uncertainty associated with the stress. A more detailed description of these different theories and the decision rule modules is provided in the report 3.1: "Exploring dynamic system properties of agricultural supply chains in rural regions – An agent-based model". In summary, the six different decision rule modules are described below:

Table 1 Interpretation of different response actions towards shocks and shifts

Decision rule module	Description
Factual – Deliberate (FD)	A shock/shift presents a new reality and requires a response. All possible responses should be explored to see what fits the new situation.
Factual – Habitual (FH)	A shock/shift presents a new reality and requires a response. Actors are unsure about their responses and therefore choose those that they are most familiar with.
Factual – Imitation (FI)	A shock/shift presents a new reality and requires a response. Actors do not know how to respond and therefore copy the activities of other farmers operating within the region

Decision rule module	Description
Social – Deliberate (SD)	A shock/shift presents only a new reality if others respond to it. Actors only choose from those responses that 'important others' (their social network) display.
Social – Habitual (SH)	A shock/shift presents only a new reality if others respond to it. Actors only choose from those responses that important others display and which are familiar to them.
Social – Imitation (SI)	A shock/shift presents only a new reality if others respond to it. Actors choose those responses that the majority of important others choose.

The first three (factual) decision rule modules explore a situation whereby actors respond directly to changes in their environment. If a change occurs, they will explore any possible response to determine what would provide the best outcome for them. There are three ways in which they decide on which is the best response: 1) they try to maximise their individual utility (deliberate), 2) they base their decisions on previous experience (habitual), or 3) they imitate what the majority of actors are doing (imitation). Each of these three different ways of making a decision represents a different perception of the uncertainty associated with the stress. If actors are confident about the consequences of the stress, they act deliberate. If actors are unsure about the consequences of the stress, they imitate.

The last three (social) decision rule modules reflect a different way of responding to changes in the environment. Instead of exploring all possible responses to a change, actors will only contemplate those responses or actions with which they are familiar. This reflects a situation where actors place more value on what people believe the consequence of the stress are going to be; their perception of the stress and their possible responses is socially embedded. Again, the way in which they eventually decide upon one of the different responses depends on whether they behave deliberate, habitual or imitative.

The exploration of the consequences of different decision rule modules is an attempt to understand how different perceptions of changes within an environment affect agents' actions and therefore the evolution of the system over time. This framework is not used to explore whether there are any responses that are better or worse with regard to a particular stress. Furthermore, the different decision rule modules are stylised responses and are used as analytical devices to explore distinctly different evolutions of a socio-ecological system. In reality, a plurality of responses is possible, not only between actors but also from a single actor at different points in time.

2 RESEARCH METHODOLOGY

This section discusses the research methodology used to explore how the potency of action and the temporality of change affect the dynamic system properties of agricultural supply chains within a region. The focus is on the role of diversity in each of these potential states of agricultural supply chains within the region. The first section discusses the general approach used to explore the relationship between diversity, temporality of change and potency of action. The second section discusses in more detail how diversity is measured and the third section discusses the introduction of stresses to the system.

2.1 Relating diversity, potency of action and temporality of change

At any point in time, agricultural supply chains are characterised by different elements:

- The number of actors, their relationships and their activities;
- The overall function (performance) of the system;
- The state of the environment (external and internal to the system);
- Behaviours based on different decision rules.

The diversity of a system is characterised using elements from the first category: the number of elements, their contributions and their characteristics. Each of these three categories can affect the way in which the system responds to a stress. The number of actors affects the variety within the system and therefore the system's ability to deal with stresses if one or more actors would fail. The contribution of each actor affects the balance within the system and therefore its ability to deal with stresses of high magnitude and the characteristics of the different elements affect the way in which the system is able to cope with different stresses.

A system's function (determining its performance) can change over time, even if the number of actors, their relationships and their activities remain the same. The state of the system of a whole affects its ability to cope with stresses. For example, a system might be very vulnerable at the beginning of the year to a particular stress, while at the end of the year it would easily cope with the same stress despite the number of actors, their relationships and activities remaining similar.

The environment at the point of the stress also affects the system's performance. If the system is already operating on the margins, its ability to cope with stresses of high magnitude will be limited, as it is already in a critical state. However, if a system is operating in a fairly comfortable environment, its ability to cope with stresses might be higher due to available slack capacities.

The final category that affects the system's ability to cope with stresses is the behaviour of the actors within the system at the time of stress. Some behaviours might be more appropriate than others although that might not always be known to the actors at the time of the stress.

From a dynamic perspective, all four characterisations of the system are interdependent. The number of actors and their actions affect the overall performance of the system, which is simultaneously linked to the state of the environment at that particular point in time. Accordingly, the state of the system triggers particular behaviours and subsequently any of the other three characteristics of the system. As such, it is difficult to separate any of these characteristics and how they contribute to the system's ability to cope with stress.

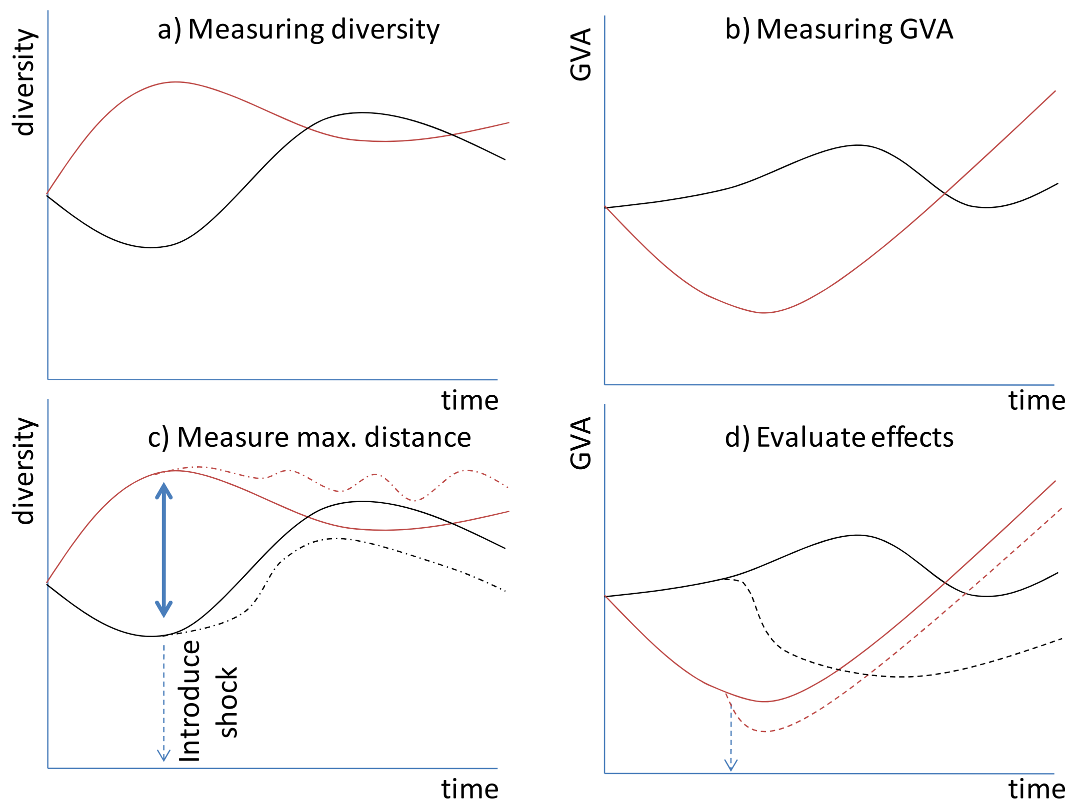
The following research methodology has been devised to understand how these different characteristics are interrelated and contribute to the system's ability to deal with stresses.

1. Each region is modelled separately. This means that the initial conditions for each exploration are the same (they are based on the 2006 data gathered by the case study authors).
2. A context scenario is developed. The context scenario specifies the characteristics of the environment of a region throughout the modelling run (in this particular case from 2006 to 2025). This context scenario is the same for any simulation run, which means that the environment remains constant for each exploration.
3. Within a single context scenario, six different decision rule modules are explored. Each decision rule module consists of a single decision rule applied to all the supply chain actors within the region. As such, within each context scenario there are six different evolutionary pathways possible whereby each pathway is a function of a particular decision rule.
4. The next step is to compare the characteristics of the agricultural supply chains at any point in time throughout the model. The characteristics of the agricultural supply chains is measured using the diversity heuristic, which incorporates the number of supply chains, the contribution of the supply chains to the overall performance of the system and the disparity between the different supply chains.

For a single region, this exploration provides us with six different performance profiles (each based on a different decision rule) and six associated diversity profiles. The environment within these different profiles has changed over time, but is comparable at any point in time along the different simulations. In other words, the environment in year 2006 is different from the environment in 2008; however, the environment in 2008 is comparable along the different simulations based on different decision modules. Furthermore, it provides us with an initial starting point where the performance, structure and environment of the region are equal. This information is subsequently used to explore the relationships between diversity, structure, action and different stresses. The comparative analysis takes place in three steps. A description of the **first step** follows:

The first hypothesis tested is that a higher level of diversity positively affects the dynamic system properties of agricultural supply chains within a region. Thus, an agricultural system should be better able to cope with stresses if the diversity of the system is higher. However, there are two other system characteristics that might affect the dynamic system properties of the agricultural supply chains: 1) the function of the system at the time of the stress and 2) the response of the actors towards the stress. Therefore, we have to assume at this stage that the function of the system and the response of the actors to the stress do not affect the dynamic system properties of an agricultural system. These assumptions will be relaxed in the following steps of the exploration. If the above mentioned assumptions hold, then those evolutionary pathways which display higher levels of diversity should be able to cope better with stresses than those evolutionary pathways with a low level of diversity. Since a shock or a shift changes the environmental conditions under which a network evolves, we have to make sure that we introduce the shock and/or shift at the same point in time throughout the model (if we would introduce shocks at different point in time, the environments are not equal to each other anymore and therefore the results could be a function of the changed environment). To keep the environment constant for any of the evolutionary pathways, we introduce the shock and/or shift at the point throughout the evolution where there is the largest difference in the level of diversity between the different evolutionary pathways (remember that each pathway is a function of a different decision rule). The approach is illustrated in Figure 7.

Figure 7 Research methodology to explore the relationship between diversity and the dynamic system properties of agricultural supply chains.



The four pictorial representations reflect the different steps in our approach. Figure 7a and Figure 7b show the different pathways for both performance and diversity which are a function of the different decision rule modules. Figure 7c shows how the different evolutionary pathways can be compared to each other to find the point in time with the highest difference between the levels of diversity measured within the agricultural system. After introducing the stress, Figure 7d shows how the performance of the evolutionary pathways can be compared to each other to explore how well each pathway managed to cope with the stress. The initial hypothesis is confirmed if the results show that a higher level of diversity leads to systems that are better able to deal with stresses.

The **second step** of the methodology explores the role of the function of the system and how it affects the dynamic system properties of the agricultural supply chain. This step explores whether the particular function of an agricultural system at the time of the stress might affect its ability to cope with such stress. To test this hypothesis, we introduce another stress at the same time but in the reverse direction. An example of a reverse stress is to introduce a 50% reduction of the energy prices rather than a doubling of the energy prices. If the function of a system at the time of the stress does not affect its dynamic system properties, then those systems with a higher level of diversity should be able to cope with both, the original stress as well as its inverse. If this assumption does not hold, one might expect that those evolutionary pathways that dealt positively with a stress would be negatively affected if the stress is reversed.

The **third step** is to explore the role of behaviour, which is represented by the different decision rule modules. Instead of introducing the stress at the point in time with the highest difference in diversity between the different evolutionary pathways, the stress is introduced at the beginning of the model run. At the beginning of the model run, the function of the agricultural system is equal for all evolutionary pathways and the environment is equal. The only difference between the different evolutionary pathways is the response of the actors within the system. If the different responses of actors do not impact on the dynamic system properties of the agricultural system, the results should show the same consequences for the performance of the system in all evolutionary pathways.

Together, these three steps provide an initial and rudimentary start for exploring the complex relationship between behaviours, system structure and system function. They form a basis for questioning some of the earlier assumptions on the relationship between these different system characteristics and they provide a testing ground on which further explorations can be built. However, none of these experiments provides exclusive evidence. Instead, the results should be used to ask further questions and to explore new avenues of research. Some suggestions for further research are provided at the end of this report.

2.2 Measuring dynamic system properties

As discussed in section 2.2.2 and 2.2.3, this report focuses on different actor responses towards shocks and shifts and its relationship with the resilience and robustness of the system as a whole. As such, a measure for resilience and robustness needs to be designed which reflects the system's capability to cope with a shock or shift to the system. Since the function of the agricultural supply chains has been defined as the total GVA contribution to the rural region, the dynamic system properties are measured with regard to the extent to which a system can maintain this function. Formal definitions of resilience and robustness within this context are provided below.

Resilience is defined as the extent to which the total GVA provided by the agricultural supply chains within the region is negatively affected by a shock in the energy and world food prices.

Robustness is defined as the extent to which the total GVA provided by the agricultural supply chains within the region is negatively affected by a shift in the energy and world food prices.

The effect of a shock and a shift on the agricultural supply chain is measured by the total difference in GVA contribution between the evolutionary pathway without the shock and the evolutionary pathway with the shock over the duration of the model run (year 2025). The difference is measured as the cumulative difference in each year divided by the total cumulative absolute value of the GVA of the evolutionary pathway without the shock. This normalisation takes place to compare runs based on different decision rule modules. It rules out any structural effects of the different evolutionary pathways at the time of introducing the shock or shift (i.e. an evolutionary pathway that has grown dramatically in the first couple of years has a different GVA profile at the time of the shock than an evolutionary pathway in which the supply chain remained relatively small) and to rule out any compensatory effects (i.e. several bad years with negative GVA balance out any good years with positive GVA). The assumption is that evolutionary pathways with positive effects on the total GVA are more resilient or robust than those evolutionary pathways with negative effects on the total GVA.

3 RESULTS OF DIVERSITY EVALUATION

This section provides results of the diversity analysis. The first sub-section displays results relating to the investigation of the relationship between diversity and dynamic system properties. Results are discussed for six different regions in Europe. The second and third sub-sections present the results for two case studies: the NUTS-3 regions of South Tyrol in Italy and West Sussex in the UK. The reason for choosing these two regions as examples for the diversity analysis is because the datasets for both models are most complete.

The results displayed in this section are based on the datasets provided by the case study authors of the regions. An extended report for each of these case study regions is provided separately. These case study authors have conducted extended interviews with different agricultural supply chain actors in the region and have gathered quantitative data on their decision making processes, their operations and their expectations about the future. In some cases, the quantitative picture of some agricultural supply chain actors is not complete, which could distort the use of these models for analysing the effects of policy interventions on the evolution of the region (a separate aspect of the modelling work, which is not the focus of this report). As such, the results in this diversity analysis should be regarded as an initial exercise for exploring the relationship between diversity, actions, structural features and dynamic system properties rather than an accurate reflection of how particular regions might respond to world food and energy stresses in reality.

3.1 Diversity, resilience and robustness

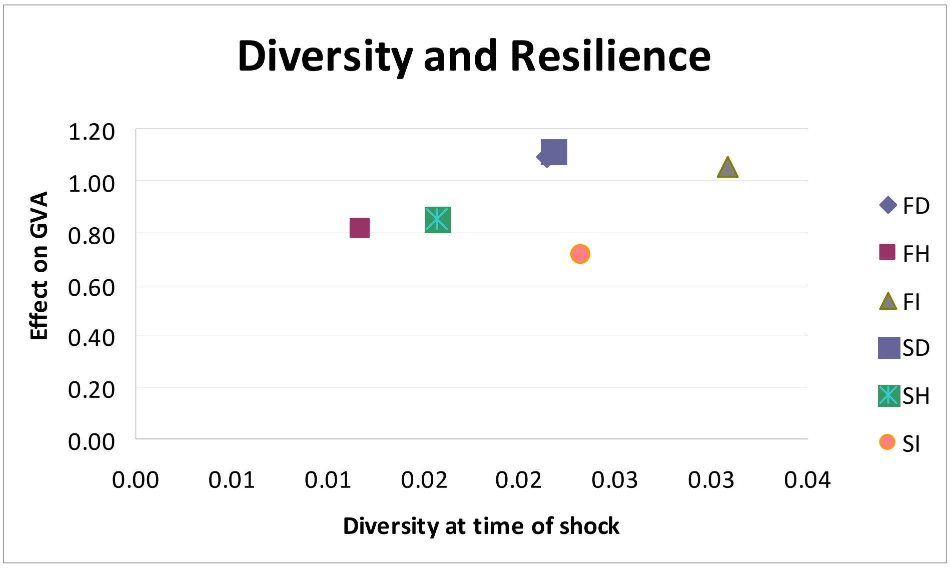
This first set of results shows the relationship between the level of diversity and the resilience and robustness for six different regions with each region having up to seven different agricultural supply chains. For each region there are two graphs. The first six graphs show the relationship between the level of diversity at the time of the shock and the effect of the shock on the total GVA. Thus, they display levels of resilience of the different regions. Six different points are displayed with each point showing the relationship between diversity and resilience for a different decision rule module within a particular region.

The time at which the shock is introduced is different for different regions, because it is introduced at the point where the difference between the lowest level and the highest level of diversity between different evolutionary pathways has been greatest. Therefore, the results of these graphs, in particular with regard to the effects of the shock, cannot be compared to each other. The extent and length of the shock has been equal for all the regions.

3.1.1 South-Tyrol

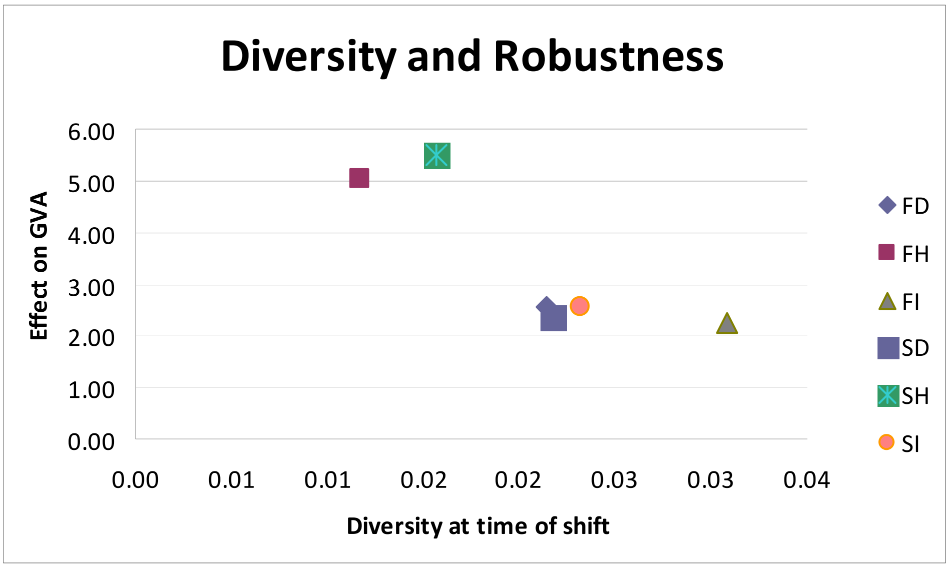
The region of South-Tyrol in Italy consists of five different supply chains; organic and non-organic production of desert apples, organic and non-organic production of grapes for wine production and speck. The latter supply chain only consists of processors converting imported pork into ham. Both, apple and wine production dominate the region's agricultural contribution to GVA. There is a possibility for wood production (included in the model), however land prices are high. The two figures below show the effects of introducing a shock and shift in energy and world staple prices in the year 2013 on the evolution of the region.

Figure 8 Relationship between diversity and resilience for the region of South-Tyrol (shock in 2013)



The robustness analysis shows the following results.

Figure 9 Relationship between diversity and robustness for the region of South-Tyrol (shift in 2013)



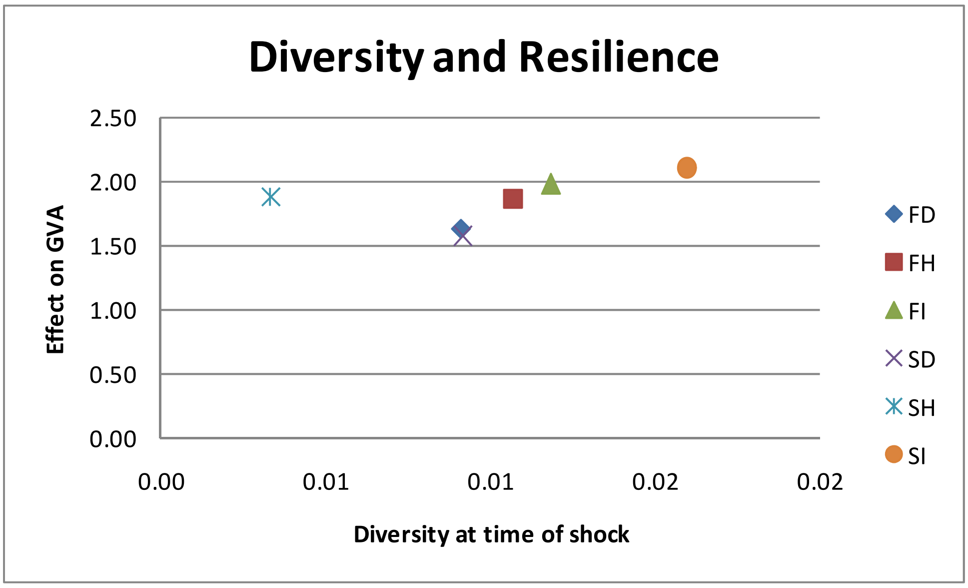
The value of diversity at the time of the shock and shift ranged between 0.013 for the FH module and 0.032 for the FI module. In all six decision modules, the shock has a positive effect on GVA. The positive effect is both a function of increased world food prices as well as supply chain actors raising their prices to accommodate for the higher energy prices. However, the effect of the shock is comparable in all different decision rule modules. There is limited evidence that there is a clear relationship between the level of diversity and the system's ability to deal with this shock. The introduction of a shift in year 2013 has a larger effect on the total GVA, since the change is permanent. In all cases, the shift has a positive effect. However, there is no evidence that those pathways with a higher diversity at the time of the shift adapted better than those systems with a lower level of diversity. In fact, the results indicate the opposite effect, whereby those pathways with a lower diversity (FH and SH) are better in dealing with the shift than the other decision modules.

3.1.2 West Sussex

The region of West Sussex in the UK consists of six different supply chains. There is winter and spring rapeseed, which is a seasonal product. There is the production of winter and spring wheat (also seasonal). Furthermore, there are a small amount of large farmers producing salad (wholeheads) with processing facilities for the production of bagged salads. Finally, there is milk production with a substantial amount of milk used for local cheese production. The region consists of mostly flat land and is close to London. There are opportunities for the production of local products for both, households and tourists. The two figures below show the effects of introducing a shock and shift in the year 2016 on the evolution of the region.

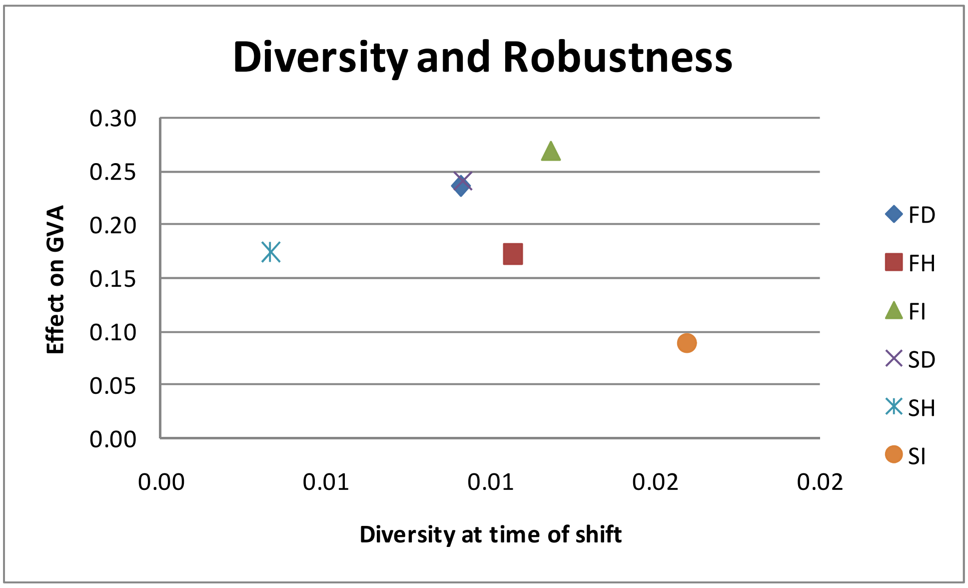
The resilience analysis for West Sussex shows the following results.

Figure 10 Relationship between diversity and resilience for the region of West Sussex (shock in 2016)



The robustness analysis for West Sussex shows the following results

Figure 11 Relationship between diversity and robustness for the region of West Sussex (shift in 2016)



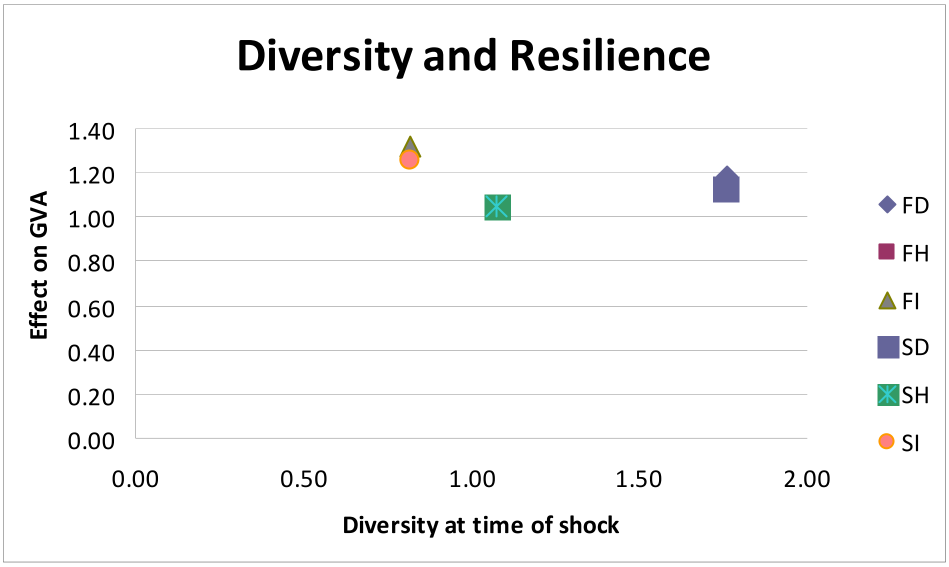
There was limited difference in the level of diversity between the different supply chains. The main reason for this is that many of the agricultural supply chain characteristics are dominated by the activities of processors, wholesalers and retailers, whose activities are not as affected by different decision rule modules as the farmers (a processor of meat cannot switch to processing of milk instantly). The results of this exploration show therefore limited support for the hypothesis that higher diversity leads to systems that are better in dealing with changes in their environment. All the six different pathways respond similar to a shock, while there is some difference in their responses to shifts. However, Figure 11 does not show a positive correlation between a higher level of diversity and a more positive response towards the shift.

3.1.3 Savoie

The region of Savoie in the south-west of France is captured in the model by four different supply chains. The region consists mostly of mountainous land and is dominated by the tourist industry. Agriculture mostly consists of milk production with about 1100 farmers producing either conventional cow milk or milk for the production of a regional specialty cheese, or goats' milk for cheese. The goat's cheese is produced locally at the farms, while the majority of milk collection and production is organised in the form of cooperatives. There is the possibility of forestry with 66 saw mills within the region. The two figures below show the effects of introducing a shock and shift in the year 2012 on the evolution of the region.

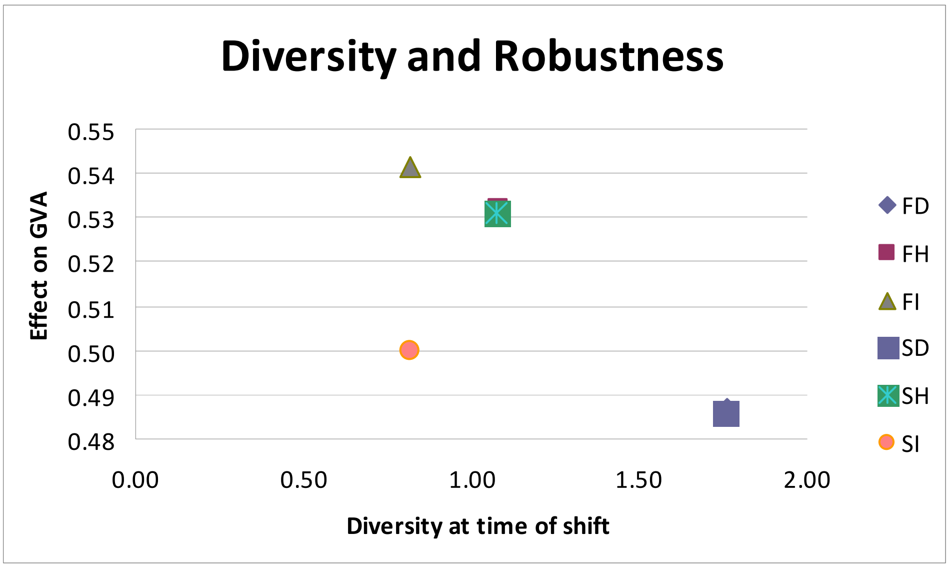
The resilience analysis for Savoie shows the following results.

Figure 12 Relationship between diversity and resilience in the region of Savoie (shock in 2012)



The robustness analysis for Savoie shows the following results.

Figure 13 Relationship between diversity and robustness for the region of Savoie (shift in 2012)



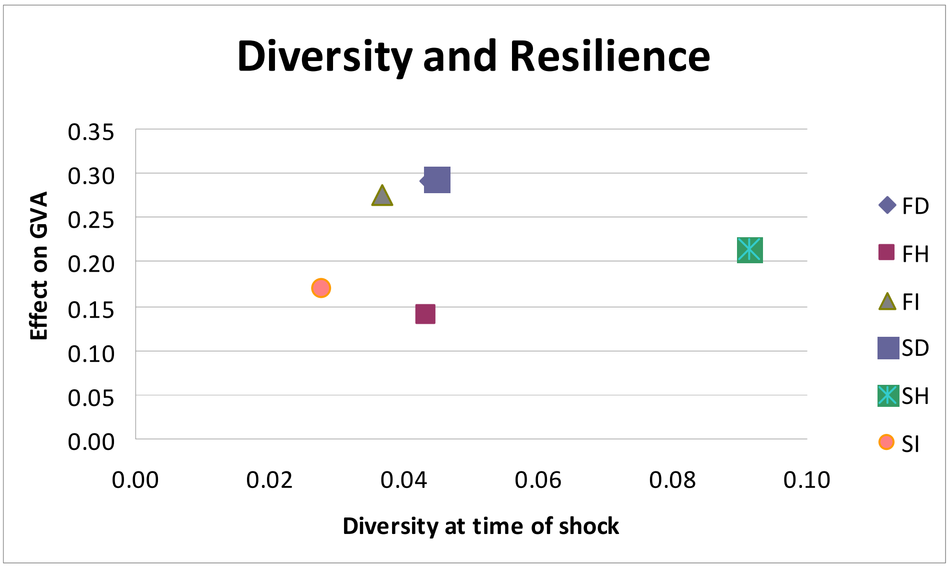
There is a large difference between the level of diversity for the decision rule modules SD and FD and the decision rule modules FI and SI. However, their resilience to the shock is equal. Furthermore, the results of the shift show that the system is positively affected by the shift, however not as much as was the case when introducing the shock. Furthermore, there is no clear relationship between the level of diversity and the robustness of the agricultural supply chains within the region.

3.1.4 Lungau

The region of Lungau is a mountainous area in Austria. The region is classified as LFA and dominated by grassland. It has limited accessibility, a low population size, is naturally diverse and has a relative high number of organic farmers (around 50%). In total, there are 1225 farmer in the region producing mainly milk, wood and local beverages (schnapps). The two figures below show the effects of introducing a shock and shift in the year 2011 on the evolution of the region.

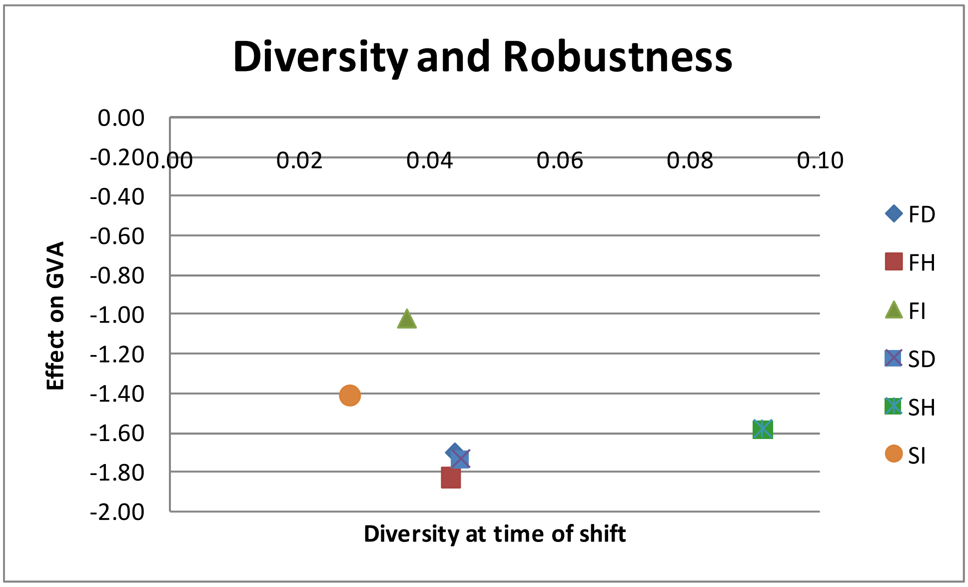
The resilience analysis for Lungau shows the following results.

Figure 14 Relationship between diversity and resilience in the region of Lungau (shock in 2011)



The robustness analysis for Lungau shows the following results.

Figure 15 Relationship between diversity and robustness for the region of Lungau (shift in 2011)



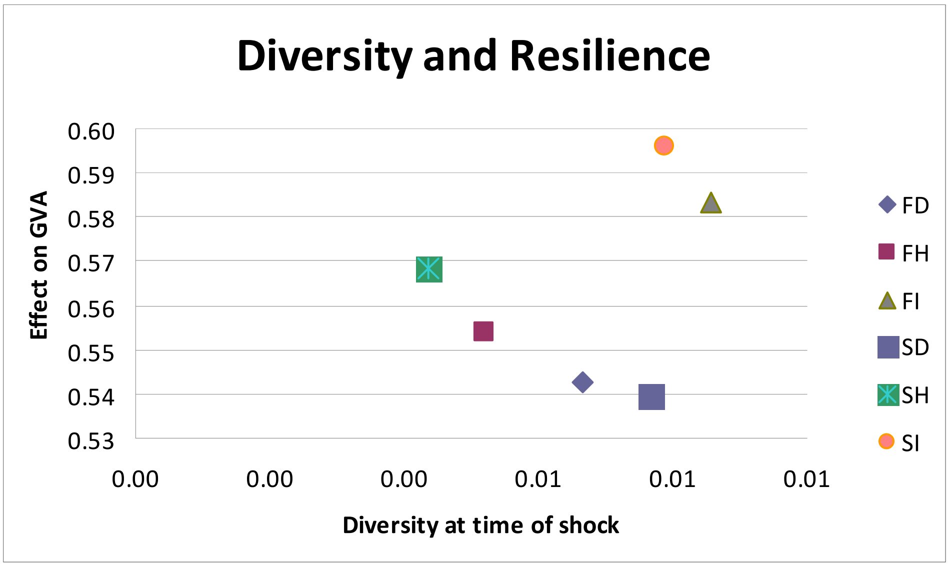
In 2011, the difference between the decision rule module SI and decision rule module SH is around 0.06. The effects of the shock are comparable for all six decision rule modules with no clear effect of diversity levels on the resilience of the agricultural supply chains. The introduction of a shift in 2011, however, has important implications for the region. While most other regions benefit from higher energy and world food prices the region of Lungau suffers, despite its use of wood for energy prices. The results do not show a relationship between the level of diversity and the resilience/robustness of the region. The decision modules FD and SD modules perform slightly better in the case of a shock, but perform worse than the other decision modules in case of a gradual shift. On the other hand, FH performs worse while faced with shocks and best while faced with a shift. This is a controversial finding, since one would assume that 'habitual' modules would be better in coping with shocks than shifts (since shocks are not permanent and return to their equilibrium), while 'deliberate' modules should better in coping with shifts (since shifts require adaptation). Further research and modelling investigations are required to analyse the exact reasons for these results.

3.1.5 Chelmsko-Zamojski

The region of Chelmsko-Zamojski is situated in the Eastern part of Poland. It consists of high fertile land on which a large range of agricultural products is produced. The agricultural supply chains that have been explored within the case study are beef, milk, rapeseed and hop. Furthermore, there is the possibility for forestry. The region is dominated by arable land, but the amount of ha per farmer is very small. The two figures below show the effects of introducing a shock and shift in the year 2007 on the evolution of the region.

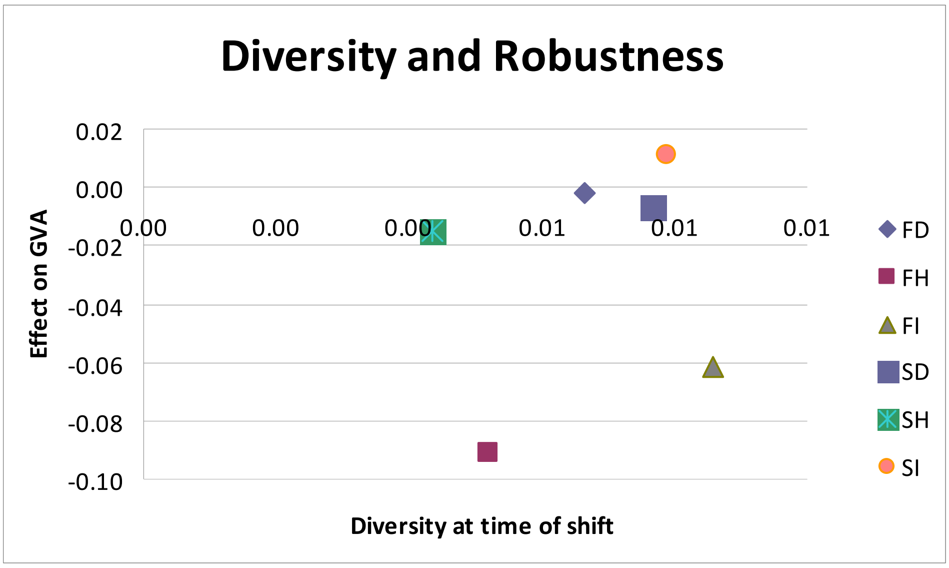
The resilience analysis for Chelmsko shows the following results:

Figure 16 Relationship between diversity and resilience in the region of Chelmsko (shock in 2007)



The robustness analysis for Chelmsko-Zamojski shows the following results:

Figure 17 Relationship between diversity and robustness for the region of Chelmsko (shift in 2007)



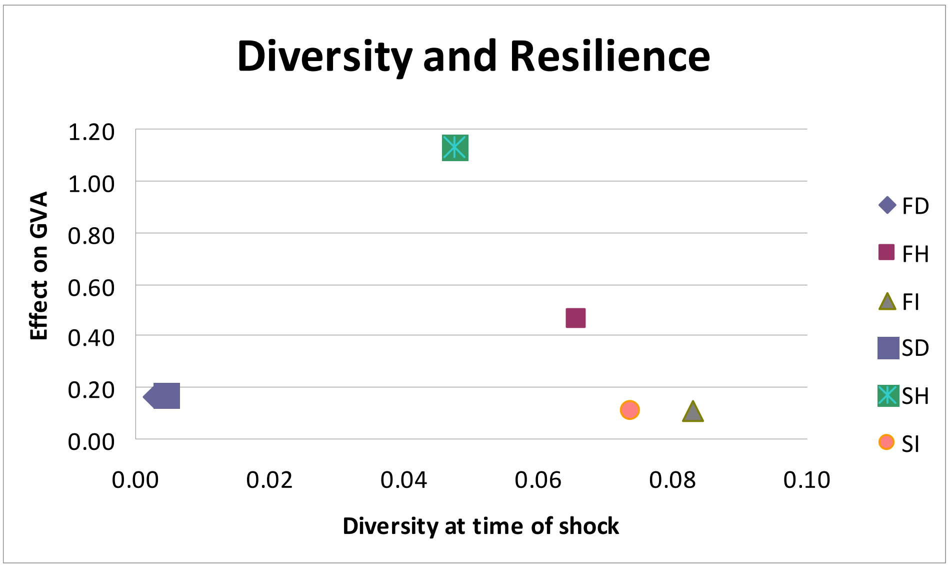
In Chelmsko-Zamojski, as was the case in West Sussex, the agricultural supply chains are dominated by activities of local processors, wholesalers and retailers. Alternative land use decisions have, although important implications for the land, no significant influence on the diversity of the agricultural supply chains as a whole. Therefore, the difference in the level of diversity between the different evolutionary pathways is small. The introduction of the shock has positive effects for all decision rule modules, but there is no positive correlation between the level of diversity of the pathways and their resilience. The introduction of a shift has mostly negative impacts for the performance of the agricultural supply chains. Except for the SI decision rule module, all other pathways perform worse. Again, there is no correlation between the robustness of the agricultural supply chains and the level of diversity.

3.1.6 Murcia

The region of Murcia is located in the South-East of Spain on the Mediterranean coast. Murcia has a large tourism industry, which initially dominated the coast line but has extended to the countryside. Murcia is characterised by a dry climate and a lack of water self-sufficiency: around 20% of the arable land is irrigated. A large variety of crops is produced in the region ranging from grapes in vineyards to citrus fruits, olives and cereals. However, the focus of the case study are three of the dominating agricultural supply chains within the region; tomatoes, salad and pork. The two figures below show the effects of introducing a shock and shift in the year 2021 on the evolution of the region.

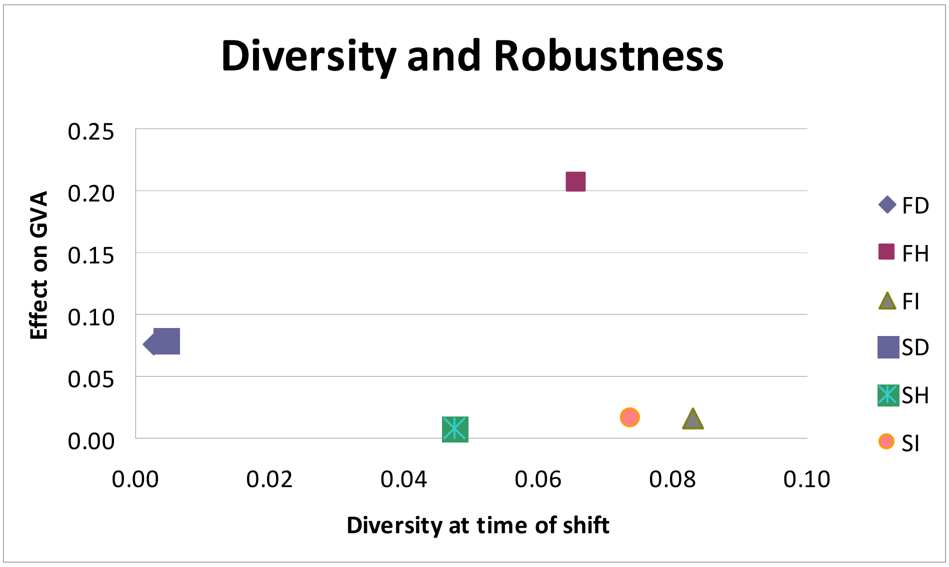
The resilience analysis for Murcia shows the following results.

Figure 18 Relationship between diversity and resilience in the region of Murcia (shock in 2021)



The robustness analysis for Murcia shows the following results:

Figure 19 Relationship between diversity and robustness in the region of Murcia (shift in 2021)



The level of diversity in year 2021 is 0.08 with the ‘deliberate’ modules having lower levels of diversity than the ‘imitation’ modules. The most resilient system is the evolutionary pathway based on the SH module, which has an average level of diversity at the introduction of the shock. The effects of the shift are positive, however, there is again no direct correlation between the level of diversity and the robustness of the supply chains. The ‘deliberate’ modules have the lowest diversity levels and the 'imitation' modules have the highest level of diversity. However, it is the FH decision module which is most robust.

3.1.7 Preliminary conclusions

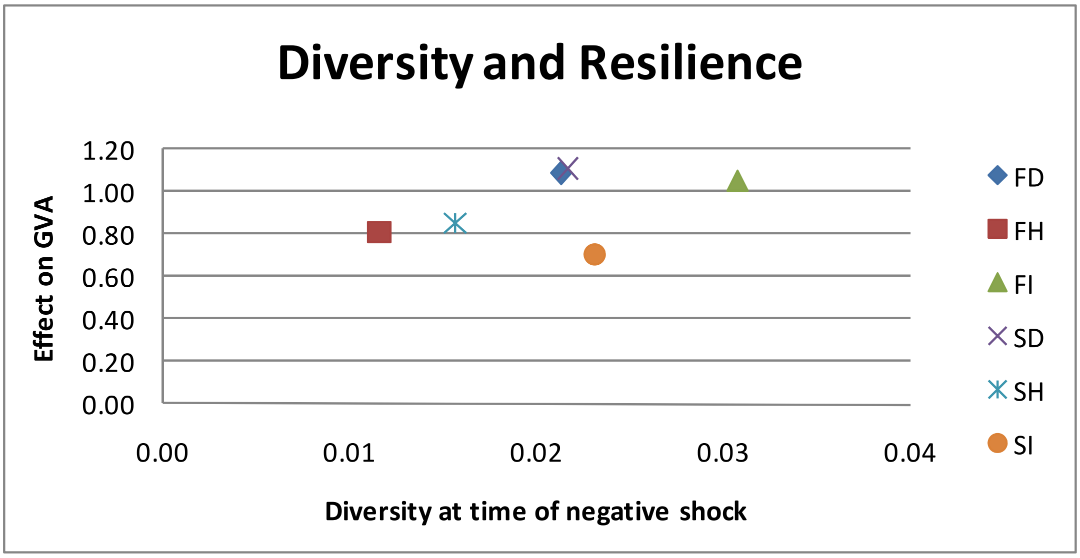
Six case studies of different rural NUTS 3 regions within Europe have been used to explore the relationship between the level of diversity and the resilience and robustness of the agricultural supply chains within those regions. The initial hypothesis tested is that systems with higher levels of diversity are better able to deal with shocks and shifts to the system. This hypothesis has been tested for each of the regions individually, since the actual effects of shocks and shifts are incomparable between the regions due to their structural differences. The results show no or limited relationships between the level of diversity at the time of the stress and the consequences for the system. This suggests that two other factors might influence the system's ability to cope with stresses: 1) the structure and function of the system at the time of the stress, and 2) the behavioural response of the actors within the region. The next two sections will explore each of these two factors individually. Section 4.2 explores the effects of functional and structural features on the resilience and robustness of agricultural supply chains, while section 4.3 explores the behavioural aspects.

3.2 Functional features, resilience and robustness

In the following, we explore the relationship between the functional features of agricultural supply chains at the time of the stress and its consequences for the resilience and robustness of the system. The functional characteristic of the agricultural supply chains is defined as the overall performance of the agricultural supply chain at any point in time. It should be noted that different structural features (as captured by the diversity heuristic) can provide the same functionality, while simultaneously different functionalities can be provided with systems that display similar structural features. Since both, function and structure can influence the performance and therefore evolution of a system, both characteristics are explored separately. The case studies of West Sussex and South-Tyrol are used as examples, since these two case studies provide the most detailed information about the different agricultural supply chains.

The following exercise is conducted. The shocks and shifts that have been introduced in the model in section 4.1 are reversed. This means that instead of a doubling of the world food prices and a tripling of the energy prices, a reduction of 50% and 66% in the price levels take place. The tested hypothesis is that functional features do not play a role in the resilience and robustness of agricultural supply chains (the structural features using the diversity heuristic are kept equal). If this hypothesis is true, then a change in the direction of the shock or shift should not give any conclusions about the resilience or robustness of the system. Thus, if an evolutionary pathway is resilient towards a positive shock, it should also show resilience when faced with a negative shock. Similarly, if an evolutionary pathway showed high robustness towards a positive shift, it also should show highest robustness towards a negative shift. The next four figures explore whether these assumptions hold in the case study of West-Sussex and South-Tyrol.

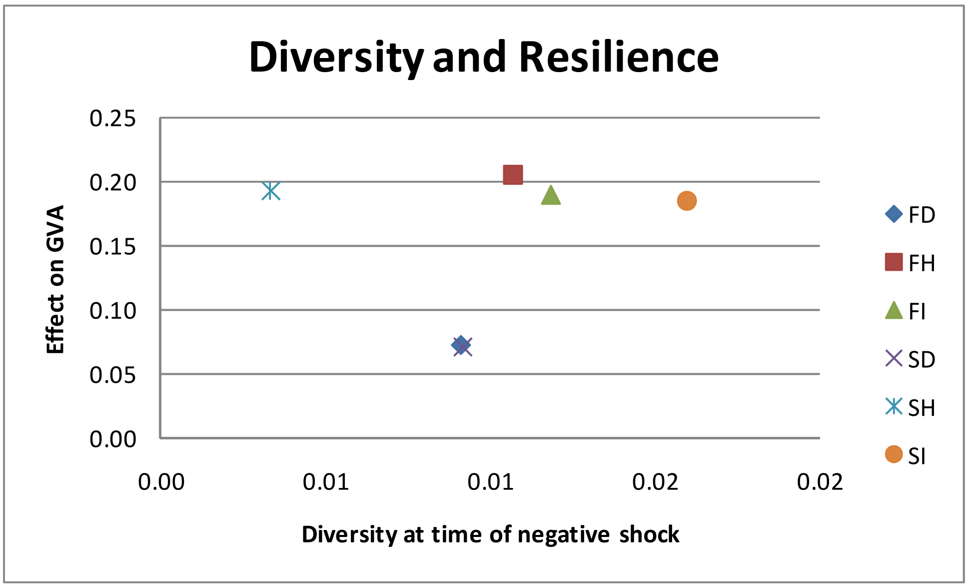
Figure 20 Effects of a negative shock to the resilience of the region of South-Tyrol (shock in 2013).



The results of Figure 20 should be compared with the results in Figure 8. In both figures, the decision rule modules FD and SD show the highest resilience, although they do not have the highest level of diversity within the system. The decision module SI shows the lowest resilience in both figures, although it does not have the lowest level of diversity. These results suggest that not the level of diversity or the structural and functional features at the time of the stress are of importance to the resilience of the system, but that instead the behavioural response is the most important influence. The results for a similar exercise for the region of West Sussex are shown in the next figure.

The results in Figure 20 do suggest a correlation between diversity and resilience, which can also be observed in Figure 8. However, the fact that in both cases SI underperforms in comparison to any of the other decision rule modules still support the conclusion that decision rule modules are more dominant than the level of diversity within the system.

Figure 21 Effects of a negative shock to the resilience of the region of West Sussex (shock in 2016)



The results of Figure 21 should be compared with the effects of a positive shock, which are displayed in Figure 10. While in the case of Tyrol the effects of either a negative or positive shock to the agricultural supply chains were similar, the results for West-Sussex show that a negative shock has in all decision rule modules a much lower positive effect on the GVA (on average 0.2 for the negative shock and 2 for the positive shock). It also shows that the comparative order of resilience between the 'imitation' and 'habitual' modules only changes slightly (the FH module seems most resilient in the case of negative shocks). However, the 'deliberate' modules show varying results. These modules are most resilient in the case of a positive shock, but are less resilient in the case of a negative shock, which suggests that the function does affect the resilience of the systems.

The next two figures show the results for robustness in the case studies of South-Tyrol and West Sussex.

Figure 22 The effects of a negative shift on the robustness of the region of Tyrol (shift in 2013)

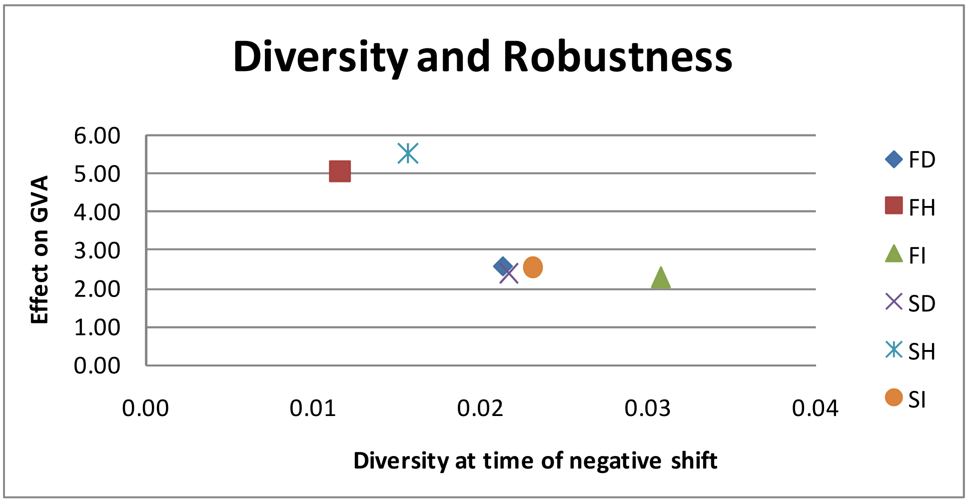


Figure 23 The effects of a negative shift on the robustness of the region of West Sussex (shift in 2016)

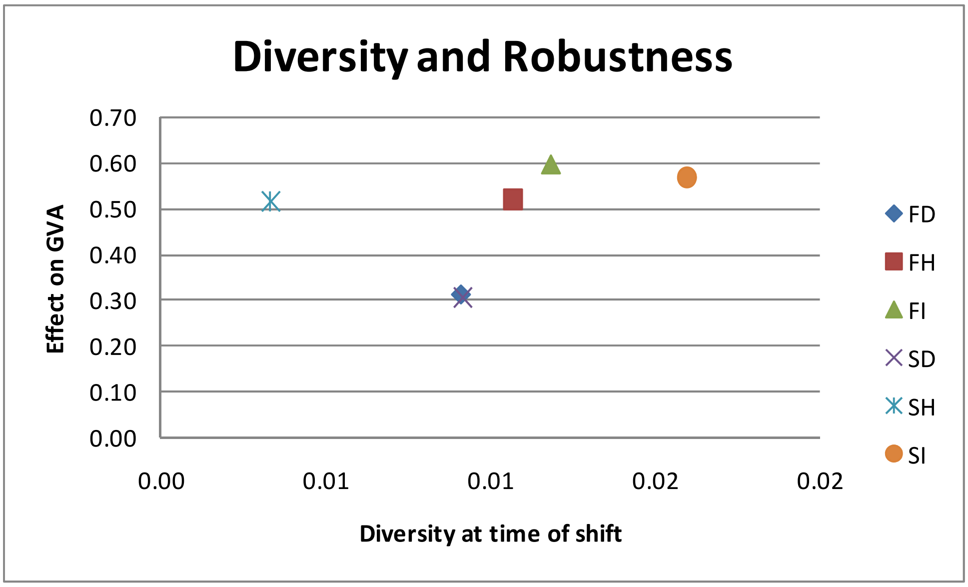


Figure 22 should be compared with Figure 9, while Figure 23 should be compared with Figure 11. In the case of South-Tyrol, the decision rule modules FH and SH show the highest level of robustness under both positive and negative shifts, although they have the lowest levels of diversity. Again, this suggests that decision rule modules are a determining factor in the robustness of agricultural supply chains. In the case of West Sussex, the FH decision rule modules score most robust in both positive and negative shifts, despite its lowest level of diversity. However, the other decision rule modules do no show consistent results. Again, the FD and SD decision modules perform well when faced with positive shifts, but worse when faced with negative shifts, while SI performs robust under negative shifts and not robust under positive shifts. These results suggest that decision rule modules are not the sole determinant in the resilience and robustness of agricultural supply chains. Furthermore, these results have shown that there is a limited relationship between the diversity of the agricultural supply chains and their ability to cope with stresses.

3.3 Response actions, resilience and robustness

This section explores the relationship between the decision rule modules that actors use with regard to dealing with changes in their environment and the effects of those modules on the resilience and robustness of the agricultural supply chains. To test this relationship, the level of diversity and the function and structure of the different evolutionary pathways should be equal to each other. Therefore, this section shows the results whereby positive and negative shocks are introduced at the start of the model run (January 2006).

The next eight figures show the results of this experiment for the regions of West Sussex and South-Tyrol. The first four figures show the results for a positive and negative shock introduced, while the latter four figures show the results for both, positive and negative shifts.

Figure 24 Effect of positive shock in 2006 on resilience of the region of South-Tyrol

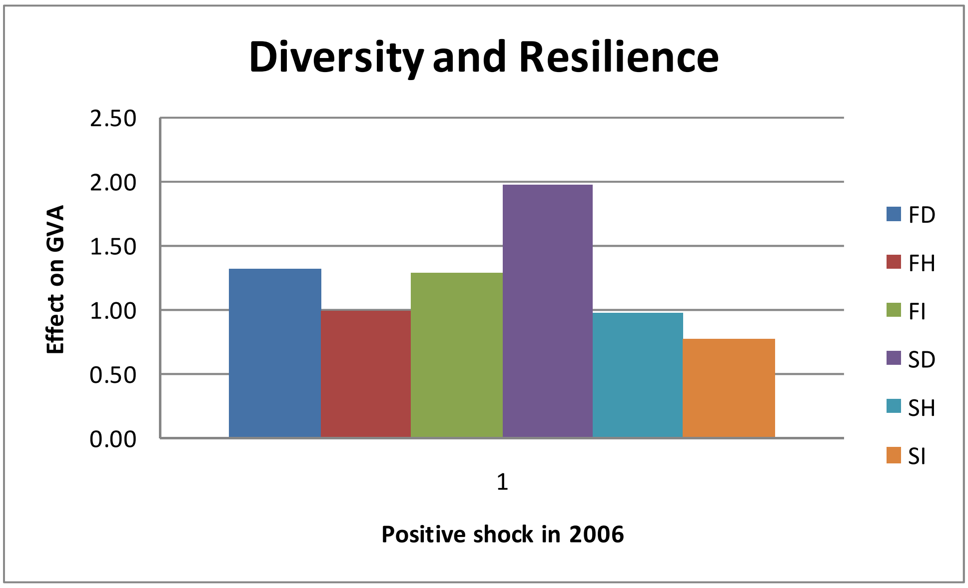


Figure 25 Effect of negative shock in 2006 on the resilience of the region of South-Tyrol

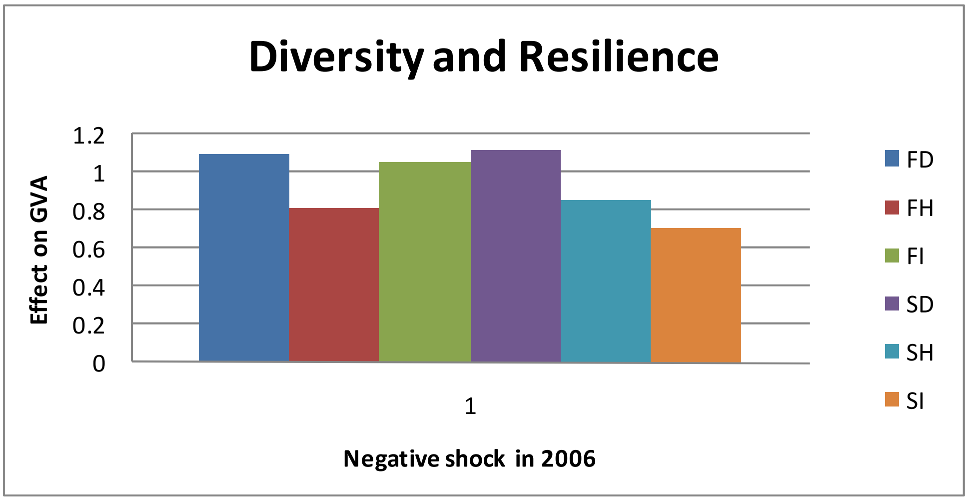


Figure 26 Effect of positive shock in 2006 on the resilience of the region of West Sussex

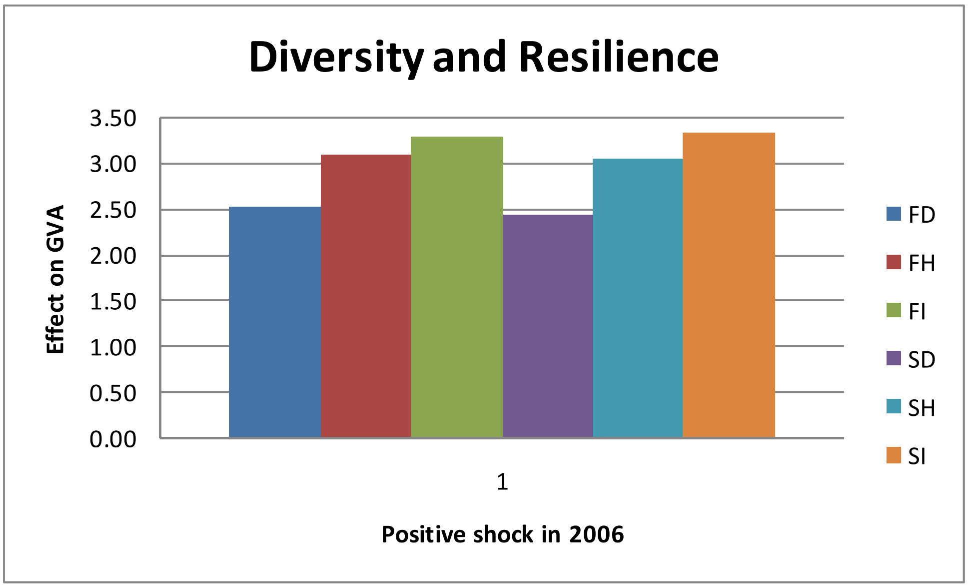
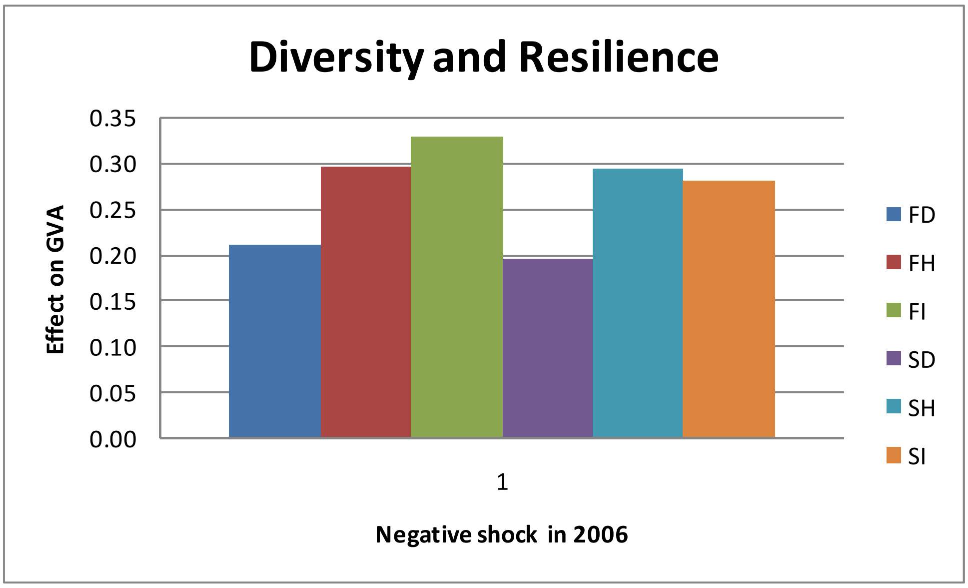


Figure 27 Effect of negative shock in 2006 on the resilience of the region of West Sussex



These four figures show that there is no single decision rule module that provides highest resilience for shocks to the system. The results show that although the diversity and function are similar at the time of shock, positive or negative shocks do change the resilience associated with the different decision rule modules (especially in the case of West Sussex). Furthermore, in the case of Tyrol, the 'deliberate' modules provide highest resilience for both positive and negative shocks, while these same modules provide the worst resilience in the case of West Sussex. This suggests that the function and structure at the time of the shock, which is only different between the different regions, affects the resilience of these systems. These observations suggest that other elements play a role in determining the resilience of systems. One hypothesis is that the actual range of choices available to actors at the time of the stress affects the resilience of the system. Furthermore, one should consider potential lock-in situations (which are incorporated into the models), which can affect the resilience of the system. Thus, actors that make a choice in the face of a stress might lock themselves into particular activities over long periods of time (i.e. development of a vineyard), which in hindsight reduces the resilience of the system.

Figure 28 Effect of a positive shift in 2006 on the robustness of the region of South-Tyrol

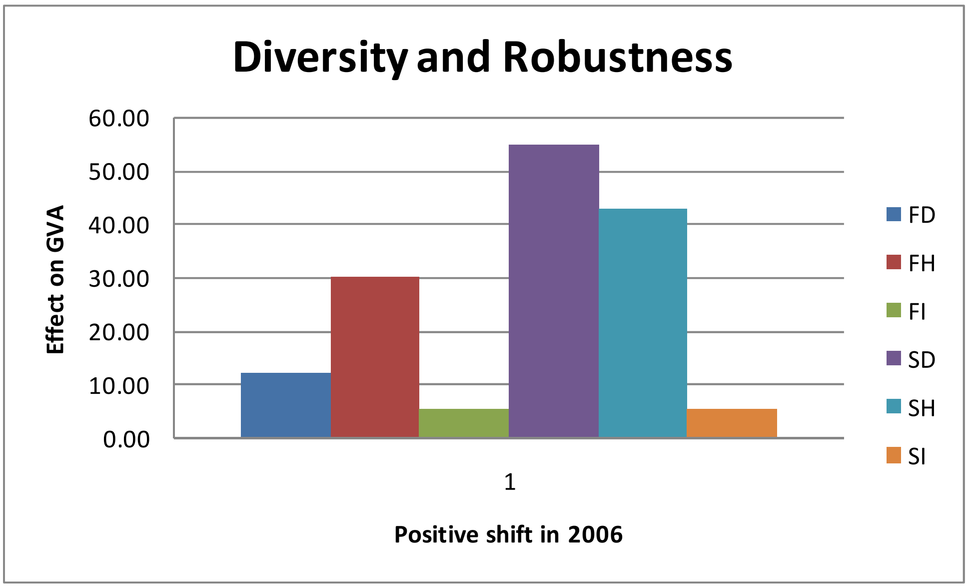


Figure 29 Effect of a negative shift in 2006 on the robustness of the region of South-Tyrol

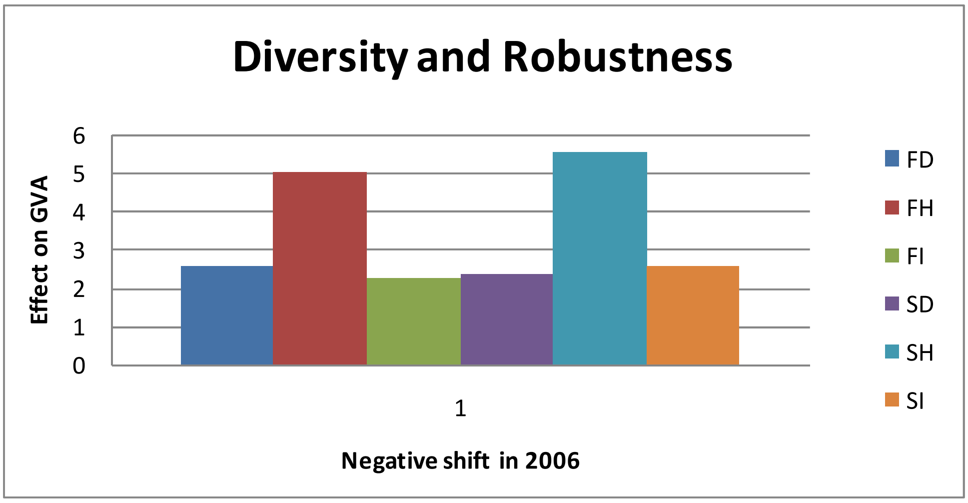


Figure 30 Effect of a positive shift in 2006 on the robustness of West Sussex

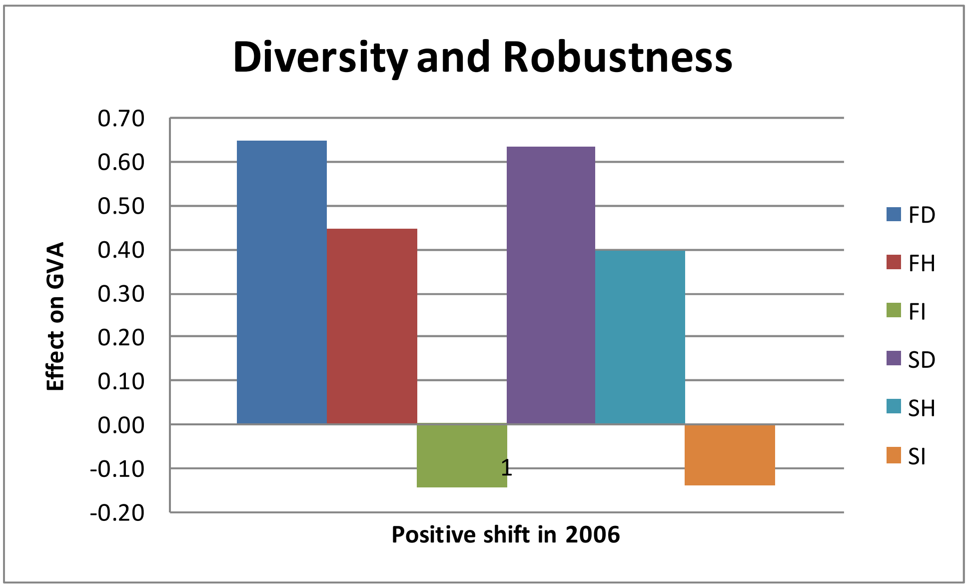
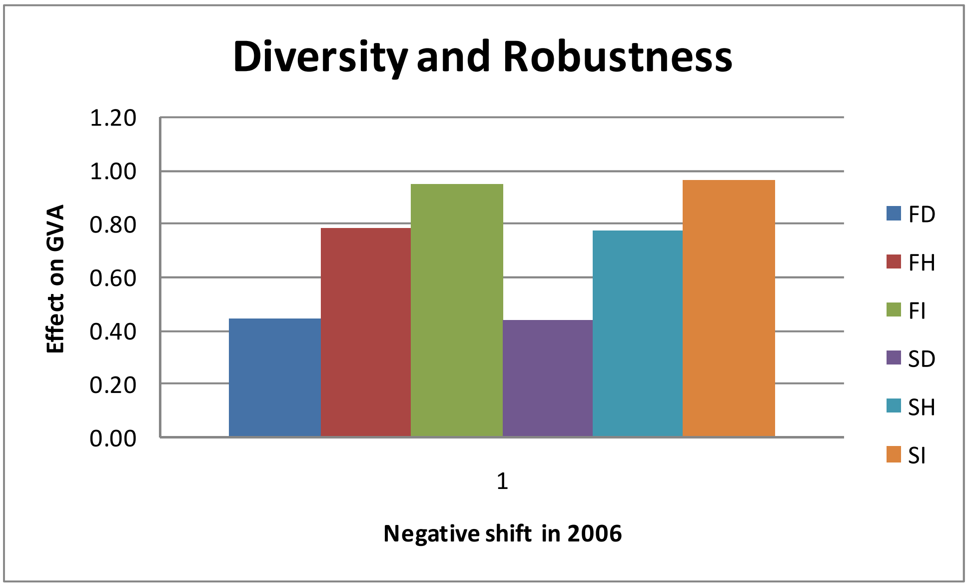


Figure 31 Effect of a negative shift in 2006 on the robustness of West Sussex



Similar to the previous exercise, Figure 28 to Figure 31 show that there is no consistency between the different decision rule modules within a particular region and their effect on the robustness of the system. In South-Tyrol, decision rule module SD provides highest robustness for positive shifts, while decision rule module SH provides the lowest level of robustness. In West Sussex, the 'deliberate' modules provide highest robustness for positive shifts and the 'imitation' modules affect the performance of these systems negatively. The results are the opposite for the negative shift, where the 'imitation' modules outperform the 'deliberate' modules.

Taken together, these results suggest that the interaction between decision rules, their effect on the function (or performance) of the system and the subsequent effects of the performance on future decisions plays an important role with regard to the resilience and robustness of agricultural supply chains. Thus, it is the interaction between function and decision rules that provides a system's ability to cope with stresses. The results show a limited role for structural features as measured by the diversity heuristics. However, this could be tested further by experimentally changing the initial structural features of the different supply chains within a region, while keeping the decision rules constant. This additional experiment has not been conducted within the scope of this project, because it would require the development of a method that can systematically relate structural agricultural supply chain features to a range of diversity levels.

4 CONCLUSIONS

This report explores the relationship between the diversity of agricultural supply chains and the dynamic system properties of these systems. Using an empirical based agent-based model of agricultural supply chains in six different regions, it presents an experimental platform to test the effects of diversity, behavioural responses and the function of agriculture (the way in which it is organised and contributes to the region) on the systems' ability to cope with shocks and shifts to the system.

The report has two major contributions. The first contribution consists of operationalising the theoretical discussion on the role of resilience and diversity in socio-ecological systems, with empirically grounded case studies of agricultural systems in rural regions. The second contribution is the development of a methodology for exploring the relationship between diversity, actor behaviour and functionality within an agent-based modelling framework.

4.1 Operationalising diversity and resilience

The terms 'diversity' and 'resilience' are often referred to as desired characteristics for agricultural systems in a rural setting, both in developed and developing countries. With increasing uncertainties due to climate change, changing trade flows due to globalisation and an increased pace of technology development and transfer, these concepts have recently become dominant issues in theories on rural development (Ellis and Beggs 2001).

This report offers an operationalisation of these concepts in the context of agricultural systems in rural regions. Diversity is measured using Stirling's (2007) diversity heuristic. This heuristic is applied on an agricultural supply chain level using Gross Value Added (GVA) as the functional unit for measuring regional performance. This means that diversity of the system is determined by (a) the number of agricultural products produced within the region, (b) the contribution of each supply chain to the overall regional performance, and (c) the difference in structural and economic, social and environmental characteristics of each supply chain. The choice for supply chains as unit of analysis allows for incorporating the effects of changing supply chains structures in the diversity heuristic and makes it possible to relate the quantitative results of the diversity heuristic and the structure of the agricultural system.

There are two qualifications to its universal applicability of the supply chain focus in comparison to measuring diversity in a farm level. First, there is a loss of information with regard to the diversity of individual farmers and other supply chain actors that could have an impact on the dynamic system properties of rural regions. Second, the diversity heuristic only considers the contribution of the agriculture-related sectors to the dynamic system properties of the region and does not consider the contribution of non-agricultural sectors like the building industry and services.

The concept of resilience has been operationalised using a theoretical framework developed by Stirling (2008), which suggests that the dynamic system properties of a system depends on the actors' perceptions, and base on these, their beliefs and intentions with regard to the stresses a system could face (see Figure 1). This report focused on actors' responses to stresses that are outside the sphere of influence. Examples of such stresses are climate change, global political changes, international trade issues or worldwide pandemics. In the context of agricultural systems, two categories of stresses were distinguished. On the one hand, there are shocks (positive and negative) which occur instantly and can take up to two years. After this period, the systems environment returns to its original conditions and dynamics. Shifts, on the other hand, occur gradually over a period of five years and permanently change the environment in which the actors operate. Actors can respond differently depending on how they view the environment in which they operate. If they view their environment as certain and a 'true' reflection of the conditions in which they operate, they will instantly respond to changes to their environment. If they view their environment as highly uncertain and unpredictable, they will be reluctant to change and will base their responses on the information and cues they receive from peers.

A range of such behavioural responses to changing environmental conditions were explored. This project shows that different conceptualisations of these behavioural responses (in the form of decision rule modules) lead to radically different evolutionary pathways, which suggests that framing actors' responses is an important determinant in understanding the dynamics of agricultural supply chains. So far, it has very often been assumed that all actors use similar behavioural responses, which is not necessarily the case in real-world situations. An extension of this work could include a representative distribution of different behaviours among supply chain actors in particular regions to show their potential consequences for the evolution of these systems.

4.2 Diversity and dynamic system properties

The second contribution of this project is the development of an experimental platform and procedure for exploring the relationship between diversity and dynamic system properties (of socio-ecological systems). This section discusses this procedure and results and some limitations of the study are highlighted. The final section concludes with some recommendations for future research.

Agricultural systems are conceptualised as complex adaptive systems. Actors are autonomous and their decisions affect not only their individual performance but also the performance of actors around them. The cumulative result of actors' decisions is the region's function at any point in time. From a dynamic perspective, their interactions, both, horizontally within their sector (farmers, processors, wholesalers and retailers) and vertically along the supply chain, change the system's structures and can affect the system's performance and its ability to cope with future changes. Finally, due to lock-in effects and interdependencies, small changes in land use and/or investments in processing capacities can have long-term effects on the systems' performance and its evolutionary pathway. All of these three elements (the systems' function, its structure and the behavioural choices of actors) are interdependent.

This project suggests a methodology to explore some of these interdependencies within a dynamic framework. The methodology is based on three experimental steps, whereby each step tests a particular hypothesis derived from previous work on the role of diversity in ecosystems and socio-ecological systems. The three hypotheses are:

H 1: The **level of diversity** has a positive impact on the resilience and robustness of agricultural systems.

H 2: The **function (and thus also performance)** of agricultural supply chains at the time of a stress do not impact the resilience and robustness of these systems.

H 3: **Behavioural responses** towards stresses determine the resilience and robustness of agricultural systems.

These three hypotheses were falsified using the regional case studies as context for exploration. The level of diversity seems not to be a determinant for the resilience and robustness of supply chains. However, behavioural responses do not seem to determine the dynamic system properties of agricultural supply chains either, although the dynamic system properties vary widely depending on what decision rule module is implemented. In other words, the effect of stresses is largely dependent on what decision rules are employed, however there is no single decision rule that provides higher resilience or robustness in all case studies. Finally, the results show that the performance of the system at the time of the stress does impact the resilience and robustness of the system.

The first hypothesis was tested using six different case studies of rural regions in Europe. The results show no or limited relationships between the level of diversity at the time of the stress and the consequences for the system. This suggests that two other factors might influence the system's ability to cope with stresses: 1) the function of the system at the time of the stress, and 2) the behavioural responses of the regional actors. Furthermore, it is also shown that changes in land use have only limited effects on the overall diversity levels within the agricultural systems. An important influence on the diversity levels is the processing, wholesaling and retailing capacities within the region. Changes in these stages of the agricultural supply chain show often substantial impacts on the overall diversity of the agricultural system in the region.

The second step explored the impact of a systems' function on the resilience and robustness of agricultural systems. We assumed a system's function, defined as the overall performance of the agricultural supply chain at any point in time, did not affect the resilience or robustness of the region. If this hypothesis is true, then a change in the direction of the shock or shift should not give any different conclusions about the resilience or robustness of the system. Thus, if an evolutionary pathway is resilient towards a positive shock, it should also show resilience when faced with a negative shock. The results showed that reversing a shock or shift's direction (from positive to negative) did not lead to different conclusions for some decision rule modules, but lead to large changes in the resilience and robustness of other decision rule modules. When faced with shocks, the 'habitual' decision modules (which assume supply chain actors that base their decisions on historical information) perform well, but for both case studies included in this particular analysis they produce average results when faced with shifts. These results would suggest that actors who base their decisions on historical information (rather than forward looking) are better in dealing with temporary shocks. However, such systems are not good in adapting to new situations with permanent changes. The 'deliberate' and 'imitation' modules show mixed results. The 'deliberate' modules (assuming actors instantly changing their operations when faced with changes in their environment) perform robust when faced with positive shifts, but performs worst when faced with negative shifts. 'Imitation' modules (assuming actors that imitate each other), on the other hand, perform well when faced with negative shifts and underperforms when faced with positive shifts. In summary, the results show that a system that is resilient or robust to one form of shock or shift is not necessarily resilient to other forms of shocks and shifts. Thus, the results showed that structure and decision rules are not the only determinants that affect the resilience or robustness of a system, but that a system's function at the time of the stress might also have an influence on the dynamic system properties of the system (resilience and robustness in this case). In other words, decision rule modules or diversity might be important determinant for the resilience and robustness of agricultural systems, but one should also consider the relationship between the function of a system at the time of the shock or shift and the characteristics of the stress itself.

The final set of experiments explored the relationship between decision rule modules and the dynamic system properties of agricultural systems. The stresses were introduced at the initialisation of the model, which means that at the time of the stress the function and level of diversity was the same for each evolutionary pathway. The only difference was the decision rule modules associated with each pathway. The results show that there is no single decision rule module that provides the highest resilience for both case studies. Similarly, there is no single decision rule module that provides the highest robustness. This suggests that the function and structure at the time of the shock, which is different between the different regions, affects the resilience of these systems.

The final conclusion of these three sets of experiments is that resilience and robustness of agricultural systems cannot be reduced to (a) the level of diversity of a system, (b) to the behavioural responses of actors to a stress or (c) to the functioning of the system at the time of the stress. Instead, these results suggest that the interactions between decision rules, their effect on the function (or performance) of the system and the subsequent effects of the performance on future decisions plays an important role with regard to the resilience and robustness of agricultural supply chains. Thus, it is the interaction between function and decision rules that provides a system's ability to cope with stresses. The results show a limited role for structural features as measured by the diversity heuristics. However, this could be tested further by experimentally changing the initial structural features of the different supply chains within a region (while keeping the decision rules constant).

4.3 Limitations and recommendations for future work

The methodology developed, the questions raised throughout the experimental set-up and the interpretation of the results have provided some directions for further research. Below are some suggestions that also address the limitations of this study.

- ➔ The unit of analysis for the diversity heuristic. This project has chosen the agricultural supply chain as the unit of analysis. The question remains in how far changes in the level of analysis (and therefore the operationalisation of the diversity heuristic) would lead to different modelling results.
- ➔ Uniform disparity measures. This project has chosen a uniform set of disparity measures for each region. Stakeholder engagement could be used to select case study specific disparity measures, which could change the results.
- ➔ Weightings of disparity measures. The weights of the disparity measures were chosen such that there was an equal weighting along the economic, social and environmental dimensions. Different methodologies could be used to elicit case study specific weightings for each disparity measure.
- ➔ The systems' function was defined in terms of GVA. Other definitions, for example in terms of social or environmental performance can be used, which would also change the way in which resilience and robustness are measured.
- ➔ The methodology assumes that all other sectors within the region operate independently from agricultural supply chain actors. This assumption can be relaxed by introducing other sectors from the region, which could also affect the way in which diversity is measured.

The results also open up questions about the relationship between agricultural systems, diversity and dynamic system properties, especially with regard to the diverse set of modelling results between the different case studies. The variety of results, both in terms of the level of diversity measured and the consequences of the stresses (the magnitude and length of the energy and world price shocks and shifts introduced in the model) as quantified by the resilience and robustness measures, suggests that there are case study specific characteristics that impact on the dynamic system properties of rural regions. One of these case study specific characteristics is the choices that farmers and other supply chain actors have with regard to land use and processing decisions. In some regions, such as South Tyrol, farmers cannot easily switch between different land use choices (apples and grapes in this particular case) because there are high initial investments. Other areas, such as Savoie, have only limited land use choices because of the particular characteristics of the land (mountainous). Other regions, such as Chelmkso-Zamojski or West-Sussex, can easily switch from one land use to another. One hypothesis is that the actual range of choices available to actors at the time of the stress affects the resilience of the system. Furthermore, one should consider potential lock-in situations (which are incorporated into the model) which can affect the resilience of the system. Thus, actors that make a choice in the face of a stress might lock themselves into particular activities over long periods of time (i.e. development of a vineyard), which in hindsight can reduce the resilience of the system. The experiments in this report do not provide a coherent answer to what elements are more or less important for the resilience and robustness of agricultural regions, however the modelling platform and experimental procedures do allow for exploring these issues in a systematic way.

Another case study specific characteristic is the difference in the organisational form of wholesalers and processors. In some regions, the dominant organisational form for wholesalers and processing activities are cooperatives, while in other regions these supply chain actors are commercial enterprises. These differences could impact on the dynamic system properties of these regions, because they affect the profitability of farmers and therefore their land use choices. Finally, it would be of interesting to explore the consequence of dominant up-stream supply chain agents on diversity, the resilience and robustness of agricultural supply chains.

The conclusions of this report, and the additional questions that have been raised, form a first step for a more informed and inclusive debate on the role of diversity in rural regions in Europe. This report has shown that such a debate that should go beyond discussing structural diversity as the only determinant for the resilience of regions, but it should (a) unpack the different dimensions of resilience and frame them in terms of dynamic systems properties and (b) consider the interaction between structural diversity, functional performance and behaviour as three important elements that play a complex and interactive role in determining evolutionary pathways of agricultural systems. However, further research is needed to understand the full complexity of agricultural systems and the potential role that policy instruments have in steering those systems towards more resilient and robust pathways. The development of the agent-based model, an experimental methodology to explore dynamic system properties, and the method for collecting case study data and interviews are three valuable tools that can be used for a continued engagement in the academic and political debate on rural sustainable development.

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