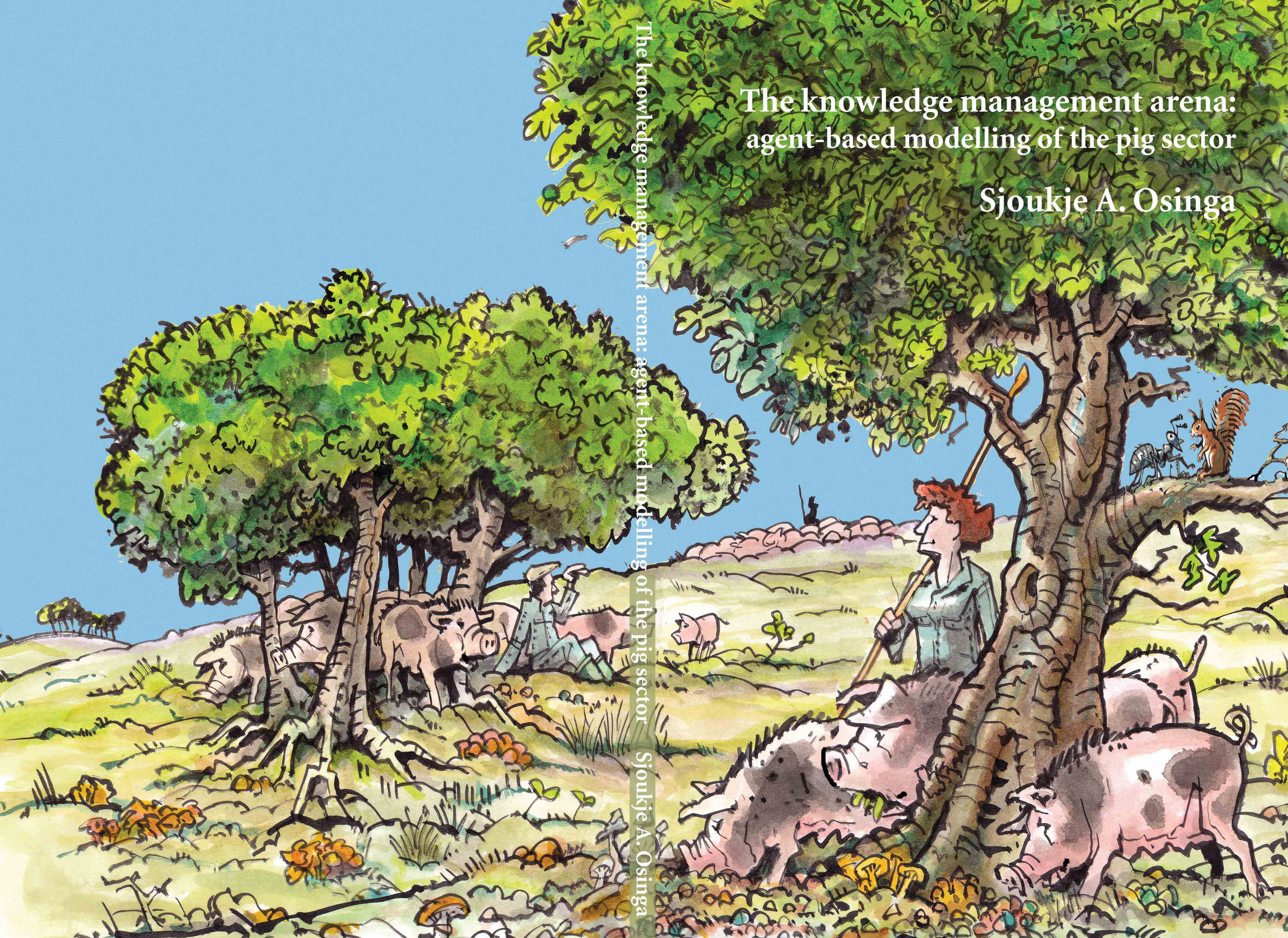

The knowledge management arena: agent-based modelling of the pig sector

Sjoukje A. Osinga

The knowledge management arena: agent-based modelling of the pig sector Sjoukje A. Osinga

Propositions

1. The interaction between system-level behaviour and actions of individuals is essential for understanding complex adaptive systems.
   (this thesis)

2. Agent-based modelling is a suitable method for representing a real-world case of sectoral knowledge management.
   (this thesis)

3. For middle range agent-based models, plausibility provides adequate validation.

4. The Higgs particle would never have been discovered without expert validation.

5. In the current social media era, it is better to change the proverb "a problem shared is a problem halved" into "a problem shared is a problem multiplied".

6. Writing and running both require three crucial qualities: talent, focus, and endurance.
   (adapted from Haruki Murakami)

7. A good mother needs to be big of heart and short of memory.
   (Mrs Verwoerd, mother and foster mother of many children)

8. Bad decisions make good stories.

Propositions belonging to the thesis, entitled

'The knowledge management arena: agent-based modelling of the pig sector'.

Sjoukje Osinga

Wageningen, 22 April 2015

The knowledge management arena:
agent-based modelling of the pig sector

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The knowledge management arena:
agent-based modelling of the pig sector

Sjoukje Antje Osinga

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Abstract

COMPLEX ADAPATIVE SYSTEMS are characterized by multiple levels of behaviour: the behaviour of individual components and the behaviour of the entire system. In this thesis we study this relationship by means of agent-based models. By modelling individuals (agents) and their behaviour only, and simulating this behaviour over time, we generate emerging patterns: we did not explicitly put them in. We try to understand these patterns by reasoning back to individual level (multi-level analysis).

Our application domain is knowledge management in the pig sector. Through a series of cases, we study the relationship between farmers' decision outcomes and their implications for the sector (bottom-up), and, vice versa, the relationship between sector-wide interventions and their effect on farmers' decision outcomes (top-down). Farmers make decisions based on knowledge, which diffuses through the population. We develop our agent-based models and the representation of knowledge throughout the thesis. Our final model is applicable to not only the pig sector, but to any sector with autonomous suppliers who need to make decisions based on criteria to be matched. A secondary aim of this thesis is methodological: to convey the merits of applying agent-based modelling to this type of multi-level research problem.

Our cases concern each farmer's decision of which quality market to supply his pigs to (agent level). As outcome, we observe the spectrum of emerging quality market shares (sector level). Knowledge is assumed to be a prerequisite for market entry, and defined as everything a farmer needs to know to match the entrance criteria set by a market segment, as perceived by that farmer. Knowledge management refers to both the individual farmer's activities to coordinate a market's criteria with his own options, and the activities at sector level to influence all farmers' decision behaviour.

One case addresses reproducing a well-known sector-level phenomenon (the pork cycle) by modelling individuals only. Other cases study the effect on emerging market shares of experimenting with agent-level properties: the amount of available knowledge and the conditions under which knowledge can be exchanged, and knowledge quality. The last case investigates the effect of experimenting with sector-level properties on individual farmer behaviour: two different policy interventions, and variations in demand. We apply multi-level analysis to seek explanations for emergent patterns in terms of individual farmer behaviour. Expert validation is used to evaluate the plausibility of model outcomes and explanations with respect to the real world.

Results show that (1) the presence of sufficient knowledge in the system is more important than the network structure between knowledge exchanging agents for emerging quality market shares; (2) efficient knowledge management increases quality, but there is a limit to that efficiency; and (3) imposing policies on a sector the hard way is not necessarily more effective than making gradual changes, while the latter is more friendly for the individuals. Multi-level analysis proves to give added value to the results: in two cases, an unexpected pattern in model outcomes occurred, for which multi-level analysis could provide an explanation in model terms. Judged by the experts, the explanation for one of the patterns was deemed plausible in reality.

In conclusion we can say that both varying individual properties and varying system-level properties result in responsive behaviour that can be explained in model terms, and that is to some extent plausible in reality. Knowledge representation power appears to differ per model. Dependent on the aim of the model, representation power can be kept deliberately modest (as in the pork cycle model), or can be rich (as in the final model, that allows representing different types of knowledge). We believe that the representation power of agent-based models make them sufficiently suitable to represent a real-world case, as long as the model has a well-defined purpose. We recommend agent-based modelling as a method, with multi-level analysis providing added value. We believe that extending this line of research is promising for any discipline where complex adaptive systems are object of study, of which knowledge management is an example.

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Part I - General Introduction

- **Chapter 1 - Introduction**
- **Chapter 2 - Research methodology**
- **Chapter 3 - Pilot study**

Op een ochtend liepen de eekhoorn en de mier door het bos.
'Waar gaan we eigenlijk heen?' vroeg de eekhoorn.
'Naar de verte,' zei de mier.
'O,' zei de eekhoorn.
Het was een mooie dag en ze liepen het bos uit, de verte in.
'De wereld is zó groot, eekhoorn...' zei de mier.
'Ja,' zei de eekhoorn.
'En hoe verder je loopt hoe groter hij wordt,' zei de mier.
De eekhoorn zweeg.
'Dus eigenlijk,' ging de mier verder, 'als je maar altijd doorloopt is hij oneindig groot.'
De eekhoorn knikte, maar hij wist niet wat oneindig was en hij geloofde niet dat iemand altijd zou kunnen doorlopen. Hij dacht zo diep mogelijk na. Als ik ga zitten, dacht hij, zou de wereld dan weer kleiner worden? En als ik dan altijd blijf zitten?
Hij vond dat een ingewikkelde gedachte en besloot alleen nog maar om zich heen te kijken.

One morning the squirrel and the ant were walking through the forest.

'By the way, where are we going?' the squirrel asked.

'To the distance,' the ant said.

'Oh,' said the squirrel.

It was a beautiful day and they walked out of the forest, into the distance.

'It's a big world, squirrel...' the ant said.

'It is,' said the squirrel.

'And the further you walk, the bigger it gets,' the ant said.

The squirrel said nothing.

'So in fact,' the ant continued, 'if you just keep on walking forever, it is infinitely big.'

The squirrel nodded, but he didn't know what infinitely was and he didn't think that anyone could keep walking forever. He thought as deeply as he could. What if I sat down, he thought, would the world become smaller again? And what if I sat down forever?

He found that a complicated thought and decided he would just look around from now on.

Preface to Chapter 1

Introduction

Op een ochtend besloot de tor de wereld op te tillen.

Dat is weer eens wat anders, dacht hij.

Hij haalde diep adem en tilde de wereld op.

Alle dieren werden door elkaar geschud, alle bomen kraakten en ruisten, de rivier stroomde leeg en enorme golven sloegen over het strand.

'Hola!' riep iedereen. 'Wat gebeurt er?'

De tor hoorde het geroep wel, maar hij zweeg. De wereld optillen en tegelijk praten, dat was te veel voor hem.

Zachtjes schommelde de wereld op zijn zwarte schouders heen en weer.

De dieren renden en vlogen naar de open plek in het bos en vroegen elkaar wat er aan de hand was.

Niemand wist het.

One morning the beetle decided to lift the world.

That makes for a nice change, he thought.

He took a deep breath and lifted the world.

All the animals were jostled around, all the trees groaned and rustled, the river emptied out, and enormous waves swept the beach.

'Ho!' everyone yelled. 'What's going on?'

Though the beetle heard them yelling, he kept silent. Lifting the world and talking at the same time was too much for him.

The world rocked gently on his black shoulders.

The animals ran and fluttered towards the clearing in the woods and asked each other what was going on.

Nobody knew.

Chapter 1
Introduction

This thesis may best be introduced by an analogy. I have been a chamber choir singer for most of my life, performing in countless choral concerts, often in series of more than one performance of the same music. Two performances are never the same. One concert, everything is perfect: choir members, conductor, and the audience are thrilled because something happened that nobody can really define. Explanations range from 'all the notes came out right', 'the atmosphere was present', to 'we could communicate what it was all about'. The next concert, even when things did not evidently go wrong, the evaluation of the concert may be completely different, having to do with causes like: 'we had to work too hard this time', or 'the music was not flowing', to 'we did not connect with each other'. From these phrases, we can deduce that it is hard to even define a 'good performance'. The elements needed to describe a successful performance are hard to measure and ambiguous: every person involved would probably evaluate a concert in different terms. Still it is there, nobody doubts of its existence.

In terms of this thesis, a concert is a complex adaptive system. It is *complex* because no-one can predict in advance what will happen during a concert given what we put in. It is *adaptive* because the participants can respond to what they observe or to clues they get from others. And it is a *system* in the sense that it is 'the whole thing', consisting of separate components that are all interacting or related to at least one other component (Scholten, 2008). The quality of a concert is an *emergent* property: it can be aimed for, but it cannot be explicitly controlled, and it cannot be produced without fail like a standard product in a factory. Instead, it self-organizes: it develops as it happens.

An interesting property of a complex adaptive system is that it can manifest a *tipping point*: the point at which a series of small changes or incidents becomes significant enough to cause a larger, more important change. A tipping point is often irreversible; it is very hard or even impossible to return back to the previous state. In the choir analogy, a tipping point occurs when a piece of music modulates from one key to another. The audience hears it coming: there are some harmonic changes, some voices already sing notes that 'itch' a little, and then suddenly it has happened, the entire choir sings in a new key. Once the modulation is complete, the new key feels like a 'homecoming'. The old key is already forgotten, and can only be brought back if the music explicitly develops back there.

CHAPTER 1

What interests us is the *multiple-level* perspective: the relationship between the emerging total performance and the behaviour of individual components, in this case the individuals involved. Can we identify regularities in concert quality, and can we trace these back to what was going on with certain constituting components? In the choir analogy, there is usually a conductor who directs the choir, and usually choir members behave according to what the conductor indicates. In many complex adaptive systems, there is no such conductor, nor a master plan or a grand scheme. Many examples of conductor-less emerging patterns exist in everyday life. No entity hierarchically controls the way ants wander in a forest, and yet patterns like neat ant rows emerge, not to mention their intricate housing system which they meticulously build without a building contractor. We can observe a V-shape pattern in the sky from a flock of geese starting to migrate south in autumn, and by taking a closer look at the relatively simple behavioural rules the birds adhere to, we can understand why the pattern emerges. In this thesis we do a similar thing: by modelling individuals and their behaviour only, we generate patterns that we did not explicitly put in, and that we try to understand by reasoning back to individual level. We give our individuals their rules of behaviour, we let the system create conditions within which they have to operate, they act according to those rules and conditions, and together they create system-level patterns.

The focus in this thesis is on the role of knowledge as an instrument for individuals' decision making. A choir conductor gives plenty of information to the choir members: rhythm and pace, but also gestures and facial expressions indicating in what style to sing the next phrase. Although it may seem that there is little decision freedom in a choir, still there are many occasions where choir members make decisions. For instance, they decide how loud or how expressive to sing a phrase, or where exactly to place a consonant. A conductor can give clues as to the desired dynamics, but cannot control every individual's voice. Choir members also take clues from neighbouring singers, for example on the pitch of the tone. Is it perhaps slightly too high or too low compared with what others do? A good singer listens to his or her neighbours, and singers continually adjust their sound to each other. Not every singer is equally inclined, sensitive, or capable to catch and respond to clues from others. The heterogeneity of the singers is another element relevant for this thesis: when modelling individuals is important, then it is also important to have an eye for individual differences. A choir consisting of identical singers would sound strangely artificial; it is the diversity that gives a choir its sound and character. For example, a piece of music sang by an English boy choir sounds very different from the same music sang by a chamber choir consisting of adults.

What might be helpful to study the relationship between patterns emerging over time and the behaviour of individuals involved, is to repeat the exercise over and over again. If we sang the same concert a hundred times, surely we would gain understanding of what produces a good performance. In reality, this is an unpractical, costly and tedious thing to do, if it is even an option.

What we can do instead is simulate the phenomenon in a computer model and run it as many times as we want, observing and inspecting individual behaviour as much as desired. The challenge in this case is to make the simulation model as rich as is necessary to capture the essential elements of the real world case, but also to keep it sparse, or we would no longer be able to relate changes in model inputs to outcomes. This is a secondary aim of this thesis: to pay attention to methodological issues. These include abstraction and selection of real world phenomena into a model without losing the representation power needed to draw any conclusions from that model; how to develop and extend such a model while ensuring that former model results are still comparable with new ones; how to handle results from multiple runs and the sensitivity of model parameters to those results; and validity issues, i.e. the question whether results have any relevance for the real world.

1.1 Complex adaptive systems and agent-based models

Adam Smith's *Wealth of Nations* (1776) is considered one of the first scientific discussions on complex adaptive systems. Smith describes the 'invisible hand' in economics: the phenomenon that the free market, without regulation, guides market participants to trade in a mutually beneficial manner, given that every individual trader interacts with other traders and that they all do what is in their best self-interest. In fact, Smith recognized the emergence of market structures that no-one explicitly intended. Complex adaptive systems as a research area started around the 1960s. In the field of theoretical computing, Von Neumann developed ideas leading to *cellular automata*, a collection of cells on a grid that could change their state according to strict rules, thus generating patterns (von Neumann, 1966). The concept of cellular automata became wider-known after it was used in the 1970s in Conway's *game of life*, or *life*, in short (Gardner, 1970).

Also in the 1970s, social scientists proposed abstract models to study social science related problems, of whom Schelling was a pioneer. To illustrate the simple beauty of these models, I will explain in a little more detail his segregation model (Schelling, 1971). In the segregation model, coloured ('green' and 'red') households are randomly placed on squares of a grid. Households can observe the colour of their neighbouring households, represented by the eight cells adjacent to their own. At each point in time, households count their neighbours of opposite colour. When the number of opposite coloured neighbours exceeds an adjustable threshold (which is a model parameter), the household decides to move and relocates to a random empty cell. Schelling's model showed how easy it is to generate segregation in an area; in fact that segregation according to these assumptions always arises - regardless of initial distribution - when the threshold is 0.3 or higher. Using these models was a novel way of gaining understanding of processes such as segregation: earlier models of the same problem were based on equations relating migration flows and the relative values of residential properties, involving more parameters to estimate and analyse, whereas Schelling's model had only one parameter and was 'growing' the process from bottom-up (Gilbert, 2008). Schelling modelled many such basic social processes, among which - returning to the choir analogy - the *standing ovation problem*: to understand how waves of audience standing up seem to arise spontaneously (Schelling, 1978; Miller and Page, 2004).

These early models from a bottom-up perspective were *theoretical exercises*, at the most tried on paper (the Von Neumann machine, cellular automata) or acted out in real life (Axelrod, 1997) let conference participants act out his model of the prisoner's dilemma). When computers entered the room of the common researcher, these models were further developed in the form of computational simulation models, opening a whole new era of complex adaptive systems research. Early computer scientists include Stephen Wolfram, who studied cellular automata by means of computer simulations (Wolfram, 1984). In the early 1990s, dedicated computer environments such as Starlogo, Swarm, Mason, Repast and Netlogo (Wilensky, 1999) facilitated that this type of modelling as a method came within reach of researchers of a wide range of disciplines (Bonabeau, 2002).

The term *agent-based modelling*, as the computer simulations researchers called it, was by then generally associated with complex adaptive systems research, defined by Gilbert as "a computational method that enables a researcher to create, analyse and experiment with models composed of agents that interact within an environment" (Gilbert, 2008, p. 2). The agent-based modelling community consists of groups of various flavours. The term *multi-agent system* is generally reserved for agent-based models whose goal is primarily to focus on explaining collective behaviour of relatively simple agents who behave according to certain rules, such as the ant and geese flock examples and Schelling's model, rather than to focus on the design of the agents themselves (Niazi and Hussain, 2011). The term *intelligent agent* is used in areas where the population aspect is absent, such as the design of one or few agents in technical disciplines like robotics, or an autonomous piece of intelligent software (for example to scour the internet for cheap flight tickets). In ecology and biology the term *individual-based model* used to be preferred over *agent-based model* but the fact that Grimm and Railsback renamed their standard book *individual-based modeling* (Grimm and Railsback, 2005) to *agent-based and individual-based modeling* (Railsback and Grimm, 2012) indicates that differences are fading.

Application domains for agent-based models nowadays range from biology to computer science and from economics to sociology. Notable contributors to the field - and leading authorities - include Epstein and Axtell (Epstein and Axtell, 1996; Epstein, 2006) with their emphasis on growing artificial societies, Miller and Page (2007) from a general computational perspective, Railsback and Grimm (2012) from an ecological view, and Gilbert (2008) from sociology. Methodological aspects are also discussed in e.g. (Garcia and Jager) on innovation diffusion, in (Squazzoni et al., 2013) on heterogeneity and the micro-macro relationship, in (Troitzsch, 2013a, 2014) on how to handle simulations and analysis. A generous, high-quality source of and outlet for social science related applications is the free, online *Journal of Artificial Societies and Social Simulation* (JASSS, 2015). Axelrod and Tesfatsion actively maintain a comprehensive website on agent-based models in social science and economics (Axelrod and Tesfatsion, 2015). There is a growing number of conferences and seminars for complex adaptive systems related research, e.g. *Artificial Economics* (Artificial Economics, 2015); *European Social Simulation Association* (ESSA, 2015); *Autonomous Agents & Multi-Agent Systems* (AAMAS, 2015). There are several lively internet discussion groups as well where both new and well-known contributors discuss current topics, e.g. the discussion group on computer simulation in the social sciences (SimSoc, 2015). Wageningen University maintains a complex adaptive systems Facebook group.

1.2 Thesis objective

The objective of this thesis is to study what knowledge management at individual level implies for knowledge management at sector level, and vice versa. More specifically, within the complex adaptive systems domain of knowledge management, we[1] study the relationship between patterns emerging at sector level and behaviour of individual actors. We explore this relationship by means of a series of agent-based modelling cases of situations where suppliers are matched with available markets. Another objective is to highlight methodological aspects of this research approach, and to evaluate how suitable agent-based modelling as a method is to represent knowledge and multi-level knowledge management. This objective is relevant in the sense that including a multi-level perspective in knowledge management (1) adds insight in the field of knowledge management, and (2) evaluates agent-based modelling as a candidate method for the toolbox available to knowledge management researchers.

In this thesis, supplier and market are applied to cases in an SME sector, specifically the pig sector: we model farmers who select a market segment to supply their pigs to. Our final model is generic in the sense that it is applicable to any situation where suppliers with certain characteristics are matched with customers who set criteria, for example in other supply chain domains or at the job market. An important assumption is that the suppliers are autonomous in their decision making and not under control of a larger organization as employees in a firm would be. From section 1.3.2 on, we assume 'farmer' for 'supplier' and 'pig quality market segment' for 'market'. We define markets as the set of available market segments, each of which is well-defined in terms of the products, of the processes and resources used, and of a set of (legal and cer-

[1] In Chapters 1, 2 and 9 (and in the summary), whenever I say "we", I also refer to my co-authors of the other chapters of this thesis.

tification) requirements and conditions that must be satisfied in order to supply there. The pattern of interest - to which to relate individual behaviour - is in most of our cases the emerging division of market shares: the proportion of farmers that selects a particular market segment.

As far as we know, knowledge management has not previously been an explicit object of study by means of agent-based modelling. Grundspenkis (2007) models enterprise and personal knowledge with an intelligent system that acquires, formalizes, represents and stores knowledge as in an artificial brain. The agents in his multi-agent systems represent parts of this artificial brain. There are several other studies like Grundspenkis, using software agents to manage organizational knowledge (Yu and Singh, 2002; Smirnov et al., 2003; Lacher and Koch, 2000). Chira et al. (2006) model heterogeneous individuals in a distributed extended enterprise, aiming at optimizing the design, manufacturing and marketing of products based on the knowledge of multiple employees. The agents cooperate to achieve enterprise-level goals; they are no autonomous decision makers who each maintain a business. Wang et al. (2009) come closest to our research because they also use an agent-based simulation model (not an intelligent agent model) in which they model both individual behaviour and organizational interventions. However, employees' behaviour in this model is determined by whether they are 'knowledge contributors' or not, and it is assumed that employees concentrate on the organization's interest. We intend to not explicitly model a shared group-interest, but to let group-outcome emerge from individual-oriented behaviour.

1.3 Information management versus knowledge management

Our notion of knowledge management combines elements from the academic fields of information management and knowledge management. The essence of agent-based modelling is that only the behaviour of individuals is modelled, from which generic patterns emerge. This does not naturally agree with how information management is typically defined, which is from a top-down perspective. Information management usually involves information systems, embedded in a managerial context, and is typically aimed at centralized decision making in larger firms involving multiple employees, for example to make work flow processes more uniform or efficient (Laudon and Laudon, 2014). Information systems that have a broader than organization's focus, e.g. the whole supply chain, tend to limit themselves to specific applications (Beulens, 2013).

Information management is usually prescriptive of nature, and assumes that people always perform activities with the organization's interest in mind. However, people are autonomous beings who work from their own local perspective, doing the things that are central in their own world, which is only partly overlapping with the organization's world. Wilson (1997) defines information management from a perspective that comes closer to this latter notion:

> Information management is the application of management principles to the acquisition, organization, control, dissemination and use of information relevant to the effective operation of organizations of all kinds. 'Information' here refers to all information of value, whether having their origin inside or outside the organization, including data resources, such as production data; records and files related, for example, to the personnel function; market research data; and competitive intelligence from a wide range of sources. Information management deals with the value, quality, ownership, use and security of information in the context of organizational performance

In this definition the term 'information' primarily refers to data, and information management is concerned with maintaining and protecting this data, so the technological focus of information management is highlighted. *Knowledge management*, according to Wilson, started out as a new term with approximately the same meaning as information management, but at least the term itself acknowledges the fact that people must interpret the information before they can do anything with it. Wilson therefore argues that knowledge management consists of (1) information management and (2) management of work practices. About the latter he assumes that this can only work well in a situation where "the benefits of information exchange are shared by all", and "where individuals are given autonomy in the development of their expertise", or in other words when organizations allow for "sharing knowledge and enabling people to use their creativity in innovative ways" (Wilson, 2002).

In 2002 Wilson believed that his assumptions for knowledge management require a utopian situation that we are a long way removed from. However, nowadays, knowledge management has developed into a mature area of research. Today, knowledge management deals with making knowledge understandable and available to all people involved, manageable by computers, and easy to maintain or improve (Scholten, 2008, p. 44). This is the technical perspective of what knowledge management is. The practical challenge is that people must be able to use it. It implies that building a knowledge base or ontology is a bottom-up process, emerging within a population of its users, changing over time and, undoubtedly still utopian, open and transparent to those involved.

In our research we combine the technological 'data'-oriented meaning of information management and the behavioural notion of knowledge management as in knowledge sharing and learning. In this thesis, both the terms 'information management' and 'knowledge management' refer to this combined definition. In the sub paragraphs below we zoom in on knowledge, decision making behaviour and management to indicate how we apply these concepts in our research.

1.3.1 Knowledge

In this thesis, *knowledge* is defined as everything a supplier needs to know to match the entrance criteria set by a market segment, as perceived by that supplier, and instrumental in his/her[2] decision making process. We leave implicit that this required knowledge is of heterogeneous nature. It represents factual knowledge, for example regarding requirements with respect to the product itself and the manufacturing process of the product. It also represents skills and know-how that require experience to build up. It represents personal capabilities. It represents constraints to a supplier's options, for example access to financial resources needed to invest. It represents the available 'action repertoire' that a supplier has at his disposal, enabled or constrained by factors beyond our concern. Throughout the thesis, the terms 'information' and 'knowledge' are used interchangeably, both referring to the definition given here.

Knowledge is shared between individuals and diffuses over a population. We stated 'as perceived by the supplier', meaning that even when knowledge seems easy to share, like factual knowledge, still one receiver attaches different meaning to this piece of knowledge than another (Brown and Duguid, 2002). This also implies that not all knowledge is equally transferrable to others.

The notion that knowledge is transferrable to others within a population of individuals belongs to the theory of diffusion of innovations by Rogers (1962, 2003). This theory is often used within the agent-based modelling research community, and iconic examples are widely available (Wilensky, 1999), as well as specific applications such as opinion dynamics (Delre et al., 2010; Deffuant et al., 2002). Dependent on initial conditions like the amount of starting points (seeds) of the innovation, conditions for adoption and the speed of the decision process, the model provides insight into the rate at which an innovation (or an opinion) gets adopted in a population. When the innovation is interpreted as for example 'technology', or 'managerial hype', this is also applicable to knowledge: it starts somewhere, and at a certain speed and at a certain rate it gets adopted by the population. Given the initial amount of knowledge, the conditions under which knowledge can be exchanged, and the connections between individuals, this will emerge to a population where some have this particular knowledge and others do not.

A complication with respect to knowledge sharing is that knowledge can refer to so-called 'tacit knowledge', or hidden knowledge, hidden even from the consciousness of the person who owns this knowledge (Polanyi, 1958). Polanyi summarizes this as: "We know more than we can tell". In information techno-

[2] Whenever I refer to a supplier or farmer as 'he' in the remainder of this thesis, it could equally well be 'she'. Both in China and in the Netherlands, I met many female pig farmers.

logy, this type of knowledge is recognized as very valuable knowledge ('expert knowledge') that should be made explicit and put to use for the benefit of the entire organization (Nonaka and Takeuchi, 1995), even though this is very difficult (Turban et al., 2007). In our notion of knowledge, 'skills and know-how' fit in this category. Knowledge of this type cannot simply be exchanged with others, but needs time to build up. From our modelling perspective, our definition of knowledge assumes that knowledge and skills are a joint concept, and that it also includes knowing how to operationalize this.

1.3.2 Decision making behaviour

The behaviour of the farmer in this context boils down to his decision of what market to supply to. Wolfert has applied De Leeuw's framework (de Leeuw, 2000) to the farmer context before (Wolfert, 2002, p. 42). De Leeuw mentions five conditions for effective management control: a management objective for the total system, a model of the production system, information on the environment and production system, potential control measures, and an information processing capacity. To be able to decide which market to choose requires that the farmer has all relevant knowledge at his disposal, and that he has the flexibility and means to actually take that decision. The management objective is presumed to be to safeguard continuity and to make a profit; the production system is reduced here to farm characteristics; information on the environment and production system is interpreted as the collection of knowledge in the broad sense (described in the previous paragraph), either in possession of the farmer or reaching him through exchange with other individuals; potential control measures are the option to choose for another market segment, and the information processing capacity is the decision mechanism of the farmer.

The decision mechanism of the farmer is not that of the rational man who consciously considers all alternative options, as *homo economicus*. Instead, farmers are social creatures that make their decisions within a context of other decision-makers. They exhibit *bounded rationality* (Simon, 1957), meaning that they take on a satisficing rather than an optimizing approach. Kahneman adds to this that people act according to their cognitive abilities (Kahneman, 2003). The satisficing approach also implies that not only cognitive abilities, but time, resources or personal circumstances constrain decision making (Keen and Scott Morton, 1978). Jager and Janssen (2012) propose Consumat, a set of four decision strategies based on their consumers studies: repetition (do as you always do), imitation (do as your close peers do), inquiring (study what all peers do and do as the majority do), and optimizing (calculate all alternatives and choose the best). It is plausible to assume that farmers use similar kinds of heuristics when they make the decision of what market to opt for. There is ample evidence from sociology that farmers in real life are not all rational, conscious, individual decision makers (Commandeur, 2006; van der Ploeg, 2010), and that their decisions are influenced by interactions with other farmers, farm advisors, farm suppliers, veterinaries, and others (Bock and Van Huik, 2007; Jansen and Vellema, 2011). The extent to which farmers are influenced by others differs per individual (McCrae and Costa, 2003). In this thesis, studying decision making in itself is not an explicit aim.

1.3.3 Management, or influencing decision behaviour

The term *knowledge management* in a model of behaviour of individuals requires a multi-level explanation. One managerial level is that of the individual famer. In line with De Leeuw's management framework, the farmer needs to manage his knowledge and apply it in order to make a market decision, which includes a coordination aspect of matching the potential market's requirements with what the farmer has to offer. In our research context, a farmer's individual management comes down to having an adequate representation for his knowledge, and a decision mechanism for how to choose a particular market based on that knowledge.

There is also management at sector level from a policy perspective, for example from the government. Even though farmers are autonomous decision makers, they need to comply with the law. When the law changes, they have to adapt their behaviour accordingly. A government can exert power by altering requirements for farmers. A Dutch example is the law on housing of sows, which was changed because of animal welfare concerns, and became effective as of January 2013. This law entailed that pregnant sows should no longer be individually housed and tethered, but should be held in groups with a minimal spatial requirement and with some additional requirements. The resulting regulation implied that all farmers needed to invest in their housing system and change their management practice. In a similar way, farmers can be influenced by the sector to voluntarily change behaviour, to which they may be more or less sensitive. An example is that farmers may choose to voluntarily meet additional requirements in order to obtain a quality certificate enabling them to produce for the organic market. A sectoral body can stimulate this by influencing farmers, for example by informing them about certification requirements, thus increasing their knowledge or improving its quality. As a result, farmers may successfully undergo required audits and acquire the necessary certificates to actually change to another market concept.

In summary, knowledge management in this thesis is applied as follows. Knowledge management at farmer level implies influencing farmers' personal knowledge base as a basis for decision making. Knowledge management at population level implies influencing the way knowledge diffuses through the farmer population or the quality of that knowledge. From a policy perspective, knowledge management implies influencing requirements a farmer has to meet, either to comply with the law or to enter another market. Our research questions link to these levels of knowledge management.

An important issue is how to represent knowledge under these assumptions, how to design the agent-based models such that they allow multiple-level inspection, and how to elaborate these managerial issues in our selection of cases. Both the representation and design issues and the multi-level analysis issue develop throughout the thesis.

1.4 Research questions

From the research objective the following research questions are derived, each consisting of two sub-questions:

1. What is the relationship between sector-level knowledge management measures (top-down), actions of individuals, and the system behaviour resulting from these actions (bottom-up) in the context of a sector of autonomous suppliers, specifically applied to the case of pig farmers?
   a) What is the effect of agent-level variations with respect to knowledge management on total system behaviour?
   b) What is the effect of system-level interventions on agent behaviour and total system behaviour?
2. How suitable is agent-based modelling as a method for representing a real-world case of sectoral knowledge management?
   a) *Representation*: How well does the design of the agent-based model permit representing knowledge management and representing the multiple levels of the real-world case?
   b) *Validity*: Do the evaluated simulation results lead to increased understanding of the interdependence of emerging system behaviour and individual agent behaviour in the real-world case?

1.5 Thesis outline

This thesis consists of three parts. *Part I (General introduction)* consists of this introduction (Chapter 1), the methodology of our research (Chapter 2), and a pilot study (Chapter 3). This pilot study was our first attempt to model decision behaviour of individual farmers and the emerging pattern of quality markets they chose. The model was very dense and essentially a 'black box': we could relate observed outcomes to our chosen inputs, but because of the richness of the model we could not easily explain this relationship. After this exercise, we decided to make our models as sparse as we could, so that we could learn more from their behaviour.

Part II (Cases) contains the cases we studied next, using sparser models that were, as a trade-off, also more abstract in representation. Chapter 4 describes the first case. Before doing anything more elaborate, we wanted to demonstrate whether we could regenerate a generally known pattern by modelling individual behaviour only. We took the classical pork cycle as an example, the sector-level phenomenon of periodic over- and under-supply due to delay and non-optimal predictions, and used information in a simple form as a means for the farmers to make predictions. Chapter 5 describes the next case, in which we wanted to make a more elaborate representation of knowledge. We varied the amount of knowledge going round in the farmer population, and we varied the network structures between farmers, to see whether the resulting pattern of quality market choices changed according to what we expected. In Chapter 6 we study the effect of increasing knowledge quality. What if we maintain only knowledge that is of high value to us? In Chapter 7, we describe the last case: this time we modelled two policy interventions and compared what the implications were for individual farmers.

Part III (Synthesis) begins with a synthesis chapter (Chapter 8), in which cases are revisited and methodological aspects are highlighted. Model assumptions are explicitly grounded in theory, experiments are repeated more thoroughly, and additional multi-level analyses provide added insight in the relationship between sector and individual levels. In this chapter we also perform expert validation, to find out how plausible our results, patterns and explanations are with respect to the real world. The synthesis part concludes with Chapter 9, which answers the research questions and provides a general discussion. Answers for research question 1 relate directly to results from the cases. Chapters 3, 4, 5 and 6 address research question 1a: we observed sector-level differences after we made agent-level variations. The cases from Chapters 3, 5 and 7 address research question 1b: the effect of sector-level interventions on behaviour of individuals. Answering research question 2a requires comparing how we represented knowledge throughout our cases, and what we learned from these successive representations. Research question 2b can be answered by what we learned from all our cases and synthesis.

Models and summarized results of our work can be found at: harmoniqua.wur.nl/OsingaPhDthesis.

Preface to Chapter 2

Research methodology

Toen de eekhoorn eens sliep in het hoge gras aan de oever van de vaart, vroeg de goudvis aan de reiger: 'Wat is er aan de hand met jou? Je laat me zo rustig zwemmen vandaag.'

'Ach...' zei de reiger.

'Ben je ziek?' vroeg de goudvis. 'Dat lijkt me niks voor jou.'

'Nee,' zei de reiger. Hij zuchtte en ging verder: 'Ik heb je wel honderd keer opgegeten...'

'Ik denk wel duizend keer,' zei de goudvis. 'Maar goed, ga verder.'

'Wel duizend keer,' zei de reiger. 'En als ik je net op heb ben ik ook wel heel tevreden. Maar nog geen uur later heb ik al weer honger en zie ik je hier weer zwemmen. Het lijkt wel of er nooit een eind aan komt...'

[...]

'Goed dan,' zei de goudvis en hij liet zich voor de laatste keer naar binnen slokken. 'Als het hierna dan ook echt afgelopen is...' riep hij nog toen hij door de lange kronkelige hals van de reiger gleed.

One day when the squirrel was asleep in the high grass on the banks of the canal, the goldfish asked the heron: 'Is something wrong? You are letting me swim so peacefully today.'

'Oh...' the heron said.

'Aren't you feeling well?' said the goldfish. 'That doesn't seem like you.'

'No,' the heron said. He sighed and continued: 'I've eaten you at least a hundred times...'

'A thousand times at least,' the goldfish said. 'But never mind, go on.'

'A thousand times,' the heron said. 'And after I've eaten you I feel very satisfied. But less than an hour later I'm already hungry again, and I see you swimming around back here. There just seems no end to it...'

[...]

'All right then,' the goldfish said, and he let himself be swallowed for the last time. 'As long as it's really over after this...' he cried, as he slipped down the heron's long, twisting neck.

Chapter 2
Research methodology

In this thesis we apply the design research approach in an information systems context as proposed by Hevner (Hevner et al., 2004; Hevner, 2007), see Figure 2.1. Hevner defines design research as the "building and evaluation of artefacts designed to meet the identified business need" (Hevner et al., 2004, p. 80). This artefact is what he considers the result of design research. As artefact qualify "the constructs, models, and methods applied in the development and use of information systems". The artefact "must be described effectively, enabling its implementation and application in an appropriate domain". The artefacts do not need to be full-grown information systems used in practice, so long as they provide a proof of feasibility of what can be accomplished. By these definitions we assume that our agent-based simulation models serve as artefacts to address a certain organizational problem or business need. In our case, this need is to understand the multi-level aspect of knowledge management in the context of our domain. A methodological aim is to evaluate whether agent-based modelling is a suitable method to fulfil that need.

Hevner proposes three design research cycles that must be present and clearly identifiable in a design science research project (Figure 2.1). One is the *relevance* cycle, bridging the "environment of the research project with the design science activities". Another one is the *rigour* cycle, connecting the design research activities with the "knowledge base of scientific foundations, experience, and expertise that informs the research project". The third one is the central *design* cycle, which "iterates between the core activities of building and evaluating the design artefacts and processes in the research". They are called cycles because they can be alternated and iterated.

Figure 2.2 shows how the thesis chapters fit in these three research cycles: relevance to the left, rigour to the right, and design in the middle. The introduction in Chapter 1 starts off in the relevance cycle by introducing why our research is relevant at all. It justifies the objective (why our multi-level approach adds insight to the field of knowledge management and why agent-based modelling is a suitable candidate method to be added to the knowledge management researcher's toolbox) and the research questions themselves that are derived from this objective. Chapter 1 deals with the rigour cycle as well, since a connection is made with existing scientific theories and practice. This is why Chapter 1 also appears on the right hand rigour side. The same holds for the present chapter, Chapter 2. It starts out with describing the methodology of the thesis, which clearly belongs to the rigour cycle. Prior to the cases, a field study

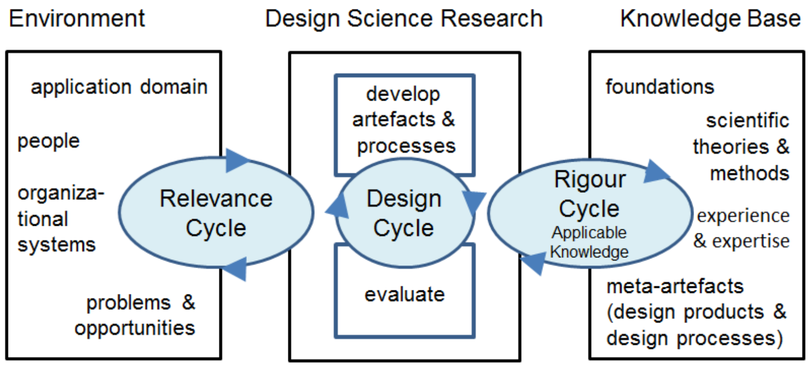

Figure 2.1: Hevner's design science research cycles (after Hevner et al., 2004; Hevner, 2007).

was carried out in China, which is briefly described first. This field study belongs to the relevance cycle on the left hand side, because the everyday reality of Chinese pig farmers that I came to know quite well triggered this very research. The remainder of this chapter explains how the cases relate to each other, and why the next case makes sense as a follow-up to the previous one. Chapters 3 to 7 all belong to the design cycle, since they concern either a pilot study or a case, each leading to an artefact, in our case being an agent-based simulation model. Throughout the thesis, we use the word 'case' for these chapters in the sense of 'model study', comparable to how Yin uses the word 'case study' (Yin, 2009), intended to investigate a real life phenomenon by means of a modelled example. All chapters describe a model with its own research questions and experiments. There is a gradual development in these cases with respect to their topic, but also with respect to their maturity. The successive models mature from 'black box' model, whose behaviour is difficult to access, to fully transparent model, the behaviour of which we can vouch for as researchers.

Hevner stresses in his guidelines that evaluating the artefacts is as important as designing them. In the overview of cases, later in this section, we pay attention to the evaluation of each case as well.

Chapter 8, the synthesis chapter, is placed at the rigour side. Content-wise, the chapter cannot be termed another design cycle, because it does not develop a new model. Instead, it grounds the existing model's assumptions in theory, and it makes the results from three previous design cycles more solid by performing additional runs. It also extends them by adding multi-level analyses as well as expert validation. All these activities belong to the rigour cycle because they are methods derived from and meant to be used within a research context.

The majority of Chapter 9 belongs again to the relevance cycle. It refers back to the research questions from Chapter 1, and answers them in similar terms:

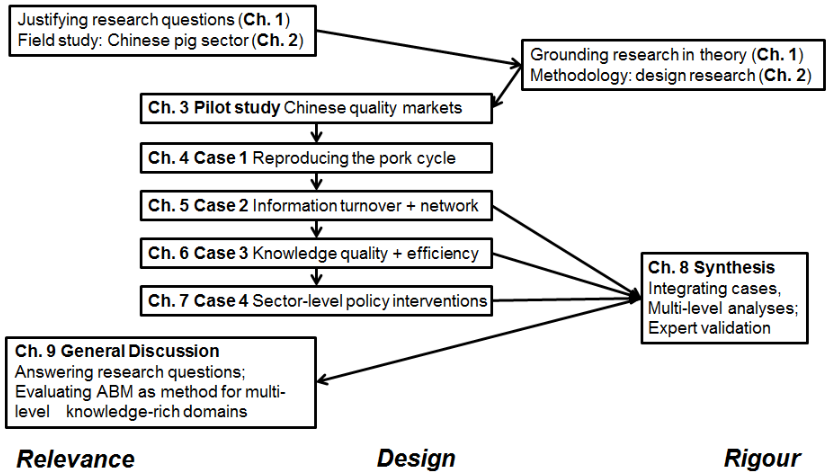

Figure 2.2: The thesis chapters organized according to relevance, design and rigour cycle.

now that we have finished all the work, what was the relevance of this research, and how do we evaluate agent-based modelling as a method? The discussion also refers back to reality by addressing assumptions and plausibility aspects of the research.

Middle range model

In every chapter we emphasize that our agent-based models are middle range models in terms of Gilbert (2008). Gilbert distinguishes three levels of agent-based models: abstract models to test theories (such as the Schelling examples from the introduction); one-to-one facsimile models of a specific real life case; or, in-between, middle range models of model cases that have qualitative resemblance with reality but that maintain a level of abstraction facilitating analysis.

Agent-based modellers tend to refer to these 'qualitative resemblances with reality' as stylized facts: broad, but not necessarily universal generalizations of empirical observations describing essential characteristics of a phenomenon (Railsback and Grimm, 2012). The term stylized facts is borrowed from economics (Kaldor, 1961), where it is used both to motivate the construction of a model and to validate it. We apply this approach most clearly in our case of the pork cycle - without mentioning the term stylized fact in that chapter. We take the classical pork cycle pattern, which is a nice example of a stylized fact, to be the starting point of our model: can we reproduce this pattern by modelling individual behaviour only? In our other cases we have emerging patterns that we try to understand, but these are not so evidently stylized facts. We could call them, however, 'macro-level regularities', another term Gilbert likes to use (Gilbert, 2008, p. 33). The extent at which these patterns emerge depends on the inputs we provide, which is the relationship we seek to explain. This category of middle range agent-based models, to which our work belongs, is not useful to make predictions in specific real-world cases, but is meant to be used to explore plausible explanations of phenomena.

In the sections below we first elaborate on the research activities that fit in Hevner's relevance cycle and that are not mentioned elsewhere in the thesis, or only briefly: these concern a field study in China and a mini-traineeship in the Netherlands, both of the pig sector. Next, we explain the coherence of our cases (Hevner's design cycle). Most thesis chapters are self-explanatory with respect to the model and research questions they address, but do not answer the question: why did we choose the case the way we did? What is specific for each case, and what was our evaluation of the case that led to the choices made for the next case?

2.1 Relevance: Field study in China

Prior to our cases we carried out an exploratory field study in China, which we now classify as belonging to Hevner's relevance cycle. This field study was essential in the sense that it provided the empirical foundation of our first conceptual model: the Chinese pig sector, with a focus on information management, addressing multiple levels. Throughout the thesis the pig sector has continued to be our model case, except that in the latter cases it was no longer the Chinese but the Dutch pig sector. The conceptual model formed the basis for our first agent-based model, the pilot study in this thesis. Results from the field study were presented in (Osinga et al., 2010b). The field study took place in 2006. We interviewed 40 stakeholders throughout the pig sector in China, face to face interviews with help of an interpreter. Half of the interviewees were pig farmers, the other half were representatives of slaughterhouses, processing companies, feed sellers, a pig dealer (intermediary between farmer and slaughterhouse), and a livestock bureau official (LBO). They were mainly from Greater Beijing and from high pork production provinces Anhui and Sichuan. These interviews gave us a qualitative understanding of (variations of) the pork chain, the issues stakeholders had to deal with, how they managed information, and the role of the government. Later in 2006, survey data were collected by survey teams for 223 Chinese pig farmers in provinces Sichuan and Anhui. The survey concerned farmers' information management practices, supply chain partner relationships, peer relationships, access to services, governmental institutions experiences, farm data and personality-related questions.

	Total		Anhui		Sichuan	
Freq. of LBO visits	n	%	n	%	n	%
Never	81	36	28	31	53	39
1-6 times a year	17	8	9	10	8	6
Once a month	55	25	27	30	28	21
Twice a month	44	20	22	24	22	17
Every week	17	8	4	4	13	10
Every (other) day	9	4	0	0	9	7
Total	223	100	90	100	133	100

Table 2.1: Frequency of visits of Livestock Bureau representatives as reported by the farmers in provinces Anhui and Sichuan.

2.1.1 Conceptual model

The conceptual model is based on the field study and reflects what we had in mind when we started our first agent-based model. It takes the perspective of the pig farmer, and holds the assumption that improving information provision to individual farmers will increase the sector's average product quality.

Informing behaviour of the government

The livestock bureau is a governmental institute that implements national policy at provincial level. It delegates to county bureaus that send out their officials to villages to address the farmers in their districts and pass relevant information on to them. They inspect, give instruction, and distribute medicines. There are also veterinary service providers or independent companies who offer services to farmers. Not all farmers receive information and service equally frequently. Table 2.1 shows the visit frequencies of the LBO as reported by the farmers themselves. More than a third of the farmers never see anybody, about 45% of the farmers receive a visit once or twice a month, and a minority gets even more frequent visits. There are no significant differences between response in Anhui and in Sichuan.

The farmers were also asked what services were offered to them by the LBO, a veterinarian, or a company. Table 2.2 shows the results (jointly for both provinces). The LBO comes out as most important to the farm for all types of services. The LBO offers medical services and training, informs about rules and regulations, and inspects the farm for the majority of the farmers. A large group of farmers either never receives any services, or prefers to do everything themselves: in total, they form about one third of all surveyed farmers. Companies are relatively active when it comes to offering training services (18% of all farmers), which is almost as much as the LBO. These companies are often feed companies, interested in contracting farmers to buy their feed more regularly.

	Medical services		Training (pig raising, quality, hygiene)		Inform about rules, regulations		On-farm inspection	
Service by	n	%	n	%	n	%	n	%
Not offered to me	12	5	46	21	63	28	56	25
Offered, but not accepted	53	24	36	16	40	18	25	11
LBO	122	55	85	38	111	50	134	60
Veterinarian	30	13	12	5	0	0	1	0
Company	5	2	40	18	8	4	7	3
Other	1	1	5	2	1	0	0	0
Total	223	100	223	100	223	100	223	100

Table 2.2: Answers to the question: "Were the following services offered to you, and if so: by whom?"

Social network of farmers

We learned from our qualitative interviews that farmers share practices with each other, especially with family members and neighbours. Also, we noticed that groups of related farmers may share certain beliefs regarding e.g. hygiene or feed quality. It seems very plausible to assume that their social network plays a role with respect to the information they have at their disposal, and when making decisions.

We asked the farmers what information they exchange with whom, i.e. what issues they discuss with others. Their responses were aggregated in Table 2.3.

Table 2.3 shows that most issues (pig raising, housing, quality, ideas and plans) are discussed with family members and friends, i.e. within the social network. Also, 40% of the farmers in our dataset are member of a farmers' organization. Farmer organizations form another platform for interaction and exchanging information.

Discuss / exchange info with whom?	Price & market	Pig raising housing	Pig quality	Health safety	Ideas & plans
Family and friends		x	x		x
Pig buyer	x				
Livestock bureau			x	x	

Table 2.3: Summary of data showing what issues farmers discuss with whom.

	Total		Anhui		Sichuan	
Main pig buyer	n	%	n	%	n	%
Another farmer	4	20	1	1	3	2
Pig dealer	106	48	53	60	53	40
Slaughterhouse < 5 pigs/day	35	16	12	13	23	17
Slaughterhouse 5-100 pigs/day	19	9	10	11	9	7
Slaughterhouse >100 pigs/day	54	24	11	12	43	32
Other (company, school, gov.)	4	2	2	2	2	2
Total	222	100	89	100	133	100

Table 2.4: Overview of farmers' answers to the question "Who is your main pig buyer?"

Business network of farmers

China's pork chain is dominated by many small-scale pig farmers who sell their pigs to individual intermediaries ('pig dealers'). From the qualitative interviews, we learned that farmers sometimes have an agreement with a small, local slaughter who sells the meat himself in the same neighbourhood. Others arrange their pigs to be taken to middle-sized slaughterhouses with a capacity of less than 100 pigs per day, the meat of which goes to the so-called wet markets (fresh meat markets in market squares). Or they deliver to larger slaughterhouses that have contacts with restaurants or local supermarkets. Direct contact with a slaughterhouse is worthwhile for a farmer, because it requires no profit to be earned by an intermediary pig dealer. Not all farmers manage to have these contacts. Table 2.4 shows the type of pig buyers of our surveyed farmers.

About half of our farmers indicate that they do business with 'pig dealers', who contact them and come to take their pigs. That is easy for the farmer, but he runs a risk of losing money because of lack of price transparency. About a quarter of our farmers' pigs go directly to a slaughterhouse that processes more than 100 pigs per day. The other quarter has direct slaughterhouse contact, but with a smaller slaughterhouse. There are slight differences between Anhui and Sichuan, but the overall picture is very similar in both provinces.

Motivations, abilities and actions of farmers

For every decision to change something about their business, farmers have an underlying motivation. Motivations and abilities are difficult to measure directly. Actions are quite measurable, both as in farmer behaviour and in resulting outcome. The farmers of our dataset were asked whether they made any recent changes to their pigs' housing, how much investment those involved, and whether they were able to get a loan for it. Also we asked them why they did it. From our 223 farmers, 77 had changed their pigs' housing during the previous five years, and succeeded in raising the money for it. Concerning the reasons why they changed their pigs' housing, 55 indicated because of volume increase, 9 because of quality considerations, and 1 because of obligations from a company that had offered him a contract. As for the money: farmers were very reluctant to talk about money at all. Some said they saved it themselves, others said they borrowed it from family.

2.1.2 Suitability of this case as basis for agent-based model

In 2009, when agent-based modelling entered our research thinking, we concluded that the field study from 2006 and the conceptual model we made were well-suited as case for our first model. In retrospect, the following characteristics make the case very suitable for an agent-based model with multiple levels:

- **Clear top down strategies**. China has clear targets in times when economic growth seems unlimited: both pork volume and quality must increase. To this end, information (i.e. advice and training) needs to be spread among the target population. Especially for quality targets, product information also needs to be managed for tracking and tracing purposes. (Source: the China daily online newspaper articles, e.g. China Daily, 2007).

- **Strategies are implementable in a straightforward way**. Unlike Europe, China's centralized government has the power to implement measures in a relatively short time, in a vertical chain through successively lower levels of government. (Source: apart from what we learned during our field study, this was also the message of a course I followed, "Superpowers in global environmental politics: China and the US", given by our graduate school in 2007).

- **Success of strategy depends (also) on person delivering it**. Governmental measures are carried out by provincial livestock bureaus, who delegate to county bureaus that send out their officials to the villages to address the farmers in their districts. Therefore, much of the effect of a measure depends on the actions of these officials (LBOs), which may differ from person to person. Our qualitative interviews and survey confirmed that farmers experience these differences.

- **Bottom-up behaviour: population of autonomous individuals**. The Chinese population of pig producers consists of many farmers who, on average, have relatively small numbers of pigs. But together, they are responsible for a large share of national production: in 2005 an estimated 80% according to the literature (Pan and Kinsey, 2002; Fabiosa et al., 2005). This will have changed by now, but it is most likely still a majority. It would be desirable to address them all at once, but this is impossible. To visit every single farmer is not cost-effective, and technological means (like computer systems and internet) are not yet well developed or available to the average farmer.

- **Population is heterogeneous**. Any other strategy than direct visits to reach the target population implies assumptions about whether the information will actually reach the farmers and whether they will adopt the advice. Much then depends on the social network, the personal situation and idiosyncratic attributes of the farmers.

- **Enforcement is problematic**. Processors (like slaughterhouses) are obliged to check and register whether farmers have followed certain rules. However, technological support to make these checks is not sufficiently available, also because the population of farmers is very large. Farmers (or slaughterers) may know 'a way around' and do not suffer too severe consequences for doing so. This means that following the rules depends on other things than plain enforcement.

- **Feedback / feedforward loops, or: consequences of decisions**. Behaviour is not independent: like disease, it can be contagious within a population. If one farmer gains profit from his decision (in money, or in reputation), he will do it again, and it is likely that others will follow his example. Such influences add extra dynamics to a population, and changes in behaviour. The pork cycle (Harlow, 1960) is an iconic example in this respect.

2.1.3 Concluding remarks on field study China

This field study provided the ingredients for the conceptual model underlying the cases throughout this thesis. The pilot study implements it most directly, as can be seen in Chapter 3. The subsequent cases make abstractions, but the essence remains: heterogeneous farmers, who seek to increase their pigs' quality, try to find profitable markets to sell them to, base their decisions on information brought to them by the LBO, and share this information within their social network.

2.2 Relevance: mini-field study in The Netherlands

After returning to the Netherlands, I followed a mini-traineeship in 2007 to get more acquainted with the Dutch pig sector. I spent two days at Nutreco Swine Research Centre, where innovative concepts are investigated in an experimental farm setting. I helped taking basic care of the pigs, feeding them and transporting them internally. Meanwhile I learned a lot from my supervising researcher.

I spent another two days with a representative of Hendrix Feed, who made on-farm visits to Dutch pig farmers. I learned what it means to manage a pig farm, how farmers handle disease or health problems, with whom they discuss issues. Apart from fattening farms, I also visited a sow breeding farm.

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Striking differences with China are that Dutch pig farmers get many visits from feed seller, veterinarian, pig buyer (pig transporter), or deliverer of piglets. Also: Dutch pig farmers are reluctant to visit or invite other farmers because of hygiene issues. The farmers I visited indicated that they do not often exchange information with other farmers. And: regulations in The Netherlands seem to demotivate the farmers. They complained that the quality control system IKB is so strict. Already these farmers were thinking of investing in air scrubbers to reduce emissions, a regulation which was to be effective as of January 2013, to which they objected unambiguously.

At the sow breeding farm I heard the farmer discuss the group housing arrangement for sows, I learned that many animal management activities are automated (feed intake, climate control), that managing a sow breeding farm means to "observe, observe and observe", to notice it when something is strange, and to take timely action if that is the case.

2.3 Design cycle: coherence between cases

This section describes the coherence between my cases. For each case I start with a summary, specifying why this case was important, what the model's representation of knowledge is, which behavioural freedom farmers have, and what the simulation experiments tested. Then follows a more extensive description of the model. Finally, the evaluation gives the simulation experiments' outcomes, what kind of analysis we applied and what we learned from this modelling exercise.

2.3.1 Pilot study: Chinese quality markets model (Chapter 3)

Summary

The pilot study's objective is to model a real-world case, namely: how changing the demand per quality segment (a sector-level property) affects individual behaviour of farmers, and vice-versa. Farmers supply to a quality segment based on their information, which is a one-dimensional proxy for their quality level. Farmers have several behavioural options. A demand change affects how successful they are, which affects their satisfaction level (an individual property), which motivates them to change quality segment. The simulations test the effect of changing a system-level property (demand) and an agent-level property (frequency of information supply) on quality shares. Heterogeneity is another agent-level property present in the model (reflecting satisfaction) but its effect was difficult to evaluate due to model denseness.

Description

The conceptual model resulting from the Chinese field study forms the basis for the pilot study's agent-based model, in all its richness. The purpose of the model was inspired by a news item reporting that the local Chinese government in a town in Guangdong had assigned all live pig supply to one particular wholesaler, which resulted in the closing of 60 pork shops. How would farmers respond to such a sudden change in demand? The model has farmer agents, buyer agents and an information provider agent (LBO). Buyer agents belong to a quality market, and buy pigs from farmers until demand for that quality is satisfied. Demand is defined at system level. Farmers collect information items (discrete, numerable items that add up) which reflect the quality level of their pigs (and the price they get). Every time step in the simulation, farmers receive 'time units' to spend on actions (they have an action repertoire of 4 behaviours, each lasting for a various number of time units, of which only a few can be completed during one simulation's time step), coordinated by a messaging system. We equipped the agents with Costa and McCrae's Big Five personality attributes, but in the end we decided to use only 'openness' (Costa and McCrae, 1992). Farmers have a 'target market' for which they have to collect information items until they qualify. Farmers have an attribute 'satisfaction', calculated from how well they sold their pigs in the previous time step. The decision to change target market is based on their satisfaction: when satisfaction drops below a threshold, they change their target market, and go there as soon as they qualify. Satisfaction is updated by a reinforcement mechanism: increase of satisfaction happens according to a different mechanism than decrease. Farmers do not have any money: an implicit price mechanism (based on given demand) regulates whether they sell their pigs or not. The information items are one-dimensional (i.e. no distinction between types of information).

Evaluation

This was our first attempt at building an agent-based model (implemented in Repast Symphony), which was very rich compared to our later models. It turned out that we could only have a population of 10 farmers in our model, or it would become too slow. We varied selected parameters systematically (demand, information supply rate), but there were many more parameters that needed an initial value as well. We could produce output pictures to show the results from our structured variations, which made sense, but our model was essentially a 'black box' to us. We could not inspect the model data in a reliable way because there were simply too many parameters and too many mechanisms. We decided that our next attempt would be a very simple, sparse model.

2.3.2 Case: Pork cycle model (Chapter 4)

Summary

The objective is to see whether we can recreate a well-known stylized fact - an emerging pork cycle of periodic over- and under-supply - when we model only local behaviour of individuals. Farmers' information (a static, personal property indicating how informed they are) determines their accuracy to predict the next pig price. Their decision is: to restock their stables or to skip. Their motivation for this decision is their (personal) expected price. The simulation tests various levels of informedness.

Description

Again inspired by the Chinese case, the idea was: instead of letting the government intervene (as we learned happened in China), we can increase farmers' knowledge to make better price predictions and avoid the pork cycle. In this model there are only farmers, no markets, no information provider, and no information exchange. Farmers sell in batches, to create a time lag. Farmers are stripped from their personality, their satisfaction attribute, and their time units. Each farmer is assigned a random number of information items, indicating how informed they are. There is a supply- and demand mechanism which would produce a stable system if all farmers would use the hypothetical equilibrium price. Instead, we let all farmers determine an expected price: the better informed they are, the closer this expected price approximates the equilibrium price. Based on their expected price, the farmers decide whether they will restock their stable or not (which seems a realistic choice for Chinese pig farmers). When expected prices differ too much from the equilibrium price, this leads to over- or under-supply.

Evaluation

We were surprised to learn that a sparse model like this, implemented in Netlogo (Wilensky, 1999), could indeed reproduce patterns similar to the pork cycle. We learned that farmers can behave in a heterogeneous way just by assigning them a random attribute (in this case: information items), instead of giving them explicit personality attributes like in our previous model. The randomness causes variation in the population, which is sufficient for our aim. With respect to analysis: we applied a Fourier transformation (designed for wave frequencies) to evaluate whether there was periodicity or not.

2.3.3 Case: Markets model, multi-dimensional information (Chapter 5)

Summary

This model's essence lies partly in its enriched knowledge representation: it differentiates between several types of information and the personal value of information to its owner. The same representation is used to express a market's quality criteria: a farmer qualifies if there is a match. The objective is to model what effect changing agent-level properties (i.e. information supply frequency and network structures between farmers, both affecting how much information they have) has on system-level outcome: emerging quality market shares. Farmers' only decision concerns a boundedly rational evaluation of an alternative market, possibly resulting in changing to that market. The simulations test agent-level properties (as mentioned) and also test the effect of various market sets (a sector-level property) on emerging quality market shares.

Description

Knowing now what the power of a simple model can be, we decide to make a remake of the pilot study model, this time in Netlogo. We want to enrich the representation of information items and include *type* and *value* in the information items definition. Value is an abstraction of heterogeneity: it expresses what an item is worth to a farmer, regardless of the reason why (due to personality, experience, timing, relevance, or still other reasons that do not concern us). Farmers are also heterogeneous with respect to the number of information items they have. Information items are directly exchangeable between agents, not through a messaging system. Information items are no longer static but have a life time and also become obsolete. We re-introduce the information provider agent, now called 'institution'. Markets are no agents, but expressed as a parameter: a list of requirements and price components. Their requirements are expressed in terms of the same types and values as the information units. A price mechanism similar to that of the pork cycle model is used by farmers to decide whether to change market or not (instead of the earlier used satisfaction mechanism). Farmers no longer sell in batches, but all at the same time, because the pork cycle is no object of research anymore. Farmers have no target market, but only a current market. Farmers' decision mechanism (to change market or not) is restricted by bounded rationality. The model is more generic (no longer Chinese), and could even be applicable to other supplier-market cases.

Evaluation

We have trust in this model; it is indeed transparent, and we can understand its behaviour. The model behaves in a plausible way, at least to our own judgment. We learned that information supply rate is more important than network typology. We discovered that niche markets are attractive sometimes. Analysis-wise we took an effort to summarize results (two-step visualizations) and we did some post-processing.

2.3.4 Case: Increase the quality of information (Chapter 6)

Summary

This case's aim is to extend the knowledge management paradigm of the previous case's model (Chapter 5) with a new feature: to add a mechanism to increase the quality level of farmers' personal information. The objective is similar to that from the previous model, and also farmers' decision mechanisms do not change, only the collection of info-units has been filtered: low-quality information items are no longer there. The simulations test the effect of changing agent-level properties (quality of farmers' information) on emerging quality market

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shares. The focus is also methodological: can we keep the former and the extended model's outcomes compatible? We also include a sensitivity analysis.

Description

In the previous model, we learned that information supply rate, or: the information turnover, is very determining in the model. This triggers our next idea: since we represented information items as multi-dimensional, would it make sense if we discriminated between information that is valuable and information that is not? We decide to change the mechanism by which information becomes obsolete. We try two new mechanisms: maintaining information based on *value* (which is a personal property that differs per owner of the information item), or protecting information that is *in use* (whether the farmer needs this information item to supply to his current market, also different per owner). For this latter mechanism, we extend the information representation with an *in-use* property.

Evaluation

The changed mechanisms give some surprising results: initially, maintaining higher quality information (the value-threshold mechanism) leads to reaching higher markets. But there is an emerging pattern: maintaining too high quality information leads to a decrease again. (We name this 'boomerang' pattern, after the shape of the resulting graph). The mechanism to protect in-use information mainly reinforces the threshold-effect. With respect to methodology: we added a verification step to ensure that model outcomes with the mechanism are still comparable to the model outcomes without the mechanism. Analysis-wise: the sensitivity analysis (one-at-a-time and two together) gave us insight in relative influence of model parameters.

2.3.5 Case: System-level change: two intervention policies (Chapter 7)

Summary

The purpose is to model a system-level intervention by comparing two alternative policies. The objective is similar to that from the previous model, and also farmers' decision mechanisms did not change. The model is modified by adding a mechanism to activate a policy (to close a market) at a given time step - this mechanism can also be switched off. The simulations test the effect of changing a system-level property (demand) on emerging quality market shares.

Description

After having done three cases in which we varied properties at individual level, we wanted to do a case of a variation at system level. Inspired by a Dutch topicality (retailers jointly deciding that all pork meat should be of minimal certified quality level), we modelled the intervention of closing the lowest quality market. We implemented two intervention policies: remove the market either by 'sudden death' (close immediately) or by 'graceful degradation' (no market entry for newcomers, but current suppliers may stay until they voluntarily leave). With this case we returned to our pilot study, because closing a market is in fact a demand variation. This time, the demand change is a real intervention and happens halfway the simulation. We extended our model to allow for an intervention at a certain time step ('shock at').

Evaluation

Our results indicate that 'policy doesn't matter' for end result, but does matter during transition period. Most interesting is an emerging pattern with the graceful degradation policy: the 'Gini-bubble', indicating a temporary higher wealth inequality. The current model outputs do not allow us to inspect what causes this bubble, because we did not record all raw, individual farmer data. This is a step-up to our synthesis article, in which we want to make sure that we can do proper multi-level analysis to resolve this issue. Methodologically, we verified again that the model with the mechanism switched off produces the same results as the model before the mechanism was added. We used Troitzsch' test to assess how many model runs we needed.

2.4 Rigour cycle: synthesis chapter combining last three cases (Chapter 8)

Summary

The synthesis chapter no longer belongs to the design cycle, but to the rigour cycle, because it reinforces the last three cases by repeating all experiments. This chapter essentially focuses on methodology: all cases are redone with more simulation runs, and all cases are more thoroughly analysed. Specifically, multi-level analysis is applied to explain patterns on system level through agents' individual behaviour. Assumptions that were so far implicitly based on empirical evidence from the field study are now described and grounded in literature. We use expert validation to evaluate the plausibility of model outcomes and the explanations we provide from model inspection.

Description

The chapter starts with explicitly stating what our model assumptions actually are. So far, we only empirically grounded the model through the conceptual model resulting from the Chinese field study. This time, we also link the assumptions to theories and findings from literature. We redo the three last cases, applying Troitzsch' test to all of them to determine the amount of runs we need to do per experiment. We use the first case (Chapter 5) to inspect inter-run variation (we may have done sufficient runs, but how much variation is there between those runs?) and to see if we can gain additional insight from 'outlier-analysis'. In conventional models, outliers are often neglected, but the essence of agent-based modelling is that 'the individual matters'. We use the second case (Chapter 6) to see whether multi-level analysis can explain the boomerang pattern that we detected there. We use the last case (Chapter 7) to inspect the cause of the Gini-bubble pattern. To be able to do multi-level analysis on those patterns requires that we re-run the model with those parameter combinations that produce the pattern, but now saving all individual data, that were previously not recorded. We can then inspect this data in order to find an explanation for the pattern.

Evaluation
We learned that it pays off to pay attention to keep successive model versions compatible: we could re-run all previous cases with the latest model version without obtaining contradicting results. We also learned that it pays off to automate the simulation experiments set-up and results processing, because re-running also gave no trouble in this respect. The multi-level analysis was successful, although tedious because the individual inspection was not yet automated. The expert validation was very valuable. Experts could indeed judge whether our model results and explanations were plausible, but they could also give their opinion on our model, its assumptions and mechanisms.

2.5 In conclusion

Hevner's research framework is helpful in distinguishing between the three different cycles: the relevance cycle, the design cycle, and the rigour cycle. We have shown where all cycles are present in our research. What Hevner does not highlight so explicitly is the process of how to alternate between the three cycles and that the chronological order in doing so is an exercise of incremental learning. In that sense, our research is a complex adaptive system itself, where experience and insight gradually emerge.

Preface to Chapter 3

Pilot study

's Ochtends als hij wakker werd wist de eekhoorn soms niet goed wat hij denken moest van zichzelf.

Hij rekte zich dan uit en vroeg zich af: zou ik nu besluiteloos zijn? Dan dacht hij enige tijd na over de besluiteloosheid. Hij vond het een mooi woord, besluiteloosheid, maar hij kon er nooit goed achterkomen wat het precies betekende. Vervolgens zei hij tegen zichzelf: 'Eekhoorn, doe nu óf gewoon óf ongewoon óf iets nieuws óf niets óf je kleren aan.'

Meestal deed hij dan het vierde: niets. Maar als hij een tijdlang niets gedaan had kon hij ontevreden worden over zichzelf en roepen: 'Eekhoorn, kies nu of kies niet, één van beide! Desnoods slaak je een zucht.'

Als hij dan niets koos was hij toch tevreden want dan had hij de tweede mogelijkheid gekozen.

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Sometimes when he woke up in the morning, the squirrel wasn't sure what to make of himself.

He would have a good stretch and ask himself: am I indecisive now? Then he'd think about indecision for a while. He liked the word, indecision, but he could never really figure out what it meant exactly. Next, he'd tell himself: 'Squirrel, just get going or get out or get adventurous or get stuck or get your clothes on.'

Usually he'd take the fourth option and got stuck. But then, after being stuck for a while he grew disgruntled with himself and cried out: 'Squirrel, either decide or don't decide, one of the two! Heave a sigh if you must.'

If he didn't decide he'd be satisfied after all, because he'd taken the second option.

Chapter 3

An agent-based information management model of the Chinese pig sector

Abstract. This paper investigates the effect of a selected top-down measure (what-if scenario) on actual agent behaviour and total system behaviour by means of an agent-based simulation model, when agents' behaviour cannot fully be managed because the agents are autonomous. The Chinese pork sector serves as case. A multi-level perspective is adopted: the top-down information management measures for improving pork quality, the variation in individual farmer behaviour, and the interaction structures with supply chain partners, governmental representatives and peer farmers. To improve quality, farmers need information, which they can obtain from peers, suppliers and government. Satisfaction or dissatisfaction with their personal situation initiates change of behaviour. Aspects of personality and culture affect the agents' evaluations, decisions and actions. Results indicate that both incentive (demand) and the possibility to move (quality level within reach) on farmer level are requirements for an increase of total system quality. A more informative governmental representative enhances this effect.

3.1 Introduction and background literature

Often, there is a discrepancy between the desired effect of a policy measure and its actual effect, which is a result of failure to account for the behaviour of the target population. A recent example from the Chinese pork sector was reported in the China Daily of January 7, 2010 (China Daily, 2010). Because of pork quality and safety reasons, government officials in Gaobu town of Dongguan in Guangdong province contracted the supply of live pigs to one particular wholesaler, under the impression that this would not affect the general market order. As a result, over 60 pork shops in the largest market in town for fresh pork were closed due to the burden of increased costs. Since pork is a major food in China, especially during the holiday season, this caused a strong dissatisfaction among the town residents.

The objective of this study is to gain insight in the relationship between sector level information management strategies and actual behaviour of individuals. This insight is obtained by means of agent-based modelling, because this allows us to perform simulation experiments on the behaviour of individuals which are impractical or impossible in the real world. The objective can only be met by applying this general problem to a suitable realistic case. In the Chinese pork sector the government has targets and requirements, but the majority of producers consists of individual farmers who act on their own authority. A research assumption is that in order to reach the government's targets or to fulfil their requirements, farmers need to have certain information. The government can make an effort to disseminate this information, but whether the farmers receive it and act upon it as well, is something beyond control of the government.

Up to now, information management theory has applied a normative approach: information management models usually depict a priori designed flows of tasks, procedures and responsibilities. However, little research has been done to measure the actual effectiveness of applying such models (Hamill and Gilbert, 2009). Research does indicate that there is a gap between the high-level models and the actual behaviour of individuals: information in social and professional networks does not only travel along the lines of formal models (Brown and Duguid, 2002). This is especially true in rural communities (Isaac et al., 2007). Information management as a research field is currently in need of models that integrate actual behaviour with prescriptive models (Dimitriadis and Koh, 2005). Such models should allow system level interventions as well as include behaviour of individual actors who are part of the system, where much also depends on the interaction structure between individual actors. This boils down to a multi-level system view.

Agent-based modelling (ABM) is becoming popular in the social sciences and also in information management because it allows representing individual behaviour as a conjunction of reasoning (decision making), personality and values (Gilbert, 2008). Focussing on model purpose, Gilbert divides multi-agent models into facsimile models, abstract models and middle range models (Gilbert, 2008, p.40 et seq.). Middle-range models aim to "describe the characteristics of a particular social phenomenon, but in a sufficiently general way that their conclusions can be applied widely". Gilbert introduces the aspect of qualitative resemblance. Moss (2002) specifies this as: "The dynamics of the model should be similar to the observed dynamics, and the results of the simulation should reveal the same or similar 'statistical signatures' as observed in the real world; that is, the distributions of outcomes should be similar in shape". Our conclusion is that the strong points of ABM match the requirements of our study, and that a middle-range model fits best to integrate a multi-level view in an information management domain.

As a case study, we model Chinese pig farmers who run a family business and earn a living out of pig farming. The majority of Chinese pig production, which adds up to 50% of all pork in the world, comes from small-scale farms with up to a few hundred animals (Fabiosa et al., 2005). The case is significant because it helps to gain insight into opportunities for this sector to enhance product quality by means of improved information management strategies.

Furthermore, the choice for this case study was made because it has characteristics that are very attractive for a multi-level agent-based simulation model.

Most prominent is the fact that multiple levels are a characteristic of Chinese society: unlike the Netherlands, China's centralized government has the power to implement measures in a relatively short time, in a vertical chain through successively lower levels of government. Responsibilities are person-based rather than rule-based within a multi-layered hierarchical structure (Jahiel, 1998). The government has clear targets in these times of economic growth: both pork volume and quality must increase (China Daily, 2007). It would be desirable for the government to be able to address all farmers at once, but this is impossible. To visit every single farmer is not cost-effective, and technological means (like computers and internet) are insufficiently available for any chance of success. The population of farmers is heterogeneous: any strategy implies assumptions about whether the information will actually reach a particular farmer and whether he will adopt the advice (Narrod et al., 2006). Much depends on farmers' social network (Lu, 2007), personal situation, personality (Costa and McCrae, 1992) and values (Hofstede and Hofstede, 2005).

Finally, behaviour is not independent: like fashion, it can spread within a population. If one farmer gains profit from his decision (in money, or in reputation), he will do it again, and it is likely that others will follow his example. Such influences add extra dynamics to a population, and even cause sweeping changes in behaviour. The hog cycle (Harlow, 1960) is an iconic example in this respect. The aspect of feedback/feedforward loops and the emerging behaviour make the case very interesting for the ABM research community.

3.2 Problem definition

The specific focus of this paper will be on the representation power of agent-based modelling when applied to the Chinese pig farmer case, and to simulate the effect of a selected top down policy measure (what-if scenario) on actual agent behaviour and total system behaviour. The research questions are: Can we adequately represent the real-world case, and: can we implement the selected scenario and how plausible are the effect(s) that we find in reality?

Figure 3.1 shows our conceptual model from focal farmer perspective. We apply three modelling levels (system, agent and interaction level) as described in (Dignum, 2004). System level characteristics include informing behaviour of the governmental Livestock Bureau Official (LBO) and the availability of suitable supply chain and network (SCN) partners, i.e. pig buyers, and other farmers (friends). Interaction level characteristics entail opportunities to meet business partners and friends. Agent level characteristics include personality characteristics (motivations and abilities) that influence the actual application of acquired information (Osinga et al., 2010b).

We assume that more information leads to higher quality pigs, provided that (a) the information reached the farmer and (b) the farmer chose to apply the knowledge. We also assume that a farmer with a social network can share his friends' knowledge more easily than a farmer who has no such connections.

For the sector as a whole, representation of farmers in all market segments is desirable. The best system behaviour is not simply to attain a total pig quality as high as possible. Demand varies with respect to specific products and also depends on marketing channel. Certain pork products require high quality pig meat (e.g. cutlets for restaurants), but it is more practical to use lower quality for other pork products (e.g. sausages for the fresh market). Ideally, there is a balance between supply and demand for certain quality. When demand changes - a global, system level change - farmers should take decisions as well - at local level - in order to adapt.

The system level intervention we select for our what-if experiment is to diminish the demand for low quality pigs, inspired by the news article we used in the introduction of this paper. Based on the situation and how they evaluate it (resulting in a certain state), farmers decide to take action. They can choose (a) to do business as usual and face the consequences, (b) to change to another pig quality level - provided that they have the required information - and (c) to quit pig farming.

In order to determine system behaviour, outputs of model versions are compared with respect to the total quality of pigs in the system as well as total farmer's satisfaction, determined by market conditions and farmer personality.

3.3 Methodology

For developing (versions of) the agent-based simulation model, we apply principles of incremental software design. For the specific agent-based development steps we follow state-of-the art ABM-modelling principles as laid down by Gilbert (2008). We designed a basic version of the agent-based model, the so-called base-ABM. This is a computer model containing all elements specified in the conceptual model. We then inspected the behaviour of the base-ABM by means of a sensitivity analysis that investigates all relevant parameters' and their combined values' effect on the observables. For this paper, we implement the selected what-if scenario in the base-ABM, resulting in a new model version (experimental ABM). We run the experimental ABM and compare the outputs with those from the base-ABM, with respect to the observables specified earlier. We interpret the results and draw conclusions for each of the research questions.

3.3.1 Mechanism

We implemented the base-ABM model according to the MASQ framework (Ferber et al., 2009). MASQ divides agent logic into Mind and Bodies, which communicate inside a Space (Fig.3.1). Culture gives the common patterns employed in minds for interpreting interactions that take place in a space.

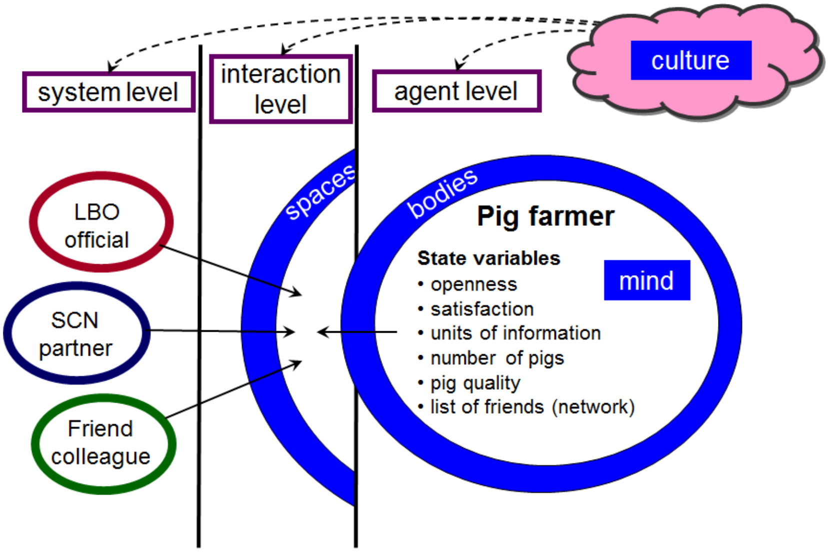

Figure 3.1: Conceptual model for our agent-based model from viewpoint of focal pig farmer, with multiple levels (system, agent, interaction). References to MASQ-architecture (mind, bodies, spaces, culture) are explained in section 3.3.1.

The main logic of an agent is located in its mind. The (one or more) bodies serve for communicating with other agents and (one or more) shared environments. Each body receives stimuli from a space, and produces actions in a space. Communication with other agents is mediated by the space. The idea in MASQ is that each different kind of interaction takes place in a specialized type of body. Thus one agent has one mind but as many bodies as necessary to define the different kinds of interactions.

For the model described here, we have three types of agents: pig farmers, SCN partners (buyers), and Livestock Bureau Officials (LBO). Currently, we have only elaborated the behaviour of the pig farmers. The other types of agents communicate with the pig farmers (mediated by spaces), but not with agents of their own type. Pig farmers communicate with other pig farmers in several ways for various purposes. For each kind of communication, a pig farmer agent has a separate body.

In our model implementation we use a message passing mechanism where all messages between agents are buffered in corresponding spaces. In this way the operations of all agents are decoupled and it is easy to organize the behavioural logic of agents. The effect of a body receiving a message is that the agent registers a change of state, which in turn influences all decisions made from that moment on. Decision making resides in the mind of the agent. So the mind interprets all information perceived through bodies and combines that information with its current state to alter the state and potentially send out information to spaces through one or more bodies.

Effectively, the possible actions of an agent are defined by the state of the agent when a message is processed - not necessarily when it is received. The full state of an agent is defined by the (values of) all its state variables. To specify behaviour, we distinguish two levels: at an aggregated level the kind of behaviour differs essentially between actions, whereas at a detailed level behaviour is expressed in terms of all state variables.

The model is set up as follows. Agent types are: farmer, buyer and LBO. Every month, each farmer has a fixed number of pigs of certain quality for sale. Quality is reflected as an integer value in the range [1, 100]. The quality is an indicator for the worth of the pig, i.e. its recommended price. Each month, every farmer tries to sell his pigs for this price. Whether a farmer succeeds depends on the demand: whether he can find a buyer who needs this quality. When demand is not sufficient, the farmer will not sell (all of) his pigs, and, as a result, he will be less satisfied. When his satisfaction drops below a certain threshold, he may decide to change his pig quality: either go up or down, dependent of demand. To go down in quality is without cost, but as a consequence, he will receive a lower income. To go up in quality requires that the farmer has enough know-how, expressed as units of information. With each information unit, the farmer's pigs quality level increases by 1. The farmer can obtain information units either from the LBO or from farmer friends.

Buyer agents try to fulfil a demand each month: buy an amount of pigs of certain quality. Demand is defined at system level. At system level, the model works with demand classes, e.g. low, medium and high, specified as contiguous subsets of the total quality range. For each quality class, a parameter at system level specifies the total number of pigs required in that class each month. During a model run, the total demand specified at system level is divided evenly over the buyers in the model. Buyers broadcast messages to all farmers, who may respond with an offer. The buyers evaluate the farmers' offers, and choose the best one, according to their criteria.

LBO agents reflect governmental influence. There is currently one LBO agent in the model. He visits a number of farmers each day, as specified by a parameter. The LBO carries a list containing all information units in the system. He supplies a number of information units to each farmer he visits, dependent on his support level (another parameter). Only new information adds up to a higher quality level. There are 100 unique information units in the system, equal to the maximum possible quality level. During the initialization of each model run, a number of information units is handed out to the farmers. The remaining units reside with the LBO.

3.3.2 Personality characteristics of agents

Agent types have personality characteristics that affect their evaluations and decisions. In contemporary psychology, the "Big Five" factors represent five broad domains or dimensions to describe human personality: Openness, Conscientiousness, Extroversion, Agreeableness and Neuroticism (OCEAN) (Costa and McCrae, 1992). Currently, our model only works with 'openness' (the tendency to try new things or to accept new ideas) and 'extraversion' (the tendency to share information with others). For farmer agents, personality affects their level of (dis)satisfaction, and consequently their decision to change quality. Personality also affects the probability that farmers will aim for a higher quality class (representing something unknown to them). For buyer and LBO agents actions are currently not affected by personality. LBO agents have a 'support level', which should be seen as a system level parameter, because it reflects a society's current practice for institutional support to farmers.

3.3.3 Cultural aspects of agents

For agent-based simulations, comparative models of culture that condense cultures into a limited number of basic issues, and assign comparative scores to cultures, are suitable modelling devices (Hofstede et al., 2010a). The most widely used and validated of these is the model by Hofstede et al. (2010b), and currently consists of six dimensions: Identity, Hierarchy, Aggression and gender, Otherness and truth, Immutability versus pragmatism and Gratification of drives. The dimensions are social patterns, not personality traits.

At system level, our model supports investigating culture effects as well. The cultural dimensions parameters may affect evaluations, decisions and actions of agents. Currently, our model only employs the first dimension, Identity: individualism versus collectivism. This parameter affects the way farmer agents accept other farmers as friends, or select buyers to offer their pigs to: in a collectivistic population, farmers tend to prefer agents who belong to their group, whereas in an individualistic population farmers tend to prefer agents whose quality level is close to their own. Our model allows to divide agents over groups, the default being that they all belong to the same group.

3.4 Simulation experiments and results

One simulation run in our model reflects the passing of a number of months, specified by a parameter. Each month consists of a fixed number of ticks. Every month, agents choose to do specific actions. Each action costs time: choosing one means that there may not be enough time for another action. Buyers and LBOs have only one possible action, but farmers can choose between finding a buyer (sell pigs), improving quality (apply information), socializing (exchange information with farmer friends) and extending friends network (finding new

Experiment	Total demand in Q-class 1	Total demand in Q-class 2	Total demand in Q-class 3
base	100	50	10
nr 1	0	0	160
nr 2	50	100	10
nr 3	30	60	70

Table 3.1: An overview of the demand variations, each time with 10 farmers, 3 buyers and 1 LBO. Total demand over all classes is equal for each experiment.

friends). An action effectively leads to sending messages to other agents. After each tick, all messages are processed, resulting in possible state changes of the agents concerned.

Once every month, the farmers evaluate their situation. They update their satisfaction according to the reinforcement mechanism in 3.1. The value of E_t is based on how well they succeeded in selling their pigs, while their their personality determined the reinforcement weights (r^+ and r^-). If necessary, they may decide to aim for another quality class. To improve quality, they will have to check whether they have enough information units to go there. The effect of arriving at another quality class is that in the next month they will deal with different buyers.

$$\begin{aligned} S_t &= r^+ E_t + (1 - r^+) S_{t-1} && \text{if } E_t > 0 \\ S_t &= r^- E_t + (1 - r^-) S_{t-1} && \text{otherwise} \end{aligned} \tag{3.1}$$

As a base-ABM, we choose a scenario where demand is approximately 80% of supply, where lower quality is preferred over medium quality, and high quality is rarely demanded. We define quality classes as follows: low [1,40], medium [41,80] and high [81,100]. The base-ABM contains 10 farmers and 3 buyers (one in each quality class). The farmers all start in the lowest quality class. Every month they have 20 pigs for sale, so supply is 200 per month. The LBO visits 2 farmers each tick. The model runs for 30 months, 30 ticks per month. All other parameters are set to neutral default values.

Our experiments focus on demand variations, by changing the parameters for total demand in each class. Table **??** gives an overview of demand variations used; overall demand is the same for each demand class variation. Below the table, we give an interpretation of the findings.

- The base model experiment results in satisfied farmers, who are comfortable in Q-class 1 and do not move. See Figure 3.2.

- In experiment 1, farmers do not move out of Q-class 1 either, but this time they are very dissatisfied. But it makes no sense to move to Q-class 2: there is no demand there. Q-class 3 is too far away from their starting situation.

- In experiment 2, the majority of the farmers moves to Q-class 2, because there is a high demand and it lies within reach. None of the farmers moves on to Q-class 3, mainly because they are satisfied in Q-class 2.
- In experiment 3, demand is going up along with Q-classes. The effect is that all farmers gradually increase their quality and change Q-class. Some end in Q-class 3. See Figure 3.3.

Each day, the LBO visits a number of farmers. How many farmers the LBO visits per day is a system level parameter. We repeated the above experiments, with a value of 10 for this parameter, to reflect that the LBO can be fully informative to all farmers. The results of this change are especially interesting in the base situation and in experiment 3:

- In the base situation, a highly frequent LBO speeds up the process of moving up to the top quality level of class 1, but still no farmer advances to another Q-class. See Figure 3.4.
- In experiment 3, a highly frequent LBO manages every single farmer to end up in Q-class 3. So the LBO effectively increased the number of farmers that moved to another Q-class. See Figure 3.5.

3.5 Conclusions and discussion

This paper introduced agent-based modelling as a promising method to gain insight into the relationship between system level interventions and agent-level behaviour. We described simulation experiments that led to the insight that if a change of quality class is desired for a population of farmers, then the 'goal' demand should be posed in such a way that farmers have both the incentive and the possibility to move. A high demand in the goal class (higher than in the current class) serves as an incentive. The possibility to move implies that the goal class should be within reach of the farmers' current situation, since farmers can change quality only gradually.

The effect of increased LBO visitation level is high, especially in situations where demand already gives farmers an incentive to change quality class. In such cases, the LBO can make the difference for certain farmers who would stay behind without this extra 'know-how'. When there is no incentive in the demand situation, the LBO does not have so much influence. However, as the average quality within the quality class increases, the total quality in the system still increases.

Our research questions were: Can we adequately represent the real-world case, and: can we implement the selected scenario and how plausible are the effect(s) that we find in reality? The real-world case at hand was derived from a

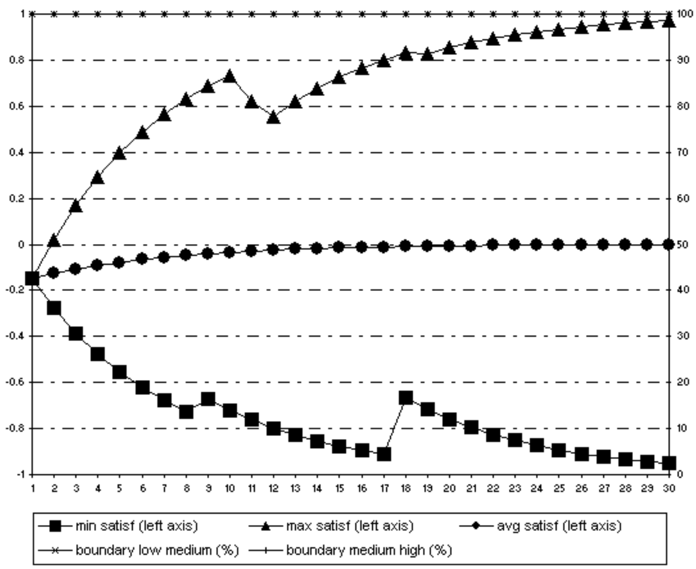

Figure 3.2: Results of the base experiment: all farmers stay in Q-class 1 (low), so boundaries between quality classes are at 100% (small crosses at top of figure).

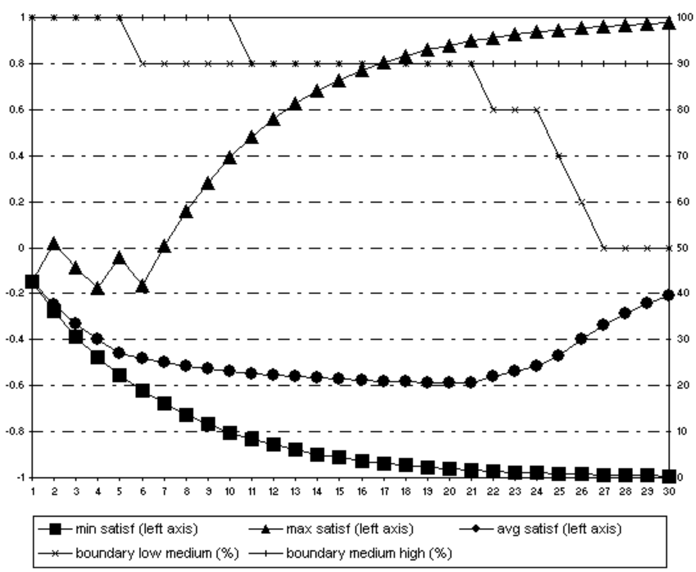

Figure 3.3: Results of experiment 3: all farmers increase quality and some reach Q-class 3.

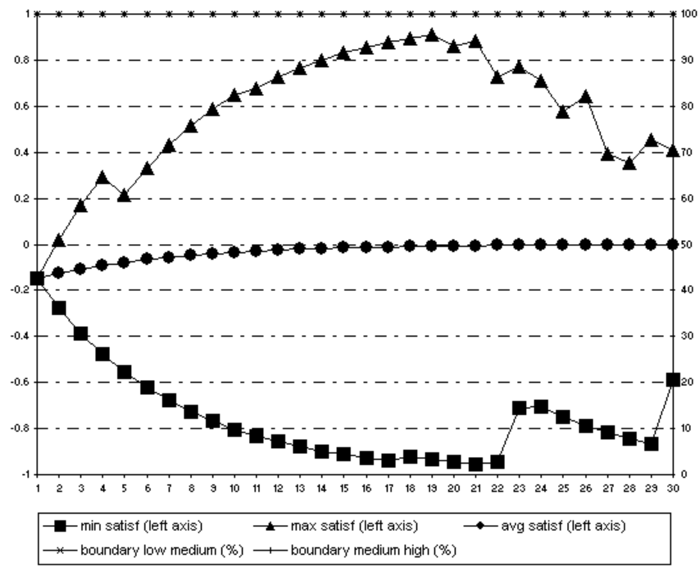

Figure 3.4: Results of the base experiment but with visitation level 10. Still, no farmer moves.

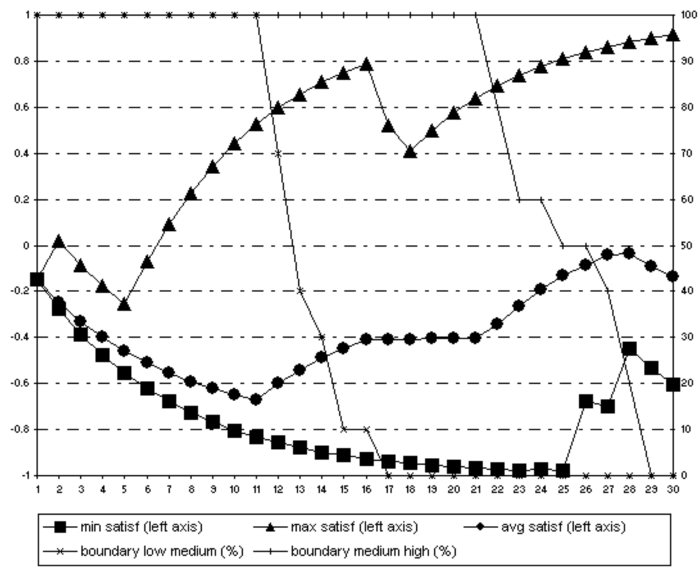

Figure 3.5: Results of experiment 3 with visitation level 10: all farmers end up in Q-class 3 (high).

CHAPTER 3

newspaper article referred to in the introduction of this paper, reporting large-scale dissatisfaction among the citizens. In our model, we could not include all factors leading to this event, but we could represent demand change in our experiments and we observed a low level of satisfaction (see experiment 1). Also the effect of exchanging information - one way or another - can be represented and investigated by means of our model.

In its current state, our agent-based model has rather rigid decision rules, and could benefit from substantial fine-tuning. Continuing work on our model will include further developing the agents' decision rules and actions repertoire, e.g. the earlier mentioned option to quit pig farming altogether, and elaborating on the effects of personality and culture. Strengthening the role of agent networks (farmer friends networks, but also buyer-farmer and buyer-buyer networks) will presumably add interesting dynamics to the agents population and simulation outcomes.

PART II - CASES

- **Chapter 4 - Case: Pork cycle**
- **Chapter 5 - Case: Information & networks**
- **Chapter 6 - Case: Information quality**
- **Chapter 7 - Case: Policy intervention**

DE MIER EN DE EEKHOORN en nog een paar dieren zaten aan de oever van de rivier toen er een reusachtige taart voorbijdreef.

Het was een witte taart, met verdiepingen, er droop room af en overal glinsterden suikerkorrels en blauw glazuur in de zon. Zoete geuren kringelden van de taart af en zweefden naar de oever.

[...]

'Wie zou die taart eigenlijk gemaakt hebben?' vroeg de eekhoorn.

'Die taart is niet gemaakt,' zei de mier. 'Zo'n taart ontstaat.'

'Ontstaat?' vroeg de eekhoorn.

'Ja,' zei de mier. 'Sommige dingen ontstaan.'

'Hoe is hij dan ontstaan?' vroeg de eekhoorn.

'Zo maar,' zei de mier, terwijl hij met gefronst voorhoofd van de ene voet op de andere sprong.

Zo maar, dacht de eekhoorn, wat is zo maar ook maar weer...

Maar de mier stak plotseling zijn hoofd in de grond, zodat de eekhoorn hem niets meer kon vragen.

The ant and the squirrel and some other animals were sitting by the river when a colossal cake floated by.

It was a white cake, with tiers, dripping with cream, and everywhere sugar pearls and blue icing sparkled in the sun. Sweet smells wafted from it and drifted to the bank.

[...]

'Who do you think made that cake?' the squirrel asked.

'That cake wasn't made,' the ant said. 'A cake like that comes into existence.'

'Comes into existence?' asked the squirrel.

'Yes,' the ant said. 'Some things come into existence.'

'How did it come into existence?' the squirrel asked.

'Just like that,' the ant said, frowning and hopping from one foot to the other.

Just like that, the squirrel thought, what does just like that mean again...

But suddenly the ant buried his head in the ground, so the squirrel could no longer ask him anything.

Preface to Chapter 4

Case: Pork cycle

Op een dag wilde de slang zich in duizend bochten wringen en vroeg de mier of hij wilde tellen. De mier zei wel dat dat goed was, maar hij had niet veel zin om tot duizend te tellen en toen de slang zich in drie bochten gewrongen had zei hij: 'Duizend.'

'Dat is vlug!' zei de slang. 'Zijn het er echt duizend?'

'Ja hoor,' zei de mier.

'Tel nog eens goed.'

'Een, twee...' telde de mier, 'brm, krm, snr, duizend. Het klopt precies.'

'Dat had ik niet gedacht,' zei de slang en hij maakte er van louter vreugde nog één bocht bij.

Chapter 4 was published as:

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One day the snake wanted to make a thousand waves, and he asked the ant if he could count. The ant said he would, but he didn't feel much like counting up to a thousand, and after the snake had made three waves, he said: 'One thousand'.

'That is quick!' the snake said. 'Are you sure it's a thousand?'

'Sure enough,' the ant said.

'Count again.'

'One, two...' the ant counted, 'brm, krm, snr, one thousand. It was exactly right.'

'I never would have thought,' said the snake, and out of sheer joy he made one more wave.

Chapter 4

An agent-based information management approach to smoothen the pork cycle in China

Abstract. The objective of our research is to study the relationship between (a) the spread of information at farmer level and (b) the emerging behaviour at sector level, applied to the case of the pork cycle in China, using an agent-based model. For this paper, we investigate the effect of farmers' individual supply decisions on the overall supply pattern in the sector. We apply a basic agent-based supply- and demand model populated with pig farmers, where supply is based on price expectations that include a time lag. The farmers decide upon their future supply (at farm level) using the price expectations they are able to make based on the information at their disposal. We compare our agent-based model with the classical cobweb model, which exhibits periodical over- and under-supply. This periodicity is not desirable, as is illustrated by a realistic example from the pork sector in China. The Chinese government tries to smoothen the overall supply and demand pattern by acting as a speculator as soon as price imbalance at total system level exceeds a threshold value, hence intervening at system level. Our agent-based model displays similar behaviour, and we can conclude that smoothening the supply curve by diminishing periodicity is also possible at individual level. An emergent result from the comparison is that mapping of economic supply and demand functions to individual agents' decisions is not straightforward. Our model is a fruitful basis for further research, which will include social interaction, imitation behaviour and a more sophisticated information diffusion process that reflects the rate at which a farmers population adopts information.

4.1 Introduction

To run their businesses, farmers take decisions for which they need information. Information includes a wide range of product and market information, managerial and technological know-how, knowledge of how to comply with legal requirements and regulations, and more. Information management is defined as the activity of acquiring and applying information to improve business performance. In this research we assume that better use of information management strategies will improve business performance (Osinga et al., 2010b).

Information management theory applies to activities within business firm environments, and often assumes state-of-the-art development (Laudon and Laudon, 2009). Family farms usually work with only basic information management systems, if at all. However, availability of adequate and accurate information and the know-how to apply it is of vital importance to any farmer's business performance (Isaac et al., 2007). Similar to an innovation diffusion process (Rogers, 2003), such information spreads over a population: a percentage of innovative farmers learn and decide to adopt, while others adopt later due to social influence, i.e. by imitating behaviour of others. The speed of diffusion depends among other things on social relationships between farmers: they may exchange information with geographical neighbours, with friends, or with both.

The objective of our research is to study the relationship between (a) the availability of information at farm level and (b) the emerging behaviour at sector level, applied to the case of the pork cycle in China, using an agent-based model (Gilbert, 2008). For this paper, we investigate the effect of farmers' individual supply decisions on the overall supply pattern in the sector. We apply a basic agent-based supply- and demand model populated with pig farmers, where supply is based on price expectations that include a time lag. The farmers decide upon their future supply (at farm level) using the price expectations they are able to make based on the information they have at their disposal. We compare our agent-based model with the classical cobweb model, which exhibits periodical over- and under-supply. This periodicity is not desirable, as is illustrated by a realistic example from the pork sector in China. The Chinese government tries to smoothen the overall supply and demand pattern by acting as a speculator as soon as price imbalance at total system level exceeds a threshold value, hence intervening at system level.

It is assumed that the quality of farmers' price expectations depends on the amount of information they have at their disposal: the emergent result of an information diffusion process. Individuals are modelled at the level of stylized facts to yield a mid-range model (Gilbert, 2008). Heterogeneous attributes, or personality characteristics such as personality ('openness') and susceptibility to social influence, affect the outcome of decision processes (McCrae and Costa, 2003). At individual level, these attributes affect each farmer's decision to adjust supply according to price expectations. At population level, the mean values of these attributes express the cultural characteristics of the population (Hofstede et al., 2010a). The model in this paper does not include yet personality and culture heterogeneity.

4.2 Background literature

In economics, the term pork cycle, or hog cycle, describes the phenomenon of cyclical fluctuations of supply and prices in livestock markets (Hanau, 1928; Coase and Fowler, 1937). A classical model to study this phenomenon is based on the cobweb theorem (Ezekiel, 1938; Kaldor, 1938). When prices are high, producers have an incentive to invest in more pigs, but with delayed effect due to the necessary breeding time. Next, the market becomes saturated, which leads to a decline in prices. As a result of this, production is reduced, which in turn takes time to be noticed, and then leads to supply falling below the demand and results in higher prices. This procedure repeats itself cyclically. The resulting supply-demand graph resembles a cobweb. The cobweb models distinguish several expectation schemes by which farmers predict future prices: naive expectation (assuming that price remains the same as it was), adaptive expectation (including previously made forecasting errors) and rational expectation (including all currently available information).

The cobweb model has been extended in several directions over the past decades. Westerhoff and Wieland (2010) describe a model that introduces heterogeneous speculators into the traditional cobweb framework. They argue that most primary producers in commodity markets are mainly concerned with the production process, but that speculators (e.g. in stock markets) actively predict commodity price movements. The speculators may apply technical analysis (extrapolating past price trends) or fundamental analysis (assuming that prices converge towards their fundamental values, i.e. the equilibrium price in a perfect market). Westerhoff and Wieland conclude that speculators may indeed have an impact on price dynamics: in most cases the impact is destabilizing, but in some situations it may stabilize the dynamics.

4.2.1 Pork cycle in China

More than half of the world's pork is produced and consumed in China. The pork cycle also occurs in the Chinese market (Nie et al., 2009). The seasonal fluctuation is significant: every year prices are high in January, then drop until the summer, then start increasing again for a second peak in October (see Figure 4.1a). This fluctuation is closely related to meat consumption patterns: when temperatures become higher, more vegetables are available and meat consumption decreases; after the summer, the weather turns cold and traditional festivals stir up the price (Spring Festival in January, Moon Festival in October). Price fluctuations also occur due to unexpected events or contingency shocks, e.g. after a disease outbreak, or when the grain price goes up (see Figure 4.1b). Grain price is a direct indicator of feed price, which represents half of the costs for pig production in China (ThePigSite.com, 2007).

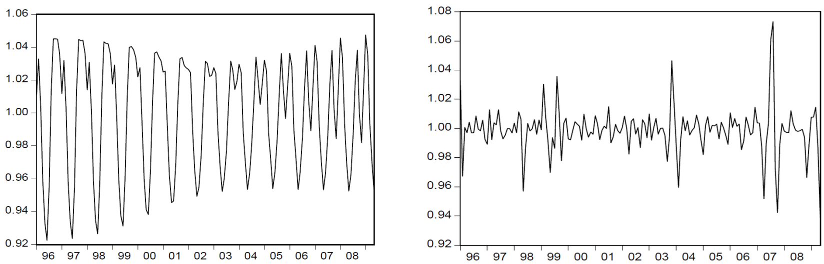

Figure 4.1: a (left): Regular, seasonal fluctuation; b (right): Irregular fluctuation. *Graphs are based on the monthly pork price (Jan 1996 to May 2009), taken from (Nie et al., 2009).*

4.2.2 Interventions from government

The Chinese government is taking an effort to control these fluctuations. In January 2009, a dedicated commission together with the ministries of Finance, Agriculture, and Commerce and others jointly issued a document containing intervention measures (USDA, 2009): if the ratio of so-called hog to grain prices falls below 6.0 for more than four weeks, the government will consider purchases for reserve stocks to reduce market supply and increase prices, to set them out in the market again in times of supply shortage. Indeed, at least two such government purchases to restrain supply and bump up prices were made in April 2009 (USDA, 2009), and interventions occurred in 2010 as well (Meat Trade News Daily, 2010). Newspapers reported by the end of 2010 that pork supply and demand were essentially in balance in 2010 thanks to the governmental interventions (Swineweb.com, 2010). However, industry experts question the long-term feasibility of these short-term solutions and fear even worse imbalance (China Economic Review, 2010).

4.2.3 Information management based approach

Instead of using the overall ratio of hog to grain price, which is the key indicator for the government to intervene, intervention can also be divided over the population of farmers. The majority of Chinese pork is produced by small-scale farmers, who run a family business of pig farming (Fabiosa et al., 2005). Improving information management, i.e. to make use of available information, may help to increase farmers' awareness and knowledge of how to estimate future prices, hence to anticipate the cyclical nature of demand and supply. In this way, the overall pork demand and supply curve will exhibit the emerging result of all individual farmers' adjusting behaviour, instead of the result of governmental control. Price expectations are calculated based on information, but not each farmer has the same information at his disposal, nor acts upon the calculated outcome in an equal way. This approach is different from Westerhoff and Wieland (2010), who include a different agent-type, i.e. the speculator, into their model. In our approach, their are no explicit speculators, but differences in price expectation occur due to heterogeneity among the farmers' accuracy of predicting future prices.

4.3 Research questions

The research questions of this paper are:

1. Can the periodic pattern of cyclical supply and demand fluctuations as described in the literature be generated by means of an agent-based model?
2. As an alternative to government intervention, can this periodicity be eliminated when farmers use improved price expectations?
3. What is the impact of heterogeneous information diffusion among farmers on the periodicity, assuming that more information leads to more accurate price expectations?

CHAPTER 4

4.4 Model

For our agent-based model of the pork cycle in line with the cobweb theorem, we apply a basic linear demand and supply system:

$$Q_d = D_0 - h_D * P \tag{4.1}$$

$$Q_s = S_0 + h_S * P \tag{4.2}$$

where Q_d and Q_s, D_0, S_0, h_D and h_S are the quantities, intercepts and slopes of the linear demand and supply functions, respectively. The actual values for intercepts and slopes were taken from a textbook example (Perloff, 2009), chapter 2. P represents the price. Assuming market clearing, Q_d equals Q_s, hence there exists an equilibrium price. When a time lag is involved, the cobweb problem arises: when price turns out to be not at equilibrium level, quantities are either too high or too low, resulting in a cyclical demand and supply pattern. At each time step, price and supply are calculated as:

$$P_t = \frac{D_0 - S_t}{h_D} \tag{4.3}$$

$$S_t = h_S * P_{t-5} - S_0 \tag{4.4}$$

where the value 5 represents a time lag of 5 time steps, i.e. P_{t-5} is the price farmers assume to receive for pigs that still need a maturing time of 5. The expected price for each farmer is based on all information available to him. When there is no information available, farmers adopt naive expectation, i.e. equal to the current observed price. With more information available, the expected price becomes a better estimate.

In the supply- and demand equations, when $h_D > h_S$, the periodic cycle is divergent, which in the movement along the (linear) supply and demand curves resembles a cobweb starting in the centre and spiralling outwards. When $h_D < h_S$, the cycle is convergent, which resembles a cobweb starting from the outside and spiralling inwards. When the slopes are equal ($h_D = h_S$), a stable cycle results. As we wish to investigate the effect on a stable situation, h_S and h_D were set to equal values for all our models.

CHAPTER 4

4.4.1 Information management approach

We assume in this research that better information management leads to better price estimates. In our model, each farmer receives a number of information items during setup. The more different information items available, the better accuracy for the estimated price. No information items available is equivalent to using the current price, maximum information is equivalent to using the (perfect) equilibrium price that is expected to exactly match supply and demand, and anything between minimum and maximum information leads to a proportional accuracy of the equilibrium price.

Accuracy (α) is calculated per farmer i as

$$\alpha_i = \frac{info\text{-}items_i}{\sum_i info\text{-}items} \tag{4.5}$$

where $info\text{-}items_i$ is the number of information items that farmer i has available, and $\sum_i info\text{-}items$ is the total number of information items available in the system.

The estimated price is calculated as:

$$EP = \alpha * P^{eq} + (1 - \alpha) * P_t \tag{4.6}$$

where α is in interval $[0, 1]$; P^{eq} is the equilibrium price, and P_t is the current price.

4.4.2 Research models

To answer the research questions we develop three models, each using a different price expectation on which farmers base their supply decisions:

1. the current-price-model, where $EP_{t+5} = P_t$
2. the perfect-price-model, where $EP_{t+5} = P^{eq}$
3. the estimated-price-model, where $EP_{t+5} = \alpha * P^{eq} + (1 - \alpha) * P_t$

In fact, the current-price-model is the estimated-price-model with a value of α equal to 0, and the perfect-price-model is the estimated-price-model with a value of α equal to 1.

4.4.3 Decision to restock

In our model, farmers without stock decide every time step whether they will restock or not. If they restock, they do so with a fixed capacity, which is the same for all farmers. After restock, pigs need 5 time steps to mature, during which time no restocking decision can be made. In reality, farmers maintain several pig batches of different age, but we assume that this refinement would not fundamentally lead to different outcomes at system level, hence we prefer the simpler model. Also, farmers would have different restock capacities, but we keep this value equal for simplicity reasons.

The decision to actually restock or not depends on the total supply S that will be needed, which each farmer calculates according to equation 4.7 using his estimated price (which differs per model):

$$Restock = r < \frac{S}{maxS} \tag{4.7}$$

where r is a discretized random number uniformly drawn from interval $(0, 1)$, and $maxS$ is the maximum supply possible, i.e. the supply in case all farmers currently without stock would choose to restock. This implies that farmers know how many other farmers are currently making the decision to restock, but they do not know the actual outcome of the other farmers' decisions.

4.4.4 Simulation process

Before simulations start, farmers are created with attributes *stock*, *pig-age*, *info-items* and *estimated-price*. There are 5 batches of farmers, each having pigs of a certain age. Their *info-items* attribute is assigned to them at random. The higher the number, the more informed they are. At each time step:

- farmers sell their pigs if these have reached maturity, which is the case for a different batch of farmers at each time step. When the pigs have been sold, those farmers' stock becomes 0, so they will be the ones who later must decide whether they will restock or not.
- the current price P_t is calculated according to equation 4.3.
- *maxS* is calculated, i.e. the total capacity of all farmers who currently have no stock.
- in the estimated-price model, farmers calculate their estimated price, based on their number of *info-items*. In the other two models, the previous price or the equilibrium price are used, respectively.

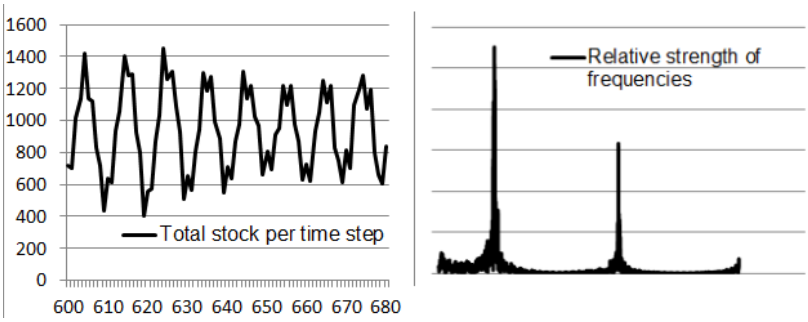

Figure 4.2: (a) Simulation output and (b) Fourier frequency diagram for the *current price model.*

- farmers decide to restock or not according to equation 4.7, and update their stock accordingly.
- total supply currently present in the system is the sum of all stock of farmers who now have mature pigs.

Because the total supply changes at every time step, the price also changes, which in its turn affects the decision to restock or not. This determines the total supply present at each time step, and defines the pattern in the resulting graph.

4.4.5 Fourier transformation

Simulation outputs of model runs show total stock changes per time step, which sometimes appears to be a periodical wave, and sometimes resembles a random walk. In order to determine whether a waveform is still periodical or not, we transform the total stock data from the simulation output into frequency diagrams, using Fast Fourier Transformation. FTT diagrams show the frequencies within the waveform period, from which it is much easier to identify periodicity.

4.5 Results

The models were implemented in Netlogo and were all run with 500 farmers. Figure 4.2 shows the results for the current price model. In this model, where farmers use the current price to estimate future stock, the pattern is clearly periodical, as expected (figure 4.2a). The Fourier frequency graph (figure 4.2b) confirms this.

Figure 4.3 shows the results for the perfect price model. In this model, farmers use the equilibrium price to estimate future stock, and only their decision

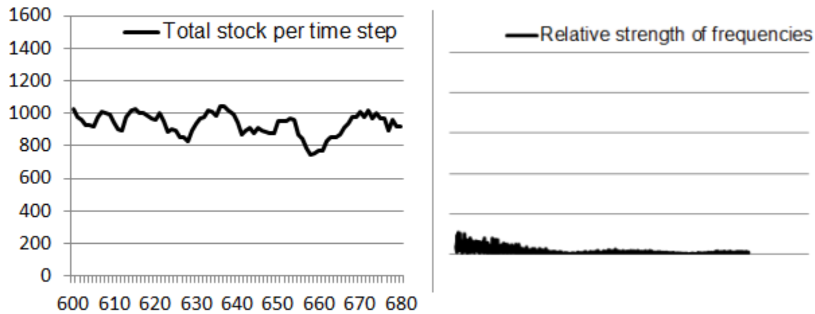

Figure 4.3: (a) Simulation output and (b) Fourier frequency diagram for the *perfect price model*.

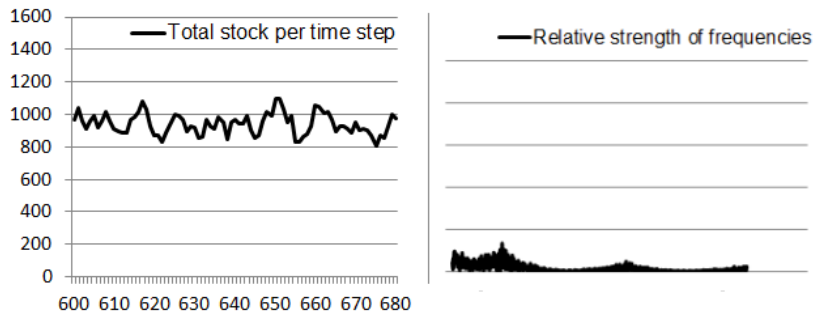

Figure 4.4: (a) Simulation output and (b) Fourier frequency diagram for the *estimated price model*, with information parameter α set to 0.5.

to restock or not was randomized. The result of this seems to be a random walk (figure 4.3a), as expected. However, in the Fourier frequency graph (figure 4.3b) we can observe that there is still a small remainder of periodicity left in the model.

Figure 4.4 displays the results for the estimated price model. In this model, we experimented with several values for the information parameter α. The more information available, the less periodicity we expected to appear. This was consistent with the outcomes. Figure 4.4a shows the result with α set to 0.5. We can observe that periodicity has indeed diminished when compared with figure 4.2a, but that it is clearly more present than in figure 4.3a. The Fourier frequency graph (figure 4.4b) confirms that some periodicity is left in the model.

4.6 Conclusion and discussion

Coming back to the research questions, we can conclude that the pattern of cyclical supply and demand fluctuations as described in the literature can indeed be generated by means of an agent-based model. When farmers assume naive expectations, there is clearly a periodic pattern that resembles the literature, as figures 4.2a + 4.2b show.

However, there are differences as well. The mapping of economic supply and demand functions to individual agents' decisions is not straightforward. The theory works with average total supply quantities at each time step. But on individual agent level, each farmer will not restock an average quantity of pigs. More likely is that he will decide either to (a) fully restock his stables when (expected) prices are worth the effort, or to (b) not restock at all and find income from alternative labour until prices increase. The alternative labour option is realistic in the Chinese situation (Wang and Watanabe, 2008). The fact that restock is a discrete choice and happens at full capacity, is an emergent property from modelling at individual level.

An implicit result from this finding is that the number of farmers actually involved in restocking may be limited, dependent on the ratio of farmers, and their maximum capacity, with respect to total demand. When this ratio is high, only a few farmers restock, and the others have to find alternative labour. This was also the case in our model experiments. In models that do not include individual farmers, the issue that a majority of farmers may be out of business does not appear. But in the real world, such a scenario would cause huge social problems. It would be worth experimenting in the model with the parameter values for maximum restock capacity and number of farmers with respect to demand, to obtain a model with a higher average of participating farmers. The agent-based model easily allows for such experiments.

There is an interesting transition point present in our model: with the current settings, there is no periodicity when there are fewer than 185 farmers, because then all farmers always restock at maximum capacity, which is still less than demand. So the cyclic pattern only appears when there is actually an overcapacity of stock. This is another emergent result from the agent-based model.

As for the second research question, we can conclude from figure 4.3 that periodicity would indeed almost be eliminated if farmers were able to use the perfect price in their estimations. The small remaining periodicity visible in the Fourier frequency graph may be a result of the fact that our model works with batches of farmers who have pigs of the same age. When the pigs reach maturity, batches of farmers make the decision to restock or not, which may cause some periodicity.

The third research question addresses the issue to what extent heterogeneous information diffusion among farmers leads to diminishing periodicity, assuming that more information leads to more accurate price expectations. Figure 4.4 shows that heterogeneous distribution of information over farmers leads indeed to a decrease in cyclical pattern. The more information, the stronger the effect.

The inspiration for this paper was the government intervention that happens in China in order to smoothen the over- and under-supply pattern. From our research questions, we can conclude that an alternative way to smoothen that pattern could be to improve the price expectations among farmers by well-informing them. Our model is too rudimentary to make a serious claim here, but it offers a good start for further refinement.

An addition to the model would be to include external influence, which happens event-wise instead of in regular cycles. One way to do that is to actually use the grain price in the model, which we currently assume as constant. Grain price changes as an independent variable, and is responsible for 50% of the farmer's pig production costs, which would be an additional factor in farmers' decision whether to restock or not.

Our model currently contains no explicit interaction mechanisms. However, there is implicit interaction, because we assume that farmers know what the maximum possible supply is. It would be interesting to see what actual interaction and information exchange would lead to. We tried this (in a rudimentary way), but we did not reach a point beyond 'what we put in, is what we get out'. We would need to add network structures among the farmers to be able to observe worthwhile interaction effects. It is realistic to assume that farmers let their decision to restock or not influence by what their peers - those in their social network - decide. Heterogeneous personality attributes and cultural population attributes that affect decision making would make the model reflect social behaviour both at individual and at population level. Finally, it would be interesting for future research to include a more sophisticated information diffusion process, reflecting the rate at which a population of farmers adopts information.

Preface to Chapter 5

Case: Information & networks

Op een dag kwam de eekhoorn erachter dat het onverstandig was om niet verder te kunnen tellen dan tot vijf. Hij ging naar de school aan de voet van de eik in het midden van het bos en vroeg aan de mus die daar onderwijzer was of hij hem tot tien wilde leren tellen.

[...]

Na een week kon de eekhoorn tot zes tellen. Vol trots vertelde hij dat aan de mier. Maar de mier was niet onder de indruk.

Na een maand kon hij tot zeven tellen. Maar de mier was nu nog minder onder de indruk.

[...]

[Hij was] zo moe geworden van het leren dat hij de volgende dag aan de mus zei dat hij niet meer naar school kwam.

'Jammer,' zei de mus, 'want acht is een prachtig getal. Vooral als je er langzaam naar toe telt.'

'Maar wat is acht dan?' vroeg de eekhoorn.

'Tja,' zei de mus en trok een geheimzinning en geleerd gezicht, alsof hij zeggen wilde: daar kom je pas achter als je acht echt helemaal kent. Maar hij zei niets meer.

De eekhoorn ging naar huis. Hij dacht die dag grondig na, maar hij kwam geen stap verder, laat staan dat hij begreep waarover hij nadacht. De volgende dagen vergat hij zeven en zes weer, zodat hij al spoedig weer even ver was als de mier die al jaren tot vijf kon tellen.

Chapter 5 was published as:

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One day the squirrel realized that it was unwise not to be able to count to more than five. He went to the school under the oak tree in the middle of the forest and asked the sparrow who taught there whether he could teach him to count to ten.

[...]

After a week, the squirrel could count to six. He proudly reported this to the ant. But the ant was not impressed.

After a month, he could count to seven. But now the ant was even less impressed.

[...]

[He had] become so tired from all the studying that the next day he told the sparrow that he wouldn't be coming to school again.

'That's a pity,' said the sparrow, 'because eight is a beautiful number. Especially if you count up to it slowly.'

'But what is eight, then?' asked the squirrel.

'Well,' the sparrow said, and he put on a mysterious and learned face as if he wanted to say: You'll find out when you really get to the bottom of eight. But he left it at that.

The squirrel went home. He thought things through for a long time that day, but it didn't get him anywhere, let alone that he understood what he was thinking about. Over the next few days he forgot seven and six, so in a little while he was on a par with the ant again, who had been able to count to five for years.

Chapter 5

Multi-dimensional information diffusion and balancing market supply: an agent-based approach

Abstract. This agent-based information management model is designed to explore how multi-dimensional information, spreading through a population of agents (for example farmers) affects market supply. Farmers make quality decisions that must be aligned with available markets. Markets distinguish themselves by means of requirements which are expressed over multiple quality dimensions. In order to supply to a market, a supplier's information should match the market's requirements. Information diffusion is affected by network structure among agents, and by information turnover. Research questions concern the effect of information turnover and network structure on market supply. Results show that there is a huge effect of information turnover. The percentage of suppliers having to resort to the dump market decreases when information supply rate (*ISR*) and average number of friends (*NFR*) increase. The higher the values of *ISR* and *NFR*, the higher the percentage of suppliers able to reach high markets. There is an influence of network structure: the more connections, the better the results with respect to market supply, but the nature of these connection seems to be of lesser importance. Contrary to our expectations, there is hardly an effect of network topology. With sufficient information in the system, differences in diffusion process appear to be not significant.

5.1 Introduction and background literature

Pig farmers must make numerous decisions regarding the desired quality of their product. A farmer has to align his intended pork quality and his desired price with the demand of market channels available to him (Wever et al., 2010). Deciding which quality to aim for is not straightforward, since quality is a multi-dimensional concept, including product-related aspects, societal concerns, and market requirements (Bonneau and Lebret, 2010). To make profitable decisions, farmers need to be sensitive and responsive to information throughout the production chain (Verbeke, 2001; Verdouw et al., 2011). This information covers the whole quality spectrum. The adequate use of information for taking the most profitable decisions can be seen as an optimization problem. However, farmers exhibit bounded rationality, meaning that "in decision-making, rationality of individuals is limited by the information they have, the cognitive limitations of their minds, and the finite amount of time they have to make a decision" (Simon, 1957). In other words, farmers do not have the time, the resources, or the mind set to behave like rational optimizers. A recent study on information use among German pig farmers concludes that factors like a farmer's intrinsic motivation and competence have a significant influence on their information use (Arens et al., 2012). In the discussion, they mention that most influential on farmers' decision making is other farmers' behaviour as well as educational activities (Theuvsen, 2003).

This implies that farmers consider other farmers and 'educators' as important sources of information, and that their personalities influence their information use. To model farmers' decision making under these assumptions, using agent-based modelling (ABM) as a method is an appropriate choice. Gilbert (2008) defines agents as autonomous, heterogeneous individuals who exhibit bounded rationality and have social interactions. That makes farmers very suitable examples of real-life human agents. Valbuena built an ABM of farmers' individual decision making regarding land-use/cover change, showing that policy is influenced by farmers' decisions (Valbuena, 2010). Valeeva and Verwaart (2011) and Verwaart and Valeeva (2011) modelled farmers' decisions to adopt food safety practices in the dairy sector in an ABM. Farmers' decisions were based on their attitudes, social network influences, and perceived availability of resources and opportunities. In the pork sector, Osinga et al. (2010b, 2011) used an ABM to model pig farmers' quality choices based on information in their network, showing emergent sector behaviour.

The present study will contribute to this body of research, but will focus on the multi-dimensional aspect of information with respect to making quality decisions leading to emergent market supply. The setup of the model is generic in such a way that it is applicable not only to the pig farmer case, but to any situation that involves autonomous suppliers who select markets with multi-dimensional criteria and associated information requirements. Multi-dimensional information has also been used by Gilbert et al. (2001), who developed SKIN, a model of innovation networks in which agents have 'kenes' that symbolize their stock of knowledge and expertise. Kenes consist of information triplets, representing capability, ability and expertise. However, they are deployed at firm level, not at individual level, and are meant to sell products to one another, focussing on innovation. In our approach, individuals exchange information, are all competing for the same markets, and do not focus on innovation but on quality that matches demand. Furthermore, we study the effect of varying network structures between agents on information diffusion and market supply. Also, turnover of information (i.e. new information entering, outdated information leaving the system) influencing the information diffusion, and how this affects decision outcomes, is taken into account.

5.2 Problem definition

In this study, we explore how diffusion of multi-dimensional information among farmers (or any other autonomous suppliers) affects market supply, an emergent property at sector level. Suppliers make quality decisions that must be aligned with available markets. Markets distinguish themselves by means of requirements which are expressed over multiple quality dimensions. In order to supply to a market, available supplier's quality information should match the market's requirements. Information diffusion is affected by network structure among agents, and by information turnover.

The research questions for this paper are the following:

1. *Design question* - Can we design an agent-based model with plausible behaviour that includes multi-dimensional quality information which diffuses through a population of suppliers, who all compete for the same markets?

2. What is the influence of information turnover (new information coming into the system through an information agency, and losing information as well) on emergent market supply?

3. How do network structures between suppliers influence the diffusion of information, hence the outcome of their decisions, hence emergent market supply?

5.3 Model

In terms of Gilbert (2008) this project is a case of a mid-range model: the aim is neither to exactly model the farmers in a certain region, nor to make a purely theoretical point. Stylized facts about system-level tendencies emerging from the simulations should be recognizable by real-world experts, without having to match any specific situation one-on-one.

Central in the model are the information items, or info-items for short. These consist of triplets holding id, type and value. The *id* is meant to distinguish info-items from one another, and to determine when they become obsolete. The *type* refers to a quality dimension (e.g. feed, health). The actual number and nature of these types is arbitrary, since the model treats them in a generic way. (For our experiments we used letters A, B, C, D for the types of information.) The *value* refers to the value that this info-item has to its current owner, on a scale of 0 to 100. For example, [24, B, 40] represents info-item nr 24, which is of type B, and for which the owner scores a value of 40%. When an info-item is exchanged between agents, the new owner receives a copy of the info-item, but its value diminishes. This reflects the fact that agents are heterogeneous and cannot simply copy information use from one another, but instead have to build up some expertise in using it for themselves.

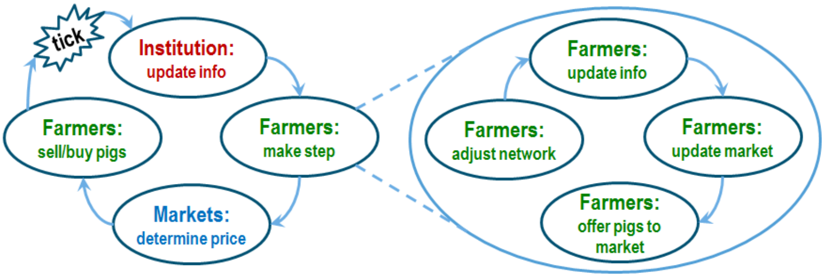

Figure 5.1: A time step in the simulation, with farmers as suppliers.

New info-item is...	Condition:	Resulting value:
not yet present	–	$random[0, newvalue]$
already present	$newvalue < oldvalue$	old value remains
already present	$newvalue > oldvalue$	$randomvalue[oldvalue, newvalue]$

Table 5.1: Calculating info-item's new value after exchange.

The model distinguishes three agent types: suppliers (in the model called farmers), markets and an institution. The institution is the source of information and considered expert: it possesses a list of all info-items, which initially all have maximum value, and it can generate new information.

Markets represent a certain quality, which is expressed as required combinations of information types and associated minimum values. Markets cover the available quality spectrum and are partially ordered. For example, one market may only require a high value on health, whereas another one requires a high value on feed and a moderate value on hygiene, yet another one requires high values on all three. The model is generic in the sense that number of markets and number of quality attributes required per market are flexible. Markets also have a price associated with them, which agents receive when they supply their product at this market. This price depends on total supply, as we will elaborate on later. There is also a dump market where suppliers can deliver if they cannot meet the requirements of any other market. The dump market sets no requirements, but pays nothing either.

One attribute of suppliers is their network, consisting of family (static), neighbourhood (static), and friends (dynamic). Their further attributes include a list of info-items; a number of products (in our case, pigs); an amount of money; and their current market. Their current market is the last market they supplied to. Initially, suppliers receive a fixed number of random info-items. When they exchange info-items with other suppliers (or the institution), new info-items are combined with the old ones. That occurs according to Table **??**: The sequence per time step in the simulation is illustrated in Figure 5.1. At each time step, the institution supplies a number of new info-items (dependent on the information supply rate, a parameter) to suppliers. At the same time, outdated information is disposed of. Then all suppliers (in turn) make a step, which is a sequence of actions: they adjust their network (in particular, their friends network); they exchange information with other people in their network (i.e. family, neighbours and friends); they update their market and offer their products to that market.

At each time step, a number of suppliers, defined by the information supply rate, receive one random information item from the institution. Also, at each time step, all suppliers request one random information item from every other supplier to which they are connected. Information items that have reached their expiry become obsolete.

As opposed to static connections, friends can be lost and gained during a simulation. At each 'adjust network' step, suppliers try to find a friend among friends' friends, or at random among all suppliers when this fails. Friends are dropped at random when the average number of friends exceeds the required population mean (a parameter). There may be large individual differences, some having few or none and others having many friends.

To identify their market, suppliers choose one new candidate market at random. When that market's expected price (i.e. its last price) is higher than the price the supplier received at his current market, the supplier will opt for the new market, which only succeeds if he meets the new market's requirements. Otherwise, he will remain at his current market, if he still meets its requirements. If that is no longer the case, he will try to find another one. The dump market is always a last resort.

After all suppliers have determined their markets, the total supply Q per market is known and the markets can determine their price. The price is calculated according to Equation 5.1:

$$price = b + c * e^{-kQ} \tag{5.1}$$

where b equals the base-price for that market (i.e. the price - related to market quality - suppliers still receive when supply is endless), c is a constant related to the price at low supply, and k is a measure for price elasticity. When the price is determined, suppliers sell the products they offered, collect their money and replenish their stock (in our case, buy new pigs). The amount of stock they will purchase is a random number between 1 and the maximum capacity they can hold, maximized to what they can afford.

5.3.1 Agent-based properties

Heterogeneity, bounded rationality, agent interaction and emergence are typical properties of agent-based models. In our model, they are present in the following way.

- *heterogeneity*: Suppliers have similar attributes and similar decision mechanisms, but they are heterogeneous in a few respects: the number of info-items, the value those info-items have for them, their current market and the number of other suppliers in their network.

- *bounded rationality*: Suppliers try only one new market per time step. By opting for only one candidate new market, the supplier runs the risk that there is a better market available which he will not find. But given the bounded rationality condition, it is assumed that suppliers have no time to check all available markets. Suppliers also show bounded rationality because they do not know the price they will actually get for their products, as this price depends on total supply for that market. This is in contrast with analytical models, where total supply is a given.

- *agent interaction*: Information exchange occurs between suppliers who are in the same network, and also (at random) between suppliers and institution. There is implicit interaction in the fact that market choice is balanced according to supply.

- *emergence*: Balancing market supply, as in distribution of market choice, is an emergent property at sector level. It is the result of the decisions of all individual suppliers.

5.4 Simulations

To see the effect of information turnover and network topology on market supply, we experimented with the model in a structured way. Elements to be varied were static network topology (family), available markets, information supply rate (*ISR*), and dynamic network (number of friends, *NFR*). Neighbours, i.e. static network members similar to family but based on geographical distance, were not included in these experiments. All experiments were run with 100 suppliers. Network topologies and markets were not derived from empirics, but abstracted in such a way that it was possible to draw conclusions on their influence. Simulations were run with all combinations of settings described below, for 2000 time steps.

5.4.1 Network topology

To set up the static networks, four different topologies were selected. To make the networks comparable, the overall connectivity degree was equal (except for *isolated*). Selected topologies are:

- *ring10d*: Suppliers are equally divided over 10 disjoint clans, within which they are connected ring wise. Consequently, the distance between clan members ranges from 1 to 5. Each clan member has 2 direct connections. There is no (static) inter-clan connectivity.

- *clan10-2d*: Suppliers are equally divided over 10 disjoint clans, within which they are connected at random with 2 other clan members. It may happen that some clan members have many direct connections and others have none at all. There is no (static) inter-clan connectivity.
- *tree1-10*: One supplier is connected with 10 others, who are each connected with 9 yet other suppliers. They are a fully connected clan, the distance between any two members only ranging from 1 to 4. Again, on average suppliers have 2 connections, 89 of them having 1 direct connection, the remaining 11 having 10 direct connections.
- *isolated*: There are no static connections at all. All connectivity comes from friends, if any.

5.4.2 Market sets

In principle, market sets could differ from each other with respect to number of markets, information types involved, required quality information levels per market, and price parameters. For our experiments, we defined 4 sets of markets. For comparability reasons, each set contained 4 information types and 8 markets. As for price parameters, we only varied the base-price (b in Equation 5.1); Values for c and k were set at 200 and 0.1, respectively. The market sets selected for our experiments are:

- *ext-diff*: Extreme markets paying a differentiated price. Markets 1-4 are defined as low quality markets, requiring quality level 10 on one of type A, B, C, or D (respectively), and 0 on the remaining types. They have a base-price of 10. Markets 5-8 are high quality markets, requiring quality level 80 instead of 10 on one type. They have a base-price of 80.
- *ext-same*: Extreme markets, with identical base-prices. This one is a duplicate of the *ext-diff* set, but now with uniform base-price of 50 for all markets.
- *unif-inc*: Uniformly increasing markets. Market 1 requires quality level 10 on all types A, B, C and D, and pays a base-price of 10. Market 2 requires 20 on all types, with base-price 20, and so on, until market 8. Markets 1-3 are defined as low markets, markets 4-5 are defined as medium markets, and markets 6-8 are defined as high markets.
- *rand-inc*: Randomly increasing markets with increasing base-price. Markets have different random requirements on types A, B, C, and D, but the average of required quality levels equals 10 for market 1, 20 for market 2, and so on. For comparibility's sake, the total required quality level per type A-D are

balanced as well. The base-price is identical to the average required level. Low, medium and high markets are defined as in *unif-inc*.

5.4.3 Information supply rate

For the experiments, we varied the *ISR* with values of 10, 50 and 90.

5.4.4 Dynamic network

For the experiments, we varied *NFR* with values of 0, 0.5, 1 and 3.

5.5 Results

For each of the 192 combinations (4 network topologies, 4 market sets, 3 values for *ISR* and 4 values for *NFR*) we performed multiple runs. The performance indicator for each result is the amount of suppliers active at each market segment throughout the simulation. Some typical sample graphs are presented in Figure 5.2. The graphs show that the percentage of suppliers having to resort to the dump market decreases when *ISR* and *NFR* increase. The higher the values of *ISR* and *NFR*, the higher the percentage of suppliers able to reach high markets.

To evaluate the effect of network structure and information turnover on market supply, each run was summarized into 4 numbers: total number of suppliers active on dump, low, medium and high market segments, accumulated over time. An overview of these numbers over all runs was represented in a graph. A small subset of this graph is presented in Figure 5.3.
Observations from the summarized results are:

- Varying the information supply rate *ISR* has a substantial, consistent effect on market performance for every combination of network topology, market set or number of friends. The higher the *ISR*, the more markets are within reach of suppliers.
- At low *ISR*, varying the number of friends *NFR* has a similar effect. Consistently, the more friends, the more markets become within reach. This phenomenon is not observed with higher *ISR*.
- It is difficult to see a clear effect from network topology, except for the *isolated* topology, which performs worse than other topologies under any circumstance. Only at low *ISR* and low *NFR*, *tree1-10* performs slightly better than the other topologies.
- With market set *ext-diff*, suppliers reached a higher market segment than with *ext-same*. For low *ISR* and *NFR*, the difference was minimal.
- Market set *unif-inc* performed slightly better than *rand-inc*, consistently.

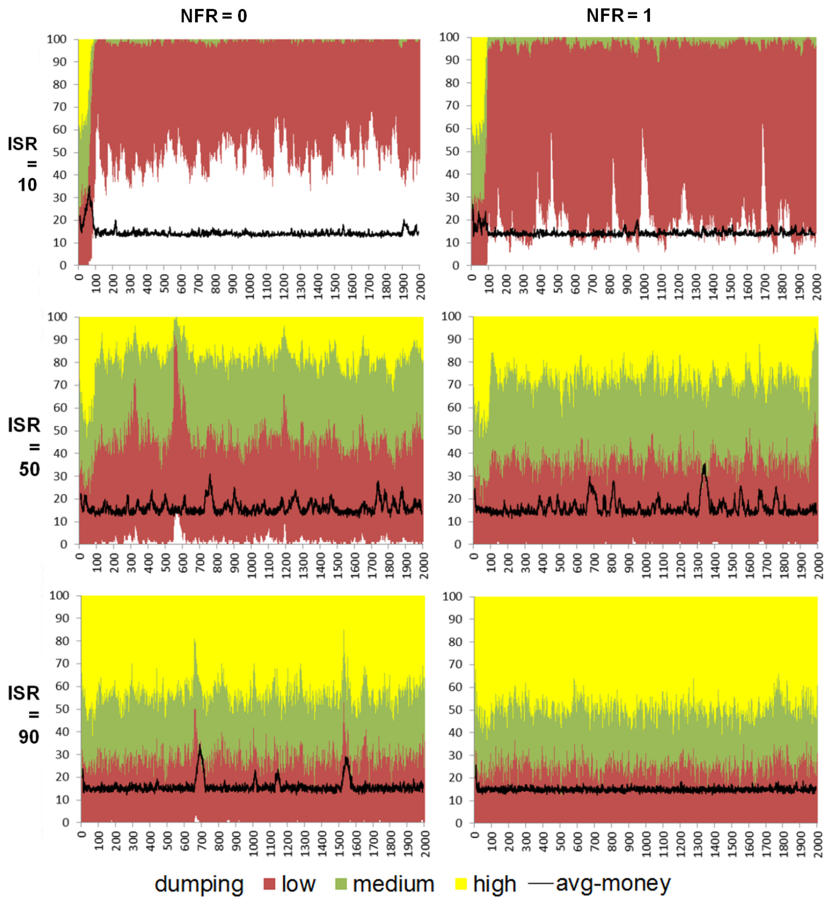

Figure 5.2: The graphs represent six simulation runs, showing the amount of suppliers active at each market segment during 2000 time steps. White (bottom) represents the dump market, followed by low (red), medium (green) and high (yellow) market segments, if present. Also, the average money of farmers is shown (black). These are the combinations of market set *unif-inc*, topology *clan10-2d*, information supply rates (*ISR*s) of 10, 50 and 90, and average number of friends (*NFR*s) of 0 and 1. Quality increases from top to bottom (increase of *ISR*) and also from left to right (increase of *NFR*).

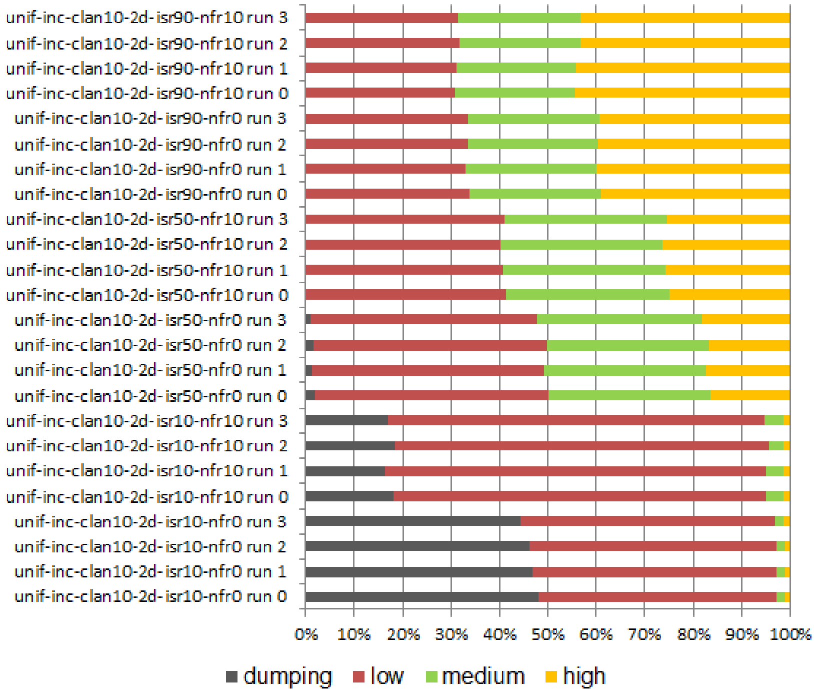

Figure 5.3: A snapshot of the overview of runs, with suppliers active on dump, low, medium and high market segments, accumulated over time. This is market set *unif-inc*, topology *clan10-2d*, *ISR*s of 10, 50 and 90, and *NFR*s of 0 and 1. Per combination, 4 runs are shown.

In an attempt to quantify the effect of network topology, the results summary was post-processed. For each combination of *ISR*, *NFR* and market set, the network topologies were pairwise compared with respect to percentage of suppliers able to supply to the high markets segment. The same was done with respect to percentage of suppliers having to supply to the dump market. These comparisons can be seen as indicators of how powerful and how poor certain network topologies are in the high and low end of the market spectrum, respectively. Observations after post-processing are:

- Varying market settings have a substantial effect on the results, but varying network topologies shows hardly any differentiation.
- *isolated* performs consistently worse than the other three network topologies.

- In almost all situations, *tree1-10* performs only slightly better than both *clan10-2d* and *ring10d*. In those cases where *tree1-10* performs worse, there were hardly any suppliers at all present in the high market segment.
- *clan10-2d* and *ring10d* perform very similarly. Sometimes *clan10-2d* is slightly better, but this could very well be a random seed effect.

Additional observations from comparisons in the dump segment are:

- With *ISR* = 50, there is no clear distinction between *tree1-10*, *ring10d* and *clan10-2d*. They alternately perform slightly better.
- With *ISR* = 90 and *NFR* = 3, there is no network effect whatsoever anymore.

5.6 Conclusion and discussion

Coming back to the first research question, our ABM seems to show indeed plausible behaviour. Although results are not always very explicit, there are no counterintuitive results either. Initial differences in possession of info-items and market options disappear over time; the diffusion of multi-dimensional info-items as described in the paper leads to a balanced distribution of market supply that differs according to the parameter settings.

As for the second research question, information turnover has a huge effect. When the information supply rate equals only 10%, a large percentage of the suppliers has to resort to the dump market, a minority is able to supply to low quality markets, and only a tiny minority shortly reaches medium quality markets. When the information supply rate equals 50%, we see that most suppliers can avoid the dump market and reach low or medium markets, and a minority can manage to supply to high markets. When the information supply rate equals 90%, hardly any suppliers need the dump market anymore and markets are pretty well balanced.

There is an influence of network structure, which was the third research question: the more connections, the better the results with respect to market supply. However, the nature of these connection seems to be of lesser importance. Contrary to our expectations, there is hardly an effect of network topology, i.e. the static family network. This is partly due to the influence of the dynamic friends network, when present. Given the fact that all network topogy settings in the simulations have an average of 2 connections per supplier, increasing *NFR* to 1 or 3 on average practically doubles a supplier's network, thus overshadowing family influence. But also in a situation with no friends, the network topology does not seem to make a significant difference. Only when *ISR* is low, there is a small network topology effect. As soon as *ISR* goes up, network topology does not make much difference anymore.

Another conclusion of this study is that, with sufficient information in the system, differences in diffusion process are not significant. Only a low number of connections between agents is sufficient to distribute the information within due time. When everybody has all the necessary information, markets balance out, driven by the price mechanism.

An interesting observation is that niche markets are attractive, despite high requirements, even when the base-price is low. In our experiments with the same base-price for all markets, still some suppliers prefer markets with higher requirements. When there are few competitors, a market with a relatively low base-price is still more attractive than a market that must be shared with more colleagues.

Further research is needed to investigate the role of *ISR* and *NFR* at both ends of their respective ranges. Interesting extsensions of this study include scalability of the model (number of suppliers as well as number of markets), and introduction of local markets.

In future, we plan to further distinguish the multi-dimensional information items in their effects on behaviour. Different kinds of information can be applied to perform different actions. Personality of agents may influence the effectiveness of information as well.

Preface to Chapter 6

Case: Information quality

Op een dag lag de eekhoorn in het gras aan de rand van het bos naar de lucht te kijken toen een woord hem ontschoot.

'Ach!' riep hij, zonder dat iemand hem hoorde, want hij was helemaal alleen.

Welk woord is het nou ook maar weer, dacht hij. Zand, gras, schors, krabben, dik...

Hij kon het zich niet meer herinneren. Het was en bleef weg.

[...]

'Pas ben ik nog iets voorgoed vergeten,' zei de zwaluw [...].

'Wat dan?' vroeg de eekhoorn.

'Ja... als ik dat wist...'

'Maar hoe weet je dat je het voorgoed vergeten bent?' vroeg de eekhoorn.

'Omdat ik het overal heb gezocht,' zei de zwaluw. 'Ik heb niets overgeslagen.' Hij zweeg even en zei toen: 'Maar ik vind het nu niet erg meer.'

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One day the squirrel was lying in the grass at the edge of the forest, looking at the sky, when a word slipped his mind.

'Oh dear!' he cried, even though nobody heard him, because he was all alone.

What was that word again, he thought. Sand, grass, bark, scratch, thick...

He couldn't remember anymore. It was lost and gone forever.

[...]

'The other day, I forgot something for good,' the swallow said [...].

'What was it?' the squirrel asked.

'Well... if only I knew...'

'But how can you be sure that you forgot it for good?' asked the squirrel.

'Because I've been looking all over for it,' the swallow said. 'I didn't miss a spot.' He was silent for a moment and then said: 'But I don't mind so much anymore.'

Chapter 6

Influence of losing multi-dimensional information in an agent-based model

Abstract. This agent-based study investigates the effect of losing information on market performance of agents in a marketplace with various quality requirements. It refines an existing model on multi-dimensional information diffusion among agents in a network. The agents need to align their supply with available markets, the quality criteria of which must match the agents' information. Turnover (information entering and leaving the system) had a significant effect in the former model. Information items became obsolete based on age, causing a risk for the agents to lose valuable information. In the refined model presented here, an information item may become obsolete based on two additional aspects: (1) whether it is 'in use' for meeting the agent's current market criteria, and (2) its value, reflecting its owner's experience or skill with the information item. The research questions concern the influence of these two aspects on model outcomes. Two key parameters are *value-threshold*, below which items are candidate for disposal, and *keep-chance*, indicating the probability that *in-use* items are not disposed of. Simulation results show that value-threshold is a more influential parameter than keep-chance. An interesting pattern suggesting a tipping point was observed: with increasing value-threshold, agents initially reach higher quality, but then the quality diminishes again. This pattern is consistently observed for the majority of parameter settings. An explanation is that agents with only high-valued information cannot afford to lose anything. The sensitivity analysis adds insight to where keep-chance and value-threshold are most influential, and where other parameters are responsible for observed outputs. The sensitivity analysis does not provide any further insight in why the observed tipping point occurs. The paper also aims to highlight methodological issues with respect to refining an existing model in such a way that results of successive model versions are still comparable, and observed differences can be attributed to newly introduced changes.

6.1 Introduction

Autonomous producers, like farmers, make quality decisions regarding their product that must be aligned with available markets (Wever et al., 2010). Markets distinguish themselves by means of requirements which are expressed over multiple dimensions. For example, in the case of pig farmers, markets set requirements with respect to the product (e.g. taste, leanness), price, societal concerns (e.g. animal welfare, antibiotics use), environmental concerns (e.g. carbon footprint), and so on (Bonneau and Lebret, 2010). Since these requirements are partially ordered, the farmer cannot achieve an optimal score for all quality aspects at the same time, so he must make a choice of which market to aim for.

To make profitable decisions, a farmer needs to be sensitive and responsive to information throughout the production chain (Verbeke, 2001; Verdouw et al., 2011). Information in this case represents the whole market requirements spectrum. Information can be seen as data (e.g. price information), knowledge (e.g. which breed gives certain meat characteristics, how to calculate carbon footprint), and skills (e.g. raising animals in optimal conditions, farm management). Information can disseminate through a population: farmers can exchange what they know with other farmers, agencies can educate farmers on new approaches or techniques. Although information can be shared, it does not have the same value to every owner. A farmer cannot simply copy some other farmers' knowledge or skill, but needs to build up expertise to be able to adequately use that information for his own situation. Not all farmers appreciate all information in the same way: personal preferences and differences in circumstances affect its worth (Arens et al., 2012).

Information has a lifetime, meaning that it can become obsolete. It makes sense that information loses its value over time. Some information is time related, like market information. Other information needs to be revived now and then, for example information on adopting a new technology. If nobody speaks about it anymore, then it was probably a hype that has blown over. But if it keeps going around, then the technology may be well worth considering.

At the Artificial Economics 2012 (AE2012) conference, Osinga et al. introduced the concept of multi-dimensional information in an agent-based model to align market supply with available markets (Osinga et al., 2012). The setup of this model is such that it is applicable not only to the pig farmer case, but to any situation that involves autonomous suppliers who select markets with multi-dimensional criteria and associated information requirements. The focus of the paper was on the effect of varying network structures between agents on information diffusion and market supply. Information turnover was modelled as well: new information entering the system and outdated information leaving the system. An interesting conclusion of this study was that when there is sufficient information in the system, the effect of network topology is no longer significant: markets balance out, driven by the price mechanism. Also, the effect of information turnover was very significant.

When the sheer presence of information appears to be determinant for balancing market supply, then a fair question to ask is: does it make any difference *which* information is present in the model?

6.2 Problem definition

The present study is a refinement of the AE2012 model. It investigates the effect on emergent market supply of varying the conditions under which information becomes obsolete. In the AE2012 model, obsoleteness was unrelentingly determined by age, so agents ran the risk of losing information that allowed them to supply to a certain market, if it had not been renewed recently. For the present study, we investigate what difference it makes (a) when old information can be protected from becoming obsolete when it has proven its use, and (b) when young but low-valued information can become obsolete as well, instead of only old, unprotected information.

Given the assumptions of the AE2012 model, the research questions are:

1. What is the influence of *protecting useful information* from becoming obsolete on emergent market supply?

2. What is the influence of disposing of *low-valued information*, in addition to disposing of unprotected old information, on emergent market supply?

An additional, methodological purpose of this study is to describe the steps needed to refine an existing model in such a way that the results of the new model are comparable to those of the old model and differences can be attributed to the model changes.

6.3 AE2012 Model

A short summary of the AE2012 model is provided here. For full details see (Osinga et al., 2012).

Information items are represented as triples of id, type and value. *Id* is meant to distinguish information items from one another and to indicate their age. *Type* refers to the quality dimension to which this information item belongs. This could be anything that is meaningful in the domain, e.g. health or feed in the case of pig farmers. In our model, we use abstract types A, B, C and so on. *Value* refers to the value that this information item has for its current owner, since different owners may have different knowledge or expertise to put the information item to use. For example, [24, B, 40] represents information item with id 24, of type B, which has a value of 40% to its owner. When an information item is exchanged between agents for the first time, the new owner receives a copy, but with diminished value. Information items become obsolete over time by age.

Markets represent a certain quality, and are defined as combinations of selected information types and required minimum values. Markets together cover the available quality spectrum and are partially ordered. Markets have a base price and elasticity associated with them. The price further depends on total supply, an emergent property at each time step. There is a dump market that sets no requirements, but pays nothing either.

Agents start out with a random collection of information items. At each time step, they receive one item from each network peer or from the institution (being the source of new information items that initially have maximum - expert - value). With their current set of information items, agents try to supply to a market for which they meet the requirements set, using bounded rationality. An agent has a current market, which is the last market to which he was able to supply. This implies that his current set of information items covers his current market's requirements.

6.4 Adjusted model

This version of the model introduces a fourth attribute to the information items: *in-use*. This attribute is set to value True when the information item contributes to the agent's current market, and to False otherwise. Instead of disposing of old information only, the model now considers two additional criteria.

The first consideration concerns the *value* of the information item. As described above, this value reflects its owner's experience or skill with the information item. Whenever the agent receives an item with the same *id* from another agent during an information exchange event, the associated values are combined to either the same or a higher value, indicating an increase in experience and a revival of the item; see for details the AE2012 paper, (Osinga et al., 2012). This implies that low-valued information items are of relatively small use to the owner. All items below the *value-threshold*, which is a parameter of the model, are candidates for disposal.

The second consideration concerns the protection of an information item that is *in-use*, meaning that its type is required for its owner's current market. There are now two possible causes of losing information: age (an information item can reach its expiracy date), or value (its value can become lower than the value-threshold). In both situations, when the item is in use, it can be saved from disposal by a certain *keep-chance*, another parameter. If the keep-chance is 100%, the item will never be disposed of when it is in use. If the keep-chance is 40%, the item runs a 60% chance of being discarded, despite its in-use status. When value-treshold and keep-chance are both set to 0, the model is equivalent to the AE2012 model.

In summary: All items below the value-threshold will be disposed of, except those that are in use for the current market. The ones in use are protected by a keep-chance: the higher the keep-chance, the higher their survival rate.

Refining the mechanism for information disposal triggered a change in the order in which agents perform their actions. Figure 6.1 presents the new order of actions. The four actions in the fat-lined ovals used to be part of one action 'farmer step'. In effect, one farmer changed his network, then updated inform-

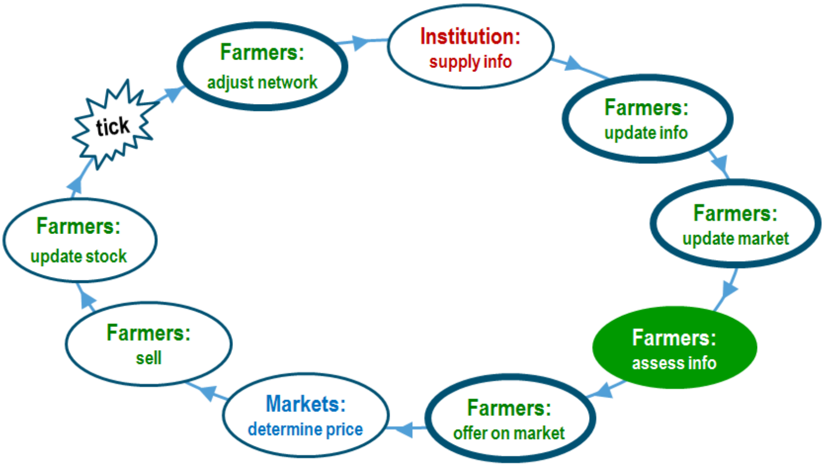

Figure 6.1: A simulation time step, with farmers as suppliers. In the former AE2012 model the four fat-outlined ovals were taken together in one 'farmer step'. The oval 'assess info' was added.

CHAPTER 6

ation, updated market, and finally determined his market offer before the next farmer executed these same actions. In the new model, all farmers adjust their network, and then they all update information using the adjusted network, and so on.

The step indicated by the oval 'assess info' is new relative to the AE2012 model. In this step all farmers determine which information they need to fulfil the requirements of their current market. Here the in-use attribute of info-items gets its value.

Another change to the model concerns the *information window*, which indicates the number of information items that an agent takes into account when determining his market options. This *window* is by default set to 5, meaning that for each type, the average value of the 5 highest information items is considered to see whether market requirements are met.

6.5 Methodological issues

Compared with the AE2012 model, the new model required a number of changes. Some mechanisms involve drawing random numbers, e.g. using keep-chance to determine whether an information item becomes obsolete. But most new mechanisms can be set to reproduce exactly identical results to a model without that mechanism, e.g. by setting the value-threshold to zero.

To ensure that the new model outcomes would be comparable to the old outcomes, and different results could be fully attributed to the model changes and not to unintended other effects, we followed a strict procedure. After each change to the model, the model was run with settings corresponding to the previous version, to verify that outcomes did not change. Whenever possible at all, the outcomes were checked by file comparison to determine whether they were exactly identical.

Special attention has to be paid to the role of random numbers in the model. In all model runs, we set the seed for the random number generator explicitly, if only to be able to reproduce interesting results. When introducing new random effects, results cannot be identical because of these random effects. But also when the order of execution of steps changes, the effects of random numbers are no longer identical. Therefore, we concentrated all (relatively few) changes of these two types into one model development step.

All other development steps - before as well as after this special step - maintained strictly identical results for corresponding settings. For example, we could already add the mechanism for recording the in-use attribute without affecting model outcomes.

For the single model development step that influenced random numbers, we verified that model outputs were statistically equivalent as follows. Even with the same random seed, outcomes were not strictly identical. Instead, we statistically compared outcomes of multiple runs of the model versions immediately before and after this step, to verify that no essential changes were introduced inadvertently.

6.6 Simulation results

For the simulations, a base case was defined in which the already present model parameters were fixed to a combination that yielded results representative for the AE2012 experiments. Only the parameters of study of the new model, value-threshold (*thr*) and keep-chance (*kch*), were systematically changed. The base case was set up with 100 farmers in a static network of 2 neighbours each and a dynamic network of an average number of friends (*NFR*) of 1; an information supply rate (*ISR*) of 50, and a market set consisting of 8 markets with randomly increasing quality requirements on 4 different information types. (Referring to the AE2012 model, the network was *ring10d* and the market set *rand-inc*). With a *thr* of 0 and a *kch* of 0, the base case corresponds to the AE2012 model behaviour.

The elements to be varied were *thr* and *kch*. After evaluating some test-runs, *thr* was set to values 0 through 80 in increments of 10; *kch* was set to 0, 30, 60, 80, 90, 100. All combinations of these parameters were repeated 10 times to mitigate the effects of randomness. The result figures below each show one run, with agents active on dump, low, medium and high market segments, accumulated over time.

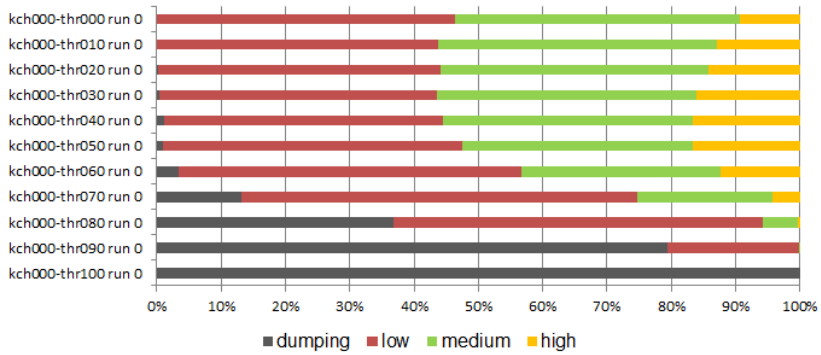

Figure 6.2: Result of one simulation run with *kch* = 0 and varied *thr*. The bars indicate the percentages of farmers active on dump, low, medium and high market segments, accumulated over time.

Figure 6.2 shows one of the runs with *kch* 0 and increasing *thr*s. The top line, *thr* 0, reflects the behaviour of the AE2012 model (the base case). The *kch* is 0, meaning that information items that are in use have no special protection, which allows us to see the influence of *thr*. We observe that a higher *thr* means a considerable shift in market balance. With a *thr* from 0 up to about 40, we observe that the market share with highest quality increases. But when *thr* increases further, we observe that the high market share decreases again, the low market share gains ground, and agents even have to take resort to the dump market. We can explain this phenomenon as follows: when *thr* is low, any information item that is disposed of has a low value, which will not hurt the agent very much. But when *thr* is high, only precious high-valued items remain, and whatever item is disposed of will be a loss to the agent. Without it, he may not be able to maintain the requirements of his high quality market anymore. We consistently observe this pattern of initially improving and subsequently losing quality with all values for *kch* tested, except value 100.

Figure 6.3 is another example result where *kch* was set to a fixed value (60 this time), and *thr* was varied up to 80. We see that the typical pattern of increasing and decreasing high qualty segments is clearly visible again. In comparison with Figure 6.2, we observe that a higher *kch* protects information slightly better so that the reached quality level is higher.

Figure 6.4 shows results for varying *kch* with a constant *thr* of 0. Again, the top line reflects the base case. With *thr* 0, age rather than low value is a reason for disposal, which allows us to see the influence of *kch*. A higher *kch* increasingly protects the agent from losing information that he currently has in use, enabling him to maintain or improve his current market. Only when *kch* is 100, the agent can keep a successful set of information items forever, and

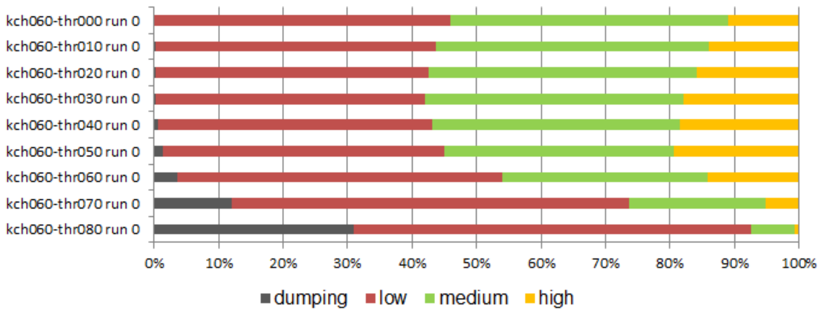

Figure 6.3: Similar to Figure 6.2, but now with *kch* = 60 and *thr* varied up to 80. The same pattern of increasing and then decreasing high market segments is visible.

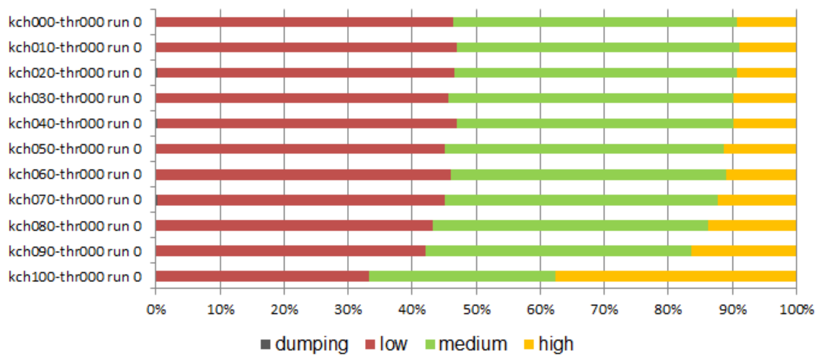

Figure 6.4: Result of one simulation run with *thr* = 0 and varied *kch*. The bars indicate the percentages of farmers active on dump, low, medium and high market segments, accumulated over time.

we see indeed that high quality market shares are relatively large. In situations where *kch* is lower and his useful information items become of old age, the information items that an agent holds will not be sufficient to maintain his quality anymore. We observe that a lower *kch* means that agents are less able to supply to high quality markets, and that medium and low quality markets gain in market share.

Figures 6.5 and 6.6 show similar results as Figure 6.4, but now with thresholds set to a fixed value of 40 and 80, respectively, and with *kch* varied over less values. For *thr* of 40 (Figure 6.5), we observe that agents reach higher quality segments than with *thr* of 0. This makes sense, because the low-valued items are disposed of and high-valued items are the ones that remain. However, when *thr* is 80 (Figure 6.6), this effect turns against itself. There are no

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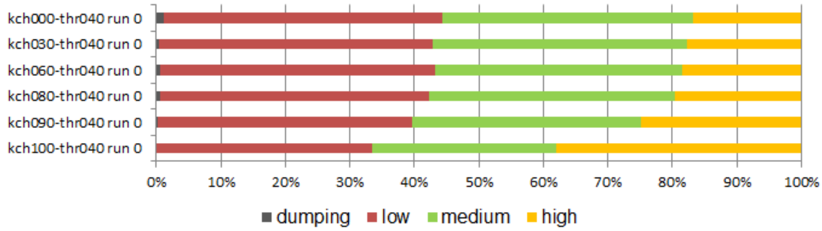

Figure 6.5: Similar to Figure 6.4, but now with *thr* = 40 and varied over less *kch*s. The higher market segments are larger, compared with *thr* 0, because disposed items are the low-valued ones.

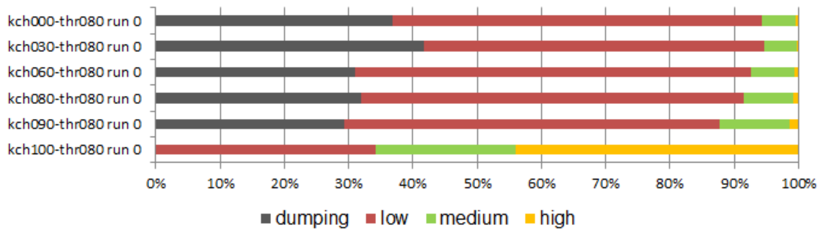

Figure 6.6: Similar to Figure 6.5, but now with *thr* = 80. Except for *kch* = 100, when there is no disposal at all, quality is much lower than with *thr* 40. When *thr* is high, only high-valued items remain, and disposal of any item is a loss to the agent.

low-valued items left to dispose of, and loss of any item is a problem. As a result, agents cannot maintain the high qualities anymore and even have to resort to the dump market. Only when *kch* is 100, and all items are protected, agents can still supply to high quality markets.

6.7 Sensitivity analysis

We performed a local sensitivity analysis in order to see how sensitive to parameter changes our results are - and especially the apparent tipping point for varying *kch* visible in Figures 6.2 and 6.3. We varied the parameters shown in Table 6.1 one at a time, with the values shown there. Only *kch* and *thr* were varied both one at a time and together. For one at the time variation, *thr* was set to 0 and *kch* from 0 to 100 in steps of 10, and the other way around. When they were varied together, their values were set to all combinations of 0, 30, 60 and 90. Each run of a particular parameter set was repeated 10 times. The mean result of these runs is reported as outcome. The parameters in the list of Table 6.1 are the number of farmers in the simulation (*farmers*), the informa-

parameters	low	base	high
farmers	90	100	110
ISR	45	50	55
NFR	0	1	2
steps	1000	2000	3000
window	4	5	6
kch			
thr		*see text*	

Table 6.1: Settings chosen for local sensitivity analysis.

tion supply rate (*ISR*), the average number of friends that a farmer has (*NFR*), the number of time steps that the simulation lasted (*steps*) and the information window that farmers have (*window*).

The sensitivity of the parameters to the outcomes were expressed according to the formula shown in Equation 6.1 and normalized according to Equation 6.2:

$$sensitivity = \frac{v_{hi} - v_{lo}}{p_{hi} - p_{lo}} \tag{6.1}$$

$$normalized\ sensitivity = \frac{v_{hi} - v_{lo}}{p_{hi} - p_{lo}} * \frac{p_b}{v_b} \tag{6.2}$$

In these equations, v represents the mean value for the variable over all runs (output), and p represents the parameter that was varied (input). The subscript b stands for the value of the base case. Subscripts lo and hi indicate the lower and higher than base case values for the parameter, respectively.

The results of the sensitivity analysis are summarized in Figures 6.7 and 6.8. Figure 6.7 shows the combined influence of *kch* and *thr*, when varied together. The left panel shows the relative influence of all parameters under consideration on the dump market share. The right panel shows this influence on the high market share. For conciseness reasons, we do not show the relative parameter influences on low and medium market shares.

We observe that the *thr* parameter has a relatively larger influence than *kch*. For the dump market, a *thr* from value 30 onwards is very dominant. We see that other parameters are responsible when *thr* is not yet so dominant, of which initially the number of farmers seems most influential, and also the information supply rate (*ISR*). The farmer influence is negative, meaning that when the number of farmers increases, fewer farmers resort to the dump market. With our current analyses we cannot explain why this happens.

For the high markets, we see that the *thr* parameter is dominant from value 90 onwards. When *thr* has value 90, all information items below 90 are thrown away, so effectively nothing happens anymore. As a consequence, no other parameter has any influence. Two other parameters have a relatively high influence as long as *thr* is not yet dominant. These are the information supply rate

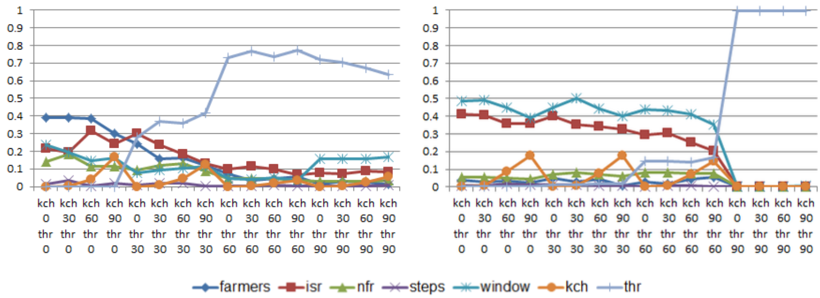

Figure 6.7: Relative sensitivity of parameters varied according to Table 6.1; *kch* and *thr* varied simultaneously. Left: dump market; right: high markets.

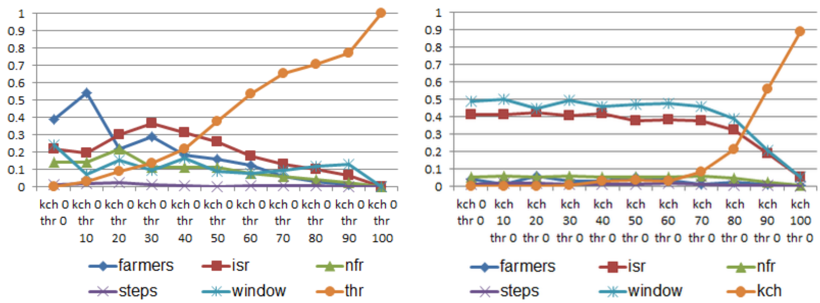

Figure 6.8: Relative sensitivity of parameters varied according to Table 6.1; *kch* and *thr* varied one at a time. Left: *kch* = 0, *thr* varied (dump market); right: *thr* = 0, *kch* varied (high markets).

(*ISR*) and the information window. This makes sense: the more information in the system, the more high quality markets come within reach (as was also an AE2012 conclusion). And for *window*: when we vary the number of information items that are taken into account during decision making, this is expected to be especially sensitive for high quality requirements. It also makes sense that the number of steps, the number of farmers, and the number of friends do not have a significant influence (the latter also being an AE2012 conclusion).

The left panel in Figure 6.8 shows the results of local sensitivity analysis with a *kch* of 0 and a varying *thr*, for the dump market segment. From the absolute results, shown in Figure 6.2, we know that farmers start to enter the dump markets when *thr* value is about 40 or higher. That is consistent with what we see here: from about value 50, the influence of *thr* is increasing and becomes very dominant. It is indeed the treshold value that is responsible for farmers having to supply to the dump market.

The right panel in Figure 6.8 shows similar results, but now for the high market segment, and with *thr* set to 0 so that the influence of *kch* can be observed. For the major part of the graph, with low and medium *kch*s, the parameters *ISR* and *window* are dominant. For values higher than 70, *kch* becomes an influential factor for the high markets. In the absolute results, shown in Figure 6.4, we saw that the high market segment is increasing with *kch*. With the sensitivity analysis results, we can add the insight that *kch* is only responsible for this when it has a value higher than 70. Below that value, parameters *ISR* and *window* mainly determine whether farmers are able to supply to high markets.

6.8 Conclusions and discussion

In this paper, we reconsidered the way agents dispose of their information in our model. Next to expiracy because of age, an information item can now also be disposed because of too low value, indicated by a *value-threshold*. An information item can receive the special status of *in-use* that indicates whether the information item is needed for an agent to keep his current market. The *keep-chance* indicates the probability that in-use items will be saved from disposal. We ran simulations where we focussed on the value-threshold and keep-chance parameters. We also performed a sensitivity analysis of the results. Returning to our research questions, of which question 1 referred to the keep-chance and question 2 to the value-threshold, we can conclude that the influence of value-threshold is very significant, and the influence of keep-chance is moderate.

Sensitivity analysis shows that the influence of most other model parameters is according to expectation. Parameters *ISR* and *NFR* behave according to the AE2012 model outcomes. The information window has an influence where it makes sense. The number of steps in the simulation has almost no influence. Sensitivity of networks and markets is difficult to establish, since they are not numerical, but those were tested and reported in our AE2012 model. The only deviation is the number of farmers, which seems to have an influence, but for the explanation of which we need further investigations.

The sensitivity analysis results add insight to the simulation results, with respect to the relative influence of value-threshold and keep-chance. Sometimes their influence is quite absolute, but sometimes other parameters are more influential. The sensitivity analysis results do not give any cause to interpretation conflicts. The simulation results show a consistent pattern where a tipping point is suggested. However, the sensitivity analysis gives no decisive explanation for or insight in this phenomenon.

An additional goal of this paper was to highlight some methodological aspects, especially concerning the procedure for guarding comparability of results from successive model versions. This is a particular concern in agent-based models, where the order in which agents execute their actions requires careful attention.

Preface to Chapter 7

Case: Policy intervention

Geachte dieren,

Hierbij deel ik u mede dat ik vanaf heden al mijn werkzaamheden een halt toeroep.

Ik doe het niet meer.

Iedereen breekt maar doormidden, wil twee slurven, andere gedachten, een kelder, ogen op zijn stekels, één schub, nieuwe vleugels, noem maar op, en ik ben er altijd weer goed voor.

Vanaf heden ben ik dicht.

De boktor

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CHAPTER 7

Dear animals,

I hereby inform you that, as of today, I put a stop to all my activities.

I am not doing it anymore.

Everyone just keeps breaking in half or demanding two trunks, second thoughts, a basement, eyes on their quills, a single scale, new wings, you name it, and I am always the one to fix it.

As of today, I am closed.

The longicorn

Chapter 7

Sustainable animal welfare: does forcing farmers into transition help?

Abstract. Dutch society is changing, and so is its attitude towards animal welfare. Meat retailers respond by laying down minimum-quality criteria for farmers who wish to supply to supermarkets - forcing them to either aim for higher quality or lose their market. Policy-wise this is a top-down measure that leads to a redistribution of markets. From farmer perspective, a transition with more individual freedom to adapt seems more sustainable. By means of an existing agent-based model, this paper investigates two policies for such a market switch: immediate transition - 'sudden death' (SD)- versus gradual change - 'graceful degradation' (GD). Both farmers and available markets are modelled as agents. Each farmer has a collection of multidimensional information items, under certain conditions exchangeable with other farmers in his network, representing his knowledge and skills. Information items are a farmer's key to the market, as market criteria are expressed in terms of information requirements. We tested the effect of SD and GD policies on market redistribution, varying markets sets, available information, and network size. Results show that policy does not matter for final market redistribution, but that GD policy indeed allows more farmers to keep away from poverty, especially in information-poor situations. With GD, we see a temporarily higher inequality of income distribution over individuals (Gini) worth exploring. Studying transitions with respect to both individuals and the system as a whole may be promising for other domains as well. The model is applicable to any situation that implies aligning heterogeneous suppliers with a multi-dimensional demand spectrum.

7.1 Introduction

Dutch society no longer seems to tolerate violation of animal welfare. In the Netherlands, animals nowadays literally have a voice: the political Party of the Animals, founded in 2002 and advocating to treat animals respectfully, won two seats in parliament in November 2006 and kept them during subsequent elections (Partij Voor De Dieren, 2013). Animal welfare was long considered 'inconvenient', because how to deal with farm animal welfare concerns when other issues compete, such as economics, international trade, environmental concerns, and food safety (McGlone, 2001)? As of re-

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cently, opinions prevail that animal production systems can only be sustainable if animal welfare is taken into account (Broom, 2010).

Dutch public debates on animal welfare in livestock production entailed long-lasting controversies between involved societal actors such as primary producers (farmers) and concerned citizens (Frewer et al., 2005; te Velde et al., 2002). These debates eventually resulted in serious attention for better husbandry systems and creating new market segments (Buurma et al., 2012). Considerable research efforts were made to develop and design more animal-friendly husbandry systems that would take animals' natural needs as a starting point and would make interventions in the animals, such as tail-cutting, less necessary (de Greef et al., 2011; Bos et al., 2011; Elzen et al., 2011). The European Union funded projects to investigate farmers' current animal welfare practices (Bock and Van Huik, 2007). Farmers themselves, represented by the Product Board Livestock and Meat (LTO), which is the Dutch farmers' association, drew up a set of rules and principles to express their view on sustainable farming with respect to animal welfare (LTO Nederland, 2008).

Despite these apparent developments in favour of animal welfare and sustainability, there are still problems to be solved. Farmers who wish to implement novel husbandry systems need to make considerable investments, but an expectedly better price for their more sustainable meat product at a higher-quality market should compensate for that. Unfortunately, consumers often show a discrepancy between perceptions and daily practices, meaning that although - as concerned citizens - they share the impression that the living conditions of livestock animals deserve improvement, most of them - as frugal consumers - still buy and eat meat from the meat industry (te Velde et al., 2002; Bauman, 2009; de Bakker and Dagevos, 2012). Currently in the Netherlands, an interesting transition with respect to this discrepancy seems to be taking place. A Dutch animal protection organization broadcasted alarming commercials showing the poor conditions in which animals live before they become food products, appealing to the audience's sense of compassion, and yielded a series of successes: white (anaemic) veal (2008), bargain meat packs (2010), and battery hens (2012) have been reduced or removed from most supermarkets' shelves (WakkerDier, 2012). Whether they want it or not, consumers can no longer pay the minimum price for meat in most regular supermarkets, thus allowing the farmers to engage in more animal-friendly production.

With respect to bargain meat packs, all joint Dutch food retailers consider the time ripe to support this initiative even further. In May 2013, they agreed to raise the minimum quality standard for all pork to so-called 'good farming star' level, which is currently the case in one large supermarket chain only (Central Bureau Of Food Retailers, 2013). They defined minimum criteria, published and explained in trade specialist journals, that pig farmers must meet in order to be allowed to supply to supermarkets. They also agreed to make an effort to further increase other market shares of even more sustainable meat types, such as organic pork.

This has its consequences for all pork farmers: all of a sudden their 'business as usual' has to change. The farmers who used to produce for lowest-quality markets can no longer supply there, because the market will disappear. They are forced to fulfil the new criteria and aim for higher markets if they do not want to lose their business. In order to make this transition, they need to get acquainted with what is required of them, take the time to select a new market, and invest in new husbandry systems. Both 'hard' technological changes and 'soft' changes such as adopting a flexible attitude may be required (Jin and Bai, 2009; Somers and Stapleton, 2013). The farmers who already produce for higher markets will face newly entering competitors and must take into account that they may likely receive a lower price for their product than they were used to. Policy-wise, one could argue that society as a whole, including animal protection organizations, retailers and even farmers' organizations, consider this transition towards more sustainable, animal-friendly markets as a top-down event, treating the farmer population as a group, not taking into account what it means for individual pig farmers to have to comply. The farmers themselves feel stressed. A third of them expects not to be able to continue their farm, and a majority expects serious financial and practical problems having to adapt their business in order to comply with the new welfare regulations (Varkensbedrijf, 2013). Here, the social aspect of sustainability comes in, implying that no policy can be considered sustainable if the people involved (i.e. the farmers) are unable to make a long-term living out of farming (Morse and McNamara, 2013). Could a more farmer-oriented, bottom-up approach (i.e. not to close the low-quality market without mercy but to allow for a voluntary transition towards the desired higher-market spectrum) be considered as an alternative policy?

7.2 Agent-based modelling, agri-business and markets

Agent-based modelling (ABM) is particularly appropriate as a method to study the behaviour of autonomous, heterogeneous individuals who have bounded rationality and exhibit social interactions (Gilbert, 2008). That makes farmers examples of real-life human agents that seem suited to be modelled in ABMs. Current literature on ABM in agriculture shows that farmers' decision-making and policy issues are a frequent combination of study. Models often include a spatial component, deploying data from geographical information systems. Valbuena (2010) built an ABM of farmers' individual decision-making regarding land-use/cover change, showing that policy is influenced by farmers' decisions. Schouten et al. (2013) uses ABM to evaluate agri-environmental policies in rural areas where farmers respond to these policies. Valeeva and Verwaart (2011) and Verwaart and Valeeva (2011) modelled farmers' decisions to adopt food safety practices in the dairy sector in an ABM. Osinga et al. (2011) used an ABM to model the classical pork cycle from farmer perspective and the potential of information management measures in the sector.

The concept of 'market' has various interpretations in ABMs. For example, there are many models for financial and stock markets (Lux, 2012), housing markets (Geanakoplos et al., 2012), and electricity markets (Weidlich and Veit, 2008). Such models tend to focus on price mechanisms, auctions, and negotiation sequences, and less on markets in the sense of finding the right channel to supply to. Ross and Westgren (2009) is an example of an agent-based model in the context of the agricultural supply chain, modelling agrifirms with entrepreneurial behaviour and firm interactions who aim for wealth creation. There are parallels with our work in the sense that the agents in Ross' model have attributes that influence their behaviour and that the context is a set of markets characterized by norms and regulations. Ross' model focusses on individual firms who perform an exhaustive search within a spatial environment for the optimal market, only limited by their own capabilities. It does not take any system-level outcomes such as market performance into account. The aspect of agents who distinguish themselves by knowledge and skills and who seek to thrive within a supply chain is implemented in the SKIN innovation model as well (Ahrweiler et al., 2004). Here, the agents are (large) business firms, not small entrepreneurs, who seek to sell products to each other while focussing on innovation. There are no explicit markets in the SKIN model.

Markets where farmers seek to supply to in a context of animal welfare and sustainability are perhaps best compared to the labour market (Tsan Sheng and Yong Chuen, 2013). Also on the labour market, departments may close, and employees need to be placed elsewhere. Sustainability is certainly an issue, both in the sense of labour quality and in the sense of societal balance.

7.3 Research questions

The aim of this paper is to apply ABM to simulate the described market switch from the perspective of the individual pig farmer, who finds himself (a) confronted with shifting or disappearing markets, (b) having to respond by choosing a new market, and (c) limited by market criteria that require knowledge, time, and investments. Can this ABM capture the dynamics of shifting market shares on population level as well, in a way that allows studying the effect of alternative transition policies i.e. how to switch a farmer population from one market situation to the other?

This paper elaborates on the following research questions:

1. Does it make a difference by what policy farmers are encouraged or forced to switch market? Candidate transition policies are (a) top-down, by 'sudden death' (SD): the low-quality market is no longer available starting from a fixed date or (b) bottom-up, by 'graceful degradation' (GD): the low-quality market is discouraged but still available from a fixed date onwards, and it is up to the farmers themselves whether they will still want to supply there or not.

2. Which policy serves sustainability and animal welfare best, both for the farmers and for society as a whole, if we take into account not just the final result but also the way towards that result?

7.4 Model

To model this complex adaptive system - capturing individual decision-making, interactions, market shifts, and price dynamics - requires covering a range of disciplines: economics, policy making, domain knowledge, and human behaviour. The model should be rich where differentiation is needed, but aim at abstraction where possible in order to keep it tractable. The core of the model presented here has been previously applied in the domain of information diffusion and market choice (Osinga et al., 2012, 2013). In terms of Gilbert (2008), this is a mid-range model: the aim is neither to exactly model the farmers in a certain region, nor to make a purely theoretical point. Stylized facts about system-level tendencies emerging from the simulations should be recognizable by real-world experts, without having to match any specific situation one-on-one.

The model distinguishes three agent types: farmers, markets, and a food quality agency ('the institution'). Main attributes of farmers are: current market, friends, information items, number of pigs, and wealth. The *current market* is the market which the farmer is currently able to supply to; *friends* are other farmers in his network with whom he can exchange information items; *information items* represent the farmer's knowledge and skills (see below); *number of pigs* is the amount of product the farmer has to supply; and *wealth* denotes his financial situation. Main attributes of markets are: quality, price, last price, total supply, and availability. *Quality* is specified as a list of criteria with required minimum values that suppliers have to satisfy; *price* is the price that this market pays to suppliers, consisting of various price determinants (see below); *last price* is the last price that this market paid, based on which farmers evaluate the market; *total supply* is the amount of farmers supplying to this market (which is also a determinant of the price); and *availability* indicates whether this market is available to farmers or not (especially relevant when the low market is to be closed). The institution's only attribute is the list of all information items.

Central in the model are information items, of which each farmer has a private collection, under certain conditions exchangeable with others in his network. A farmer's information items are his key to the market, since market criteria are expressed in terms of combinations of selected information types and required minimum values (see below). Each market thus represents a certain quality; markets together cover the available quality spectrum. Quality in this context stands for 'level of animal welfare' and other sustainability aspects.

The institution is the source of information and considered expert: it possesses a list of all information items, which initially all have maximum value, and it can generate new information items. The institution brings information into the system at an information supply rate (ISR), which is a parameter of the model. The institution is a proxy for all information sources in reality: livestock bureaus, technical journals, experts, web pages, information systems, etc. Farmers can also receive information items from other farmers in their network. Each farmer has a dynamic network of friends; the average number of friends (NFRs) on population level is another parameter of the model. The rationale behind this is that farmers seldom work alone in strategic matters, but that they talk with each other and take suggestions from each other.

The information items themselves are the abstraction of everything a farmer has to acquire or make an effort for before he qualifies for a new market. Information items are represented as triples of id, type, and value. *Id* is meant to distinguish information items from one another and to indicate their age. *Type* reflects the dimension to which the information item belongs. In the model, we use abstract types A, B, C, and D, but the number of types is flexible. A-D are dimensions for which agents can acquire information or expertise during the simulation. In our sustainability context, these could be read as the farmer's knowledge and skills concerning (A) feeding issues, (B) animal health issues, (C) housing issues, and (D) farm management. 'Attained animal welfare level of the pigs' and 'environmental impact of the farm' are examples of properties that would typically be emergent, not to be used as 'input' for dimensions A-D. *Value* refers to the value that this information item has for its current owner. For example, [24, B, 40] represents an information item with id 24, of type B, which has a value of 40% to its owner. When an information item is exchanged between agents, the new owner receives a copy of the information item, but its value diminishes. This reflects the fact that agents are heterogeneous and cannot simply copy knowledge and skills from each other, but instead have to build up some expertise for themselves. Information items become obsolete over time by age. This reflects the dynamic nature of regulations, knowledge, and skills: farmers need to continuously adapt over time.

Markets' quality criteria are expressed in terms of the same types and values as the information items. The market specification states which types this market requires minimum values for. Table 7.1 shows an example of how markets are specified. Not all types need to be present in every market specification (values can be zero). Several markets together form a *markets set*. This set defines the range of available markets for the farmer population. The markets set can be considered a parameter of the model: the same model can be tested with various markets sets. This is what we investigated in an earlier application of the model (Osinga et al., 2012). Since there are multiple dimensions (types) in each market description, there is no linear ordering of markets in a set: they are partially ordered. In a general sense, the higher the required values for a market's selected types, the higher the quality of that market. There is not necessarily a correlation between the quality and the price for the market, but it makes sense to associate a higher price with a higher-quality market. There is

	ID	price properties			required information items			
		b	*c*	*k*	A	B	C	D
low-markets set	m1-lo	20	200	0.1	20	20	20	20
	m2-lo	30	200	0.1	30	30	30	30
	m3-lo	40	200	0.1	40	40	40	40
	m4-lo	50	200	0.1	50	50	50	50
high-markets set	m1-hi	20	200	0.1	20	20	20	20
	m2-hi	40	200	0.1	40	40	40	40
	m3-hi	60	200	0.1	60	60	60	60
	m4-hi	80	200	0.1	80	80	80	80

Table 7.1: Specifications of two markets sets; *b*, *c* and *k* are price properties (see Equation 7.1); A, B, C and D indicate the required criteria for this market, for which values can range from 0 to 100.

a dump market (not specified in the markets set) that has no requirements, but pays nothing either. Apart from a last resort, the dump market is also a proxy for the other options a farmer may have, for example, to start an alternative trade alongside his farm, or to close his business.

7.5 Model mechanism

The sequence per time step in the simulation is illustrated in Figure 7.1. At each time step, all farmers adjust their friends network; the institution supplies a number of new information items to farmers and makes old information obsolete; the farmers exchange information items with a friend; they update their market and offer their pigs to that market. Markets determine the price based on supply; farmers sell the pigs they offered, collect their money, and replenish i.e. buy new pigs. The amount of pigs they will purchase is a random number between 1 and the maximum capacity they can hold, maximized to what they can afford.

To identify their market, farmers choose one new candidate market at random. When that market's expected price (i.e. its last price) is higher than the price the farmer received at his current market, he will opt for the new market, which only succeeds if he meets the new market's requirements. Otherwise, he will remain at his current market, if he still meets its requirements. If that is no longer the case, he will try to find another one. If nothing else works, he will turn to the dump market. Farmers on the dump market do not leave the system but can always return to a real market when they meet the criteria again.

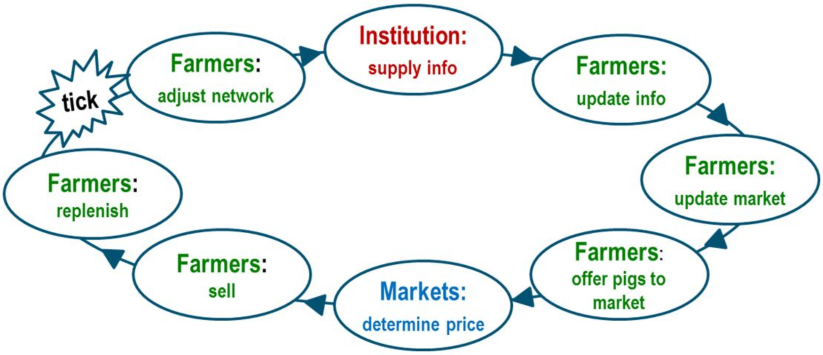

Figure 7.1: A time step in the simulation.

The model adopts a standard price mechanism from economics (Perloff, 2009). The pig price is calculated for each market according to Equation 7.1:

$$price = b + c * e^{-kQ} \tag{7.1}$$

where b equals the base-price for that market (i.e. the price - related to market quality - suppliers still receive when supply is endless), c is a constant related to the price at low supply, and k is a measure for price elasticity (i.e. how the price changes when the quantity changes). Q stands for total supply, an emergent property at each time step. Each market has its own b, c, and k associated with it.

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The two policies to be tested, 'sudden death' (SD) versus 'graceful degradation' (GD) of the market with lowest criteria (excluding the dump market), are implemented as a shock event during the simulation. A parameter in the model allows specifying the time step at which this shock should occur. For SD, at the moment of the shock, the lowest market is instantly made unavailable to all farmers, meaning that no farmer can choose that market anymore from the next time step onwards. All farmers who have the lowest market as their current market are referred to the dump market instead. For GD, the market becomes unavailable to newcomers at the moment of the shock, but existing farmers can still keep using it as their current market. As soon as those farmers voluntarily leave the market, they are not allowed to come back.

The first policy (SD) assumes that the low market becomes instantly unavailable, as if it were an unexpected natural disaster. In reality, a policy change like this will be well announced beforehand, allowing farmers to anticipate and prepare themselves for such a change. In our research, we do not take such anticipation into account.

To have a measure of the distribution of wealth over the population of farmers, as a sustainability indicator, the Gini coefficient is implemented in the model. This is a wellknown technique used by economists (Cowell, 1995). The Gini coefficient is best described by a Lorenz curve. A Lorenz curve plots the cumulative proportion of the total population against the cumulative proportion of total income when the population is ordered from lowest to highest income. In an equal society, this plot is a straight diagonal line (the line of equality). The further a Lorenz curve deviates from that diagonal, the more inequality there is in the population. The Gini coefficient is calculated as twice the area between the line of equality and the Lorenz curve. In our implementation, the Gini coefficient is a number between zero i.e. complete equality, and 100 i.e. complete inequality.

7.6 Agent-based properties

The model is agent-based in the sense that it exhibits heterogeneity, bounded rationality, agent interaction, and emergence.

- Farmers are heterogeneous in a few respects: the number of information items, the value those information items have for them, their current market and the number of other farmers in their network.

- Bounded rationality is assumed when farmers try only one new market per time step. By opting for only one candidate new market, the farmer runs the risk that there is a better market available which he will not find. But given the bounded rationality condition, it is assumed that farmers have no time to check all available markets.

- Farmers also show bounded rationality because they do not know the price they will actually get for their pigs, as this depends on total supply Q for that market, which can only be calculated after all farmers have made a decision (based on the expected price). Total supply Q is therefore an emergent property of the system, which is in contrast with analytical models where total supply is a given.

- Agent interaction occurs through information items exchange between the institution and farmers and between befriended farmers. The fact that choice of market is influenced by total supply from all farmers can be considered implicit interaction.

- The outcome of all individual farmers' market decisions is an emergent property at sector level: the distribution of farmers over available markets. Higher markets represent a higher level of animal welfare. Attained animal welfare level or sustainability is therefore also emergent at sector level.

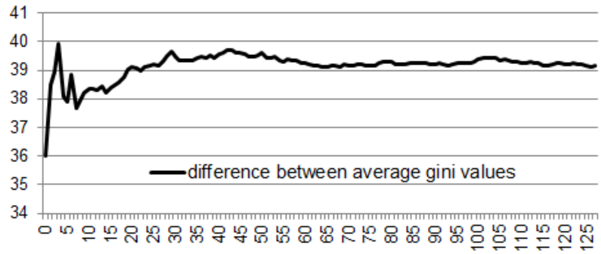

Figure 7.2: Sample convergence plot (in this case time step 300, Gini coefficient) showing how the difference between successive average values converges as the number of runs increases.

7.7 Simulation

For the simulations, we tested the two proposed policies: SD versus GD of the market with lowest-quality criteria.

Naturally, the outcome of these tests is influenced by the other parameters in the model. We therefore tested the model systematically with various input parameters on both policies. The elements to be varied were the policy itself, the available markets set, the information present in the system as controlled by ISR, and the size of the friends network NFR.

As available markets, we alternated between two sets of our uniformly increasing markets. One set was rather moderate on criteria, the other set was more challenging. Table 7.1 shows the details of both markets sets ('low' and 'high').

All simulations were run with 100 farmers, and lasted 800 time steps. At time 400, we introduced the shock. From pilot runs, we learned that 400 time steps is more than enough to obtain a stable picture of the situation before a shock. Another 400 time steps after a shock is sufficient to see what happens afterwards.

For each of the 48 scenarios (all combinations of 2 policies, 2 markets sets, 4 values for ISR, 3 values for NFR) we ran 128 simulations. We started out with 64 simulations, but then carried out a simple convergence test to see whether this number of simulation runs was sufficient. The convergence test was done according to Troitzsch (2013a,b) which entails visual inspection of graphs plotting the differences between successive average observables against increasing run numbers. Figure 7.2 shows a sample convergence plot, depicting the differences between successive average Gini coefficient values, as the number of runs increases. We randomly inspected plots, from which we concluded that 64 is not but 128 runs is sufficient for our simulations.

The model was implemented in Netlogo 5 (Wilensky, 1999)). To do the simulations, we wrote a program in Java to control the NetLogo model, using

NetLogo.jar. Our Java program takes input files containing the run specifications, passes all parameter settings to the NetLogo model, starts the run, collects outputs from the model, and produces summarized output files for every run, together with overall summary files. We chose to summarize run outputs, because storing all raw data from all simulation runs is too costly with respect to disc space. Using Java, we could also easily control Netlogo's random seeds, enabling reproduction of results. We used Python programs to further post-process the summary files. Running the model on our common office PCs required about 1 min per simulation run. For the research presented in this paper, we needed 128 runs of 48 parameter sets i.e. 6,144 runs, which would require roughly 100 h if we had run them sequentially. Running multiple parameter sets in parallel reduced this to a manageable amount of time.

7.8 Results

The results of the simulations show consistently that there is no significant difference between the two policies as to what market farmers ultimately end up supplying to. When only the end result counts, it does not matter which policy to choose. As could be expected, the transition period following right after the shock is consistently different for the respective policies. All simulation results applying a SD policy show an abrupt, straight line decline of the lowest market m1 at the time of the shock (400) and a simultaneous and equally abrupt rise of the dump market. Instead, the simulation results from scenarios applying the GD policy show a more gradual decline of the low market m1 (stretching the decline over roughly 100 time steps) and a similar increase of the dump market. After the shock, markets balance out into a new equilibrium, the extent of which depends on the other parameters. The average NFR and ISR are responsible for the level of information in the system. The more information in the system, the larger the share of higher markets will be: higher markets are not reached when there is little information in the system (Osinga et al., 2012). It also depends on the used markets set (high or low) whether farmers can or cannot gather sufficient information items to fulfil the markets' requirements.

Figures 7.3, 7.4, and 7.5 each present two sample result graphs out of a total of 48, one for every tested scenario. The graphs show the averages of all 128 simulation runs that were performed for that particular scenario. Each figure displays the SD policy on the left, and the GD policy on the right-hand side. Figure 3 shows a simulation scenario of no dynamic network (NFR = 0), an ISR of 50% and a set of low markets. All available markets are within reach; after the shock, in the GD policy scenario, market m1 still remains active for about 100 time steps.

Figure 7.4 represents an 'information rich' scenario with an average of 3 friends for each farmer (NFR = 3), an ISR of 50%, and the low-markets set. The dump market is nearly absent (apart from an artificial peak with SD policy at

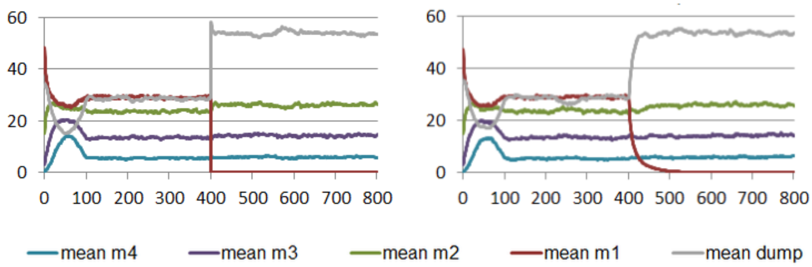

Figure 7.3: Markets reached for NFR = 0, ISR = 50, low-markets set. SD (*left*) versus GD policy (*right*).

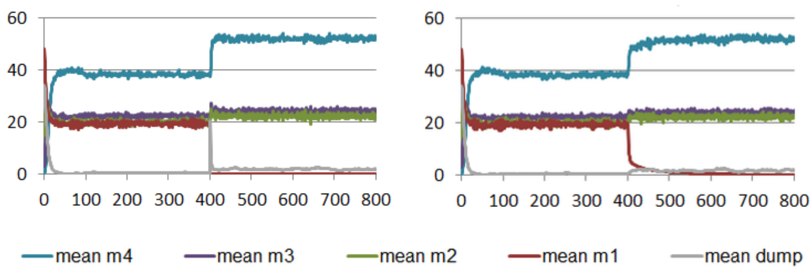

Figure 7.4: Markets reached for NFR = 3, ISR = 50, low-markets set. SD (*left*) versus GD policy (*right*).

shock time). The majority of farmers supply to highest market m4, whose share further increases after lowest market m1 falls out.

The scenario of Figure 7.5 is comparable with that of Figure 7.3 (no dynamic network, even higher ISR) except that farmers have to deal with the high instead of the low-markets set. Figure 7.5 shows that farmers supply here mainly to the lower markets: top market m4 is absent, and low markets m1 and m2 have the highest shares. After the shock, m1's share is almost entirely taken over by the dump market. At the moment of shock, SD policy shows a slight increase in m2, an increase absent with GD policy. All m1 farmers in SD are forced elsewhere after the shock. Those who qualify for it can switch to m2 (which explains the slight increase), whereas the others have no choice but to go to the dump market. In contrast, in the GD, no farmers are forced to leave. A small group remains supplying to m1, for almost 200 time steps even. The effect is temporary though, in the long run, the m2 market share is at an equal level for both SD and GD.

Plots of the average Gini coefficient of all simulation scenarios show a remarkable difference between SD and GD policies. In a number of scenarios,

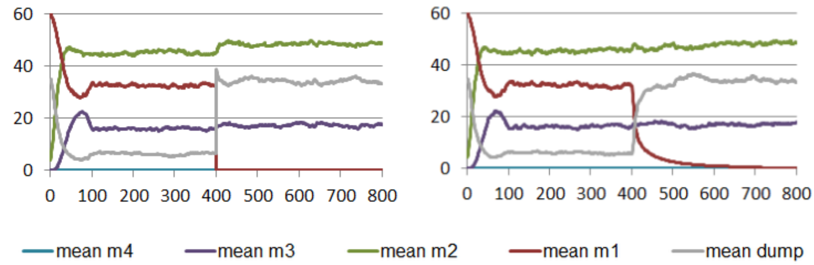

Figure 7.5: Markets reached for NFR = 0, ISR = 75, high-markets set. SD (*left*) versus GD policy (*right*).

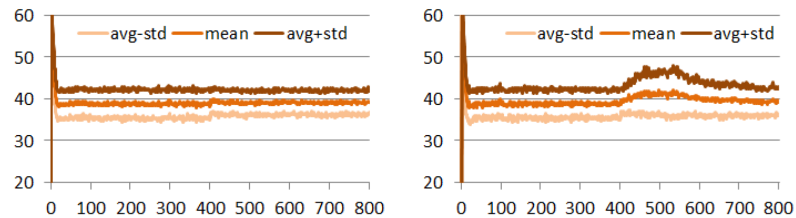

Figure 7.6: Average Gini coefficient with standard deviation for NFR = 3, ISR = 50, low-markets set. SD (*left*) versus GD policy (*right*).

most clearly in those using the low-markets set, we observe a 'bubble' in the GD policy scenarios, right after the shock, roughly between time 400 and 500. Figure 7.6 shows a sample Gini coefficients plot for the same scenario as that from Figure 7.4. The bubble shows a temporary higher Gini coefficient, indicating a higher wealth inequality among the population.

Table 7.2 shows a quantification of the size of the Gini-bubble for half of the scenarios. For conciseness reasons, the not so exciting scenarios with ISR = 25 and ISR = 100 were left out. The table shows the average Gini coefficient that was calculated over all runs for each simulation scenario (as specified with the parameters NFR, ISR, low- or high-markets set and SD or GD policy) during three successive time frames: one before the shock (time 300-400), one right after the shock (time 400-500), and one after that (time 500-600) when equilibrium has been re-established. The table also gives the standard deviations from each average Gini coefficient. The differences between the average Gini coefficients of the two policies after the shock are largest in the low-market scenarios. The difference remains visible also in time frame 500-600, well after the shock.

			low markets						high markets					
			t 300-400		t 400-500		t 500-600		t 300-400		t 400-500		t 500-600	
nfr	*isr*	*policy*	*avg*	*stdev*	*avg*	*stdev*	*avg*	*stdev*	*avg*	*stdev*	*avg*	*stdev*	*avg*	*stdev*
0	50	SD	37.93	0.35	39.25	0.70	39.98	0.31	41.55	0.81	45.40	1.54	47.67	0.78
		GD	38.11	0.37	40.57	1.07	40.57	0.59	41.14	0.80	45.97	2.14	47.97	0.91
	75	SD	37.69	0.28	38.17	0.28	38.29	0.21	42.34	0.51	45.56	0.81	46.79	0.64
		GD	37.65	0.32	39.05	0.63	40.41	0.38	42.84	0.80	46.38	1.16	48.07	0.65
1	50	SD	37.62	0.33	38.11	0.29	38.19	0.25	39.86	0.38	42.89	0.78	43.29	0.34
		GD	37.52	0.30	38.91	0.45	40.00	0.41	40.21	0.36	42.97	0.82	45.14	0.72
	75	SD	38.69	0.31	39.08	0.31	39.01	0.23	56.52	1.19	58.03	0.93	58.65	0.71
		GD	38.59	0.29	40.82	0.78	40.63	0.47	55.51	1.25	58.32	0.97	58.93	0.45
3	50	SD	38.78	0.30	39.14	0.31	39.09	0.25	48.85	0.95	50.41	1.11	50.34	0.78
		GD	38.79	0.27	40.66	0.71	40.85	0.48	48.38	0.75	50.92	1.48	51.57	0.79
	75	SD	38.87	0.28	39.06	0.35	38.98	0.24	47.31	0.48	48.45	0.67	48.48	0.47
		GD	38.88	0.28	40.37	0.54	39.44	0.51	47.22	0.65	49.57	0.89	49.11	0.56

Table 7.2: Overall average and standard deviation of Gini coefficients for each simulation scenario (specified by NFR, ISR, low- or high-markets set and policy SD or GD) during three successive time frames; policy shock at t=400.

7.9 Answering the research questions

The research questions of this study were (1) whether it makes a difference by what policy (SD or GD) farmers are encouraged or forced to switch market and (2) which policy serves sustainability and animal welfare best, when not only the final result but also the way towards that result is taken into account.

The answer to these research questions is:

1. Yes, policy matters. Looking only at the final outcome, there is no significant difference between the two policies. Both with SD and with GD policy, the low market will disappear eventually, with or without forcing farmers away from it. The remaining markets will find a new balance, dependent on the other parameters of the model. This new 'end' balance is highly similar for the two policies. Looking at the time of transition though, there is a difference. With GD policy, the farmers are able to keep away from the dump market a little bit longer. This is especially true in information-poor situations, where farmers choose to linger on in the low market before the market eventually disappears.

2. From a social sustainability perspective, GD is preferred over SD. For individual farmers, it makes a huge difference whether they can sustain their business longer under GD, even though they will eventually leave the market anyway.

Comparing the Gini coefficients of both scenarios, there is a distinct difference between policies. It depends on the cause of the inequality whether this can be considered good or bad for the farmer population and for sustainability in general.

7.10 Concluding remarks

The model we used for this study was not specifically developed for this purpose, but seems to serve well for answering our research questions. There is always the trade-off between richness of a model and clarity of simulation results i.e. to be able to allocate a relationship between model input and output to the studied effect. In this case, the conceptual model of associating acquired information items with required markets quality criteria appears to work well in the case of excluding a market in the context of animal welfare policy and sustainability developments.

One result of this work is that it makes no difference which transition policy is followed when only the final market redistribution is concerned. The resulting market redistribution after the shock shows no big surprises. Although this seems not a very noteworthy result, it is in line with findings from resilience research among farms' responses to shocks: systems often show a remarkable capability to retain similar structures and functionality after disturbances (Peerlings et al., 2014). Being able to reproduce this phenomenon with an agent-based model - employing the *grow it to show it* adage from Epstein (2006) - is reassuring for the plausibility of the model.

An unexpected but salient result is the 'Gini-bubble', appearing in the GD policy scenarios, showing a temporary higher Gini coefficient. A higher Gini coefficient indicates wealth inequality, but it depends on the cause of the inequality whether this can be considered good or bad for the farmer population. Is the inequality caused because very few 'lottery winners' get richer, and the large majority remains poor or gets even poorer? Then, the population as a whole does not benefit from the policy, which is unattractive. Or is it that the people who become richer are entrepreneurial farmers who innovate freely and get rewarded for it? Then, they constitute an example for their fellow farmers, which can be considered an attractive side effect of the policy.

So an important question remains: what is the cause of this temporal inequality? With our current method of processing simulations, it is not possible to inspect in hindsight each individual farmer's wealth at each moment in time for every simulation run. Only an aggregated wealth indicator is available, which tells us nothing about its distribution. It is, however, possible to identify how many farmers are able to supply to each market during each moment in time, so also during the time of the Gini-bubble. Farmers' current market can serve as a proxy for their wealth: if there is a substantial increase of number of farmers supplying to a higher market, then this observation supports the 'entrepreneurial' explanation. If we see only little difference for the higher-market segments (one or two farmers extra are hardly visible), then this supports the ‘lottery winners’ explanation. We randomly inspected the market distributions during the Gini-bubble which seem to be in favour of the explanation that the observed Gini-bubble gives indeed rise to entrepreneurial feelings in the population. But to claim a better grounded explanation for this effect, we need to examine it more deeply. Specifically, we need to inspect the distribution of individual farmers’ wealth during all time steps. Our model does generate this information during simulation runs, but currently stores it only on an aggregated level, for conciseness and tractability reasons.

Other topics for further research include investigating what happens if farmers could explicitly leave and (re-) enter the sector. Another interesting extension would be if markets were more dynamical: that new markets would appear on top of old markets becoming unavailable. This also better reflects reality in the pork sector, where entrepreneurial farmers always search for unexplored alleys.

Returning to the starting point of this research, which was initiated by a current policy change in the Dutch pork sector, the conclusion of the research seems applicable here. Instead of closing the lowest market by changing the minimum requirements, farmers can be allowed a transition period in which they are still able to supply to their usual market. In the long run, it makes no difference for the level of animal welfare how exactly the low-quality market is closed, if our conclusion is valid in practice. From individual perspective though, the GD policy is much more farmer-friendly. The farmer population as a whole will be more robust this way, which would mean a higher social sustainability level.

We could ask ourselves how expandable this model is to other societies. Would the Dutch situation apply to other European or world countries? A recent paper on a project studying European farmers (Ingenbleek et al., 2013) indicates that there are considerable differences between European countries where animal welfare is concerned. Animal welfare depends on more than the things we studied in our model, but Ingenbleek’s paper supports our view that economic drivers and markets do have an impact alongside of policy interference.

As for the usefulness of this research for other application domains, the aforementioned domain of labour markets could be a candidate. The structure of the model already seems to apply to labour markets: SD may be equivalent to closing a department immediately, while GD may correspond to finding new jobs for existing employees. What would need to change or be added to the model to make it suitable for the labour market? It would be interesting to investigate whether our model can be used for other transitions, both in agriculture and elsewhere.

Part III - Synthesis

- **Chapter 8 - Revisit cases + multi-level analysis**
- **Chapter 9 - General discussion**

Geachte boktor,

Zoudt u zo vriendelijk willen zijn mij eens anders in elkaar te zetten? Ik zit namelijk niet zo goed in elkaar.

Als ik goed nadenk klopt er niets aan mij: alles zit óf op de verkeerde plaats óf doet maar wat. Voelsprieten, tenen: noem maar op.

Ik zou ook graag eens een dunnere jas willen hebben. Mijn huidige jas belemmert mij namelijk bij het vliegen. Hebt u mij ooit hoog zien vliegen? In de wolken?

Ik niet.

En tenslotte ben ik niet tevreden over mijn gedachten. Ik zou wel eens iets heel anders willen denken. Maar wat? Ja, als ik dat wist, dan dacht ik het wel.

[...]

De krekel

Dear longicorn,

Would you be so kind as to reconstruct me in a different way? I seem to be somewhat misconstructed at the moment, you see.

When I think about it, nothing seems right about me: things are either in the wrong place or they just do whatever they like. Antennae, toes - you name it.

I would also like to have a thinner coat, please. My present coat hinders me when I am flying. Have you ever seen me fly high? Up in the clouds?

I haven't.

And, finally, I am not happy with my thoughts. I would like to think of something completely different for a change. But what? If I knew, I would've thought of it already.

[...]

The cricket

Preface to Chapter 8

Revisit cases + multi-level analysis

Als je nou eens precies achter mij loopt, olifant,' zei de eekhoorn, 'dan bots je nergens meer tegenaan.'

'Dat is goed,' zei de olifant en hij liep achter de eekhoorn aan.

Een hele tijd ging het goed en iedereen keek vol verbazing naar de eekhoorn en de olifant die vlak achter elkaar van de ene kant van het bos naar de andere kant liepen. Ze liepen langs slingerende paden, maar ze botsten nergens tegenaan.

De zon scheen en de builen op het hoofd van de olifant slonken.

'Lopen we eigenlijk wel goed?' vroeg de olifant na een tijd. 'Moet ik niet af en toe ergens tegenaan botsen?'

'Maar je vindt het toch erg dat je overal altijd tegenaan botst?' vroeg de eekhoorn verbaasd.

'Ja, dat is zo,' zei de olifant.

Ze liepen een tijd verder en zeiden niets.

De olifant werd somber. Ben ik zonder botsen mijzelf nog wel? dacht hij. Hij wist nooit precies hoe hij zichzelf het meeste was. Hij zuchtte diep.

Ten slotte hield hij het niet meer uit en sloeg plotseling rechtsaf.

Chapter 8 has been submitted to an ISI-rated journal:

Osinga S.A., Kramer M.R., Hofstede G.J., Beulens A.J.M. The knowledge management arena: agent-based modelling of an SME sector.

Maybe if you'd walk right behind me, elephant,' the squirrel said, 'then you wouldn't bump into things anymore.'

'All right,' said the elephant, and he walked right behind the squirrel.

It worked for quite some time and everyone watched in amazement while the squirrel and the elephant walked right behind each other from one end of the forest to the other. They followed winding roads, but didn't bump into anything once.

The sun was shining and the bumps on the elephant's head were dwindling.

'Are you sure we're doing this right?' the elefant asked after a while. 'Shouldn't I bump into something every now and then?'

'But I thought you didn't like to bump into things all the time?' the squirrel asked, astonished.

'That's true,' the elephant said.

They walked on for a while and didn't say anything.

The elephant started to get glum. Am I still myself without bumping? He never knew how exactly to be the most himself. He sighed deeply.

In the end he couldn't hold out any longer and suddenly turned right.

Chapter 8

The knowledge management arena: agent-based modelling of an SME sector

Abstract. This article is concerned with knowledge representation in a case of information management. We represent knowledge diffusion through a population in an SME sector. A sector consisting of small entrepreneurs is not managed by an executive board. What occurs in the sector as a whole is the collective result of independent decisions taken by individuals, who work from a context of friends, peers and other sector actors. Agent-based modelling as a method comes very natural to this case, because it allows modelling individual behaviour (exchanging knowledge and decision-making). The objective of this study is to gain insight in the multi-level relationship between knowledge-rich decision behaviour of individuals and emergent sector level outcomes. This generic question is applied to the case of the Dutch pig sector, specifically of farmers choosing a (quality) market to supply their pigs to, where knowledge is assumed to be a prerequisite for market entry. A secondary aim of this article is methodological: it is to convey the merits of applying agent-based modelling to this type of multi-level research problem. Three specific research questions are investigated, taking into account the multi-level perspective: the effect on farmers' decision outcomes of (1) knowledge exchange and (2) knowledge quality; and (3) the effect of imposing a sector-level policy on the farmer population. Results show that (1) the presence of sufficient knowledge in the system is more important than the network structure between knowledge exchanging agents for emerging quality market shares; (2) efficient knowledge management improves quality, but there is a limit to that efficiency; and (3) imposing policies on a sector the hard way is not necessarily more effective than making gradual changes, while the latter is more friendly for the individuals. For each of these questions, individual-level inspections provide sector level insights, which is the added value of our multi-level approach.

8.1 Introduction

Small entrepreneurs frequently take decisions to run their business for which they need knowledge, such as market information or technological know-how. They find themselves confronted with requirements and obligations on the one hand, and the need to seize opportunities by making use of offered support on the other. Requirements and obligations cover the whole range of animal health and welfare concerns, consumer demands, societal pressure, peer pressure, and environmental, financial, legal and certification constraints. Business opportunities are positively fuelled by support offered such as good farming practices, smart breeding programmes, customized nutrition, modern housing and environmental technologies (Scholten et al., 2013). Surrounded with knowledge, it is the farmer's task to make business decisions.

Now let us consider the role of governments. From a policy perspective, a strategic decision taken for the entire sector must be managed over a population of entrepreneurs, who are autonomous decision makers. Such a strategic decision could be to raise the minimum required quality level of meat, as recently happened in the Netherlands in response to animal welfare concerns (Pig Progress, 2014). Another example of a strategic decision concerns tracking and tracing of meat products and their provenance, which was a relevant issue in the recent horsemeat scandal (Reuters, 2014). Although the government might sometimes wish they could act as executive board of 'the livestock firm', the farmers in the sector cannot be managed nor controlled like employees.

This article addresses the manageability issues of a sector consisting of individual producers who make the decision of what quality market to supply their product to. Knowledge is assumed to be a prerequisite for market entry. Knowledge in this sense subsumes both requirements and obligations, and the knowhow and capabilities involved to act in line with them. Manageability could be a concern for government, sector-related organizations or other stakeholders such as associated NGOs. Complications for manageability are, in this case, the multiple level perspectives and the feedback mechanisms, explained as follows. Individual producers act from their personal context, influenced by peers and by what goes on in sector or society. As a feedback, their (joint) decision outcomes have consequences for the producers themselves, for the sector, and for society as a whole.

The generic manageability question is here applied to the case of the Dutch pig sector - in particular to the case of farmers choosing a quality market for their pigs. We define a quality market as a market segment that is well defined in terms of specifications of the products, of the processes and resources used and of a set of (legal and certification) requirements and conditions that must be satisfied. Examples range from quality markets for bargain meat, regular meat, market concepts such as 'good farming star' (a Dutch certified indication that a minimum level of animal welfare has been respected) to fully qualified organic meat. Together, the available quality markets in a sector form the market spectrum. The sum of farmers choosing for a certain quality market defines the market's share, which is an emerging property, changing over time. The pork market spectrum is very dynamic. As of the 1970s, Dutch pork price has mainly been determined by production costs, disregarding meat quality and sustainability aspects, and hence pork was sold 'too' cheap (Reinders et al., 2013). Under influence of a society that becomes more food-aware and concerned about animal welfare, and of a sector that has suffered from animal disease and food scandals, demand for sustainably produced higher quality meat is increasing. Since pigs need time to grow, it is difficult for farmers to anticipate on the price they will get for a pig of certain quality, i.e. how market developments will affect their return on investment later. Besides taking the chance of choosing for another quality, farmers also need to have the knowledge and know-how to supply to that market. Markets have quality requirements for their suppliers, and farmers can only opt for a certain market if they can meet that market's conditions. Higher quality markets pay higher prices, but price also depends on total supply, which is an emergent property of all farmers' joint decisions, unknown at the time of deciding for a certain market. Moreover, it is not always clear what 'higher quality' means, because some criteria require trade-offs, such as animal welfare versus environmental impact (Scholten et al., 2013; Commissie van Doorn, 2011).

Policy makers aiming at changing quality market shares within a sector can do this only by means of indirect measures. They may find it worth investing in (1) strengthening farmers' networks to facilitate knowledge exchange, (2) educational and training activities among farmers to increase their knowledge level, and (3) imposing top-down measures in a sector that affect farmers' options. These three issues have been translated into specific research questions: (1) How much impact does knowledge exchange between farmers have for the emerging result of all their individual market choices? (2) Does increasing the quality of farmers' knowledge lead to their opting for higher quality markets? And (3) How effective is it for a government to impose a policy decision on the farmer population, and what does that mean for individual farmers? For each of these questions, sector level perspective as well as individual and peer level perspectives are relevant.

The remainder of this article is structured as follows. First, our methodology is explained. Then, model requirements are articulated. The next section gives an overview of concepts derived from literature with respect to decision making of farmers and the role of knowledge therein. Then the model is presented, based on the concepts presented earlier. To investigate the three specific research questions, structured simulation experiments and their results are then described. Results are validated by means of expert validation, which is presented next. Conclusions based on model outcomes are then given. Finally, policy implications are presented and discussed.

8.2 Methodology

The objective of our study is to investigate the manageability of a knowledge-rich sector consisting of autonomous decision makers, by scrutinizing the relationship between the sector and the behaviour of the individuals it consists of. According to Epstein and Axtell (Epstein and Axtell, 1996; Epstein, 2006), it is difficult to test such a relationship between individuals and the system as a whole, because controlled experiments are hard to do in social sciences. Highly aggregate models used to represent social processes 'filter out' time dynamics and the consequences of heterogeneity (Squazzoni et al., 2013). A computational approach, like agent-based modelling (ABM), is considered a good alternative to study this kind of phenomenon (Miller and Page, 2007). One reason why ABM is well-suited as a method is because it allows for taking on a bottom-up (individual level), side-out (peer level) and top-down (sector level) perspective (Gilbert, 2008). Miller and Page summarize the goals for computational models of these kind of problems as: to uncover key insights into the behaviour of these systems; to understand the behaviour of both the agents within the systems and of the systems themselves; to make models as simple and accessible as possible; and to make use of computational modelling to enhance understanding of the system (Miller and Page 2007). Our methodology agrees with this approach.

8.2.1 Agent-based modelling in literature

There are several examples of ABM applied in agricultural domains. Ziervogel et al. (2005) investigate the impact of using climatological information on crop yields of farmers in Lesotho. This impact appears to depend on the farmers' initial household characteristics, what response options they choose, and the trust they place in the forecast (which in turn depends on their ability to learn and to follow their neighbours). Ross Ross and Westgren (2009) present an example of an ABM in the context of the agricultural supply chain, modelling agricultural firms with entrepreneurial behaviour and firm interactions who aim for wealth creation. Schouten et al. (2013) use a spatially explicit ABM to study the resilience of a rural area with high quality nature managed by farmers, and the effect of policy interventions in that area. Monticolo et al. (2014) give an example of an ABM in the context of knowledge use. In their model, knowledge within an innovative company is captured according to the roles of the professional actors.

Knowledge-rich applications in other sectors include Roozmand et al. (2011), who use ABM to study consumer decision making based on culture, personality and human needs, showing differences in car purchasing across eleven European countries. Gao et al. (2012) use an ABM to support urban management, assessing various inspection strategies (district-first, community-first, cooperative or random inspection). They claim that their ABM improves assessment of the effectiveness of strategies and the distribution of their impacts.

These applications concern modelling individual behaviour. For most of them multi-levelness is not explicitly an issue. It is addressed in Roozmand's application, where consumers' individual behaviour is placed within culture, i.e. group-level behaviour. It is also present in Schouten's model, where individual farmers' land use decisions are modelled under both a hierarchical governance regime and self-governance. The latter is very much in line with our research. The differences lie in the fact that Schouten observes land use change as the result of farmers' decision-making, and positions the model in a specific geographical region. Land use change happens within a long-term time frame, it is a 'slow' variable (Schouten, 2013). Our application observes the dynamics of market shares, where the geographical component is absent. Changing market is not an everyday decision for farmers, but it happens more often than making land use changes decisions.

8.2.2 Middle-range model

In terms of Gilbert (2008) the model in this research is of middle range: the aim is neither to model the behaviour of specific farmers in a certain region, nor to make a purely theoretical point, but to show model behaviour that is believably comparable to that of a range of corresponding real-world systems. System-level phenomena emerging from simulations should be recognizable by real-world experts, without having to match any specific situation one-on-one. Agent-based modellers tend to refer to these system-level phenomena as 'stylized facts': broad, but not necessarily universal generalizations of empirical observations that describe essential characteristics of a phenomenon (Railsback and Grimm, 2012). The term 'stylized facts' is borrowed from economics (Kaldor, 1961), where it is used both to motivate the construction of a model and to validate it.

Figure 8.1 shows our modelling framework; the numbers in it are explained below. We first state the system-level phenomenon (or phenomena) of interest, i.e. a pattern (1). In our case, this concerns the emerging range of quality market shares constituting the pig sector, the manageability of which we are interested in. We assume a relationship with individual actors' behaviour, in this case the farmer deciding what market to aim for (2), and it is exactly this relationship that we seek to gain insight in (3). We hold assumptions concerning this relationship that we have transformed into research questions. In our case, these hypotheses are: (i) if farmers exchange more knowledge with each other, more farmers will supply to higher quality markets; (ii) if the average quality of farmers' knowledge increases, more farmers will supply to higher quality markets; and (iii) a top-down measure imposed on the farmer population is effective. From literature about individual farmer behaviour, concepts are deduced (4) to justify (5) the design choices (6) for the ABM. Guided by these choices, the agents and their behavioural mechanisms are designed through abstraction and selection (7), and implemented into an ABM (8). For each research question, appropriate simulation scenarios are executed, generating synthetic data to be analysed (9). From these results, a pattern may emerge, dependent of the simulation scenarios (10). If the generated pattern matches the pattern of interest, judged by means of expert validation (11), we have gained something. What we have gained is insight in the relationship between this pattern and the agent behaviour underlying it (12), because our simulation results allow inspection to

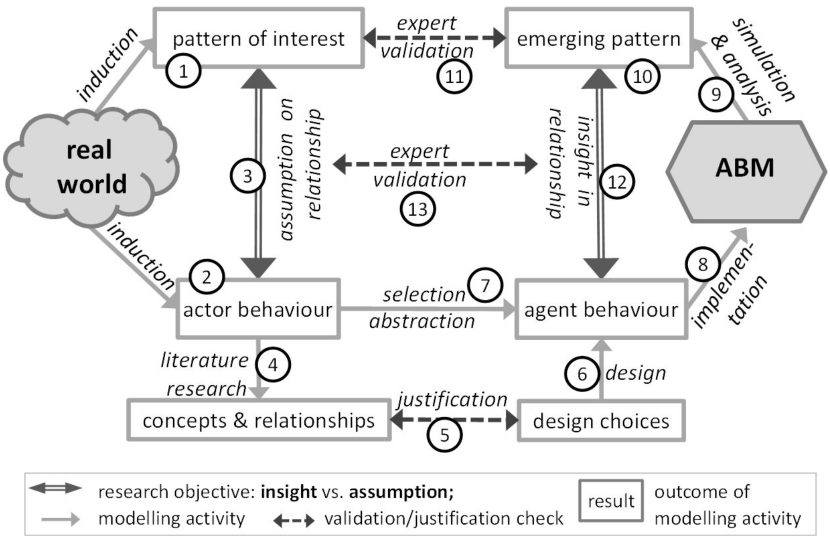

Figure 8.1: Modelling framework; numbers are explained in section 8.2.2.

explain how and why this pattern emerged. This insight can itself be validated by experts (13).

A secondary aim of our article is to convey the methodology of applying agent-based modelling to this type of research problem, since it is not common practice within the agent-based modellers' community to report each modelling step. This article makes explicit the steps from research questions to model requirements (section 8.3), to assumptions for the model taken from literature (section 8.4), to a model description (section 8.5) including design choices and implementation steps to arrive at the ABM, to genesis and analysis of synthetic data (section 8.6), and presentation and visualisation of results on different levels of analysis (section 8.7), while keeping in mind consistency and comparability of successive model versions, and the role of expert validation (section 8.8).

8.3 Model requirements: concepts and relationships

Table 8.1 shows per research question the required concepts and relationships to define.

Most elements in Table 8.1 can be derived from literature, such as: what market options do farmers have, or: what knowledge is involved when making a decision? Some can be empirically supported, like the decision mechanism and the type of knowledge and exchange mechanism farmers use. Other ele-

Research question	Concepts and relationships to define

What individual, peer and sector level influence do farmers experience when they make their market decision?
(generic research question)
	• Multi-level decision making context of farmers:
	  • *individual level* influence
	  • *peer level* influence
	  • *sector level* influence

How much impact does knowledge exchange between farmers have on the emerging result of all their individual market choices? *(research question 1)*	• *knowledge* (of what kind?) • *exchange mechanism* (which?) • *between farmers* (by which connections?) • *market* (what are the options?) • *choice* (by what decision mechanism?) • *emerging result* (how to represent?) • *influentual* (how to measure?)
Does increasing the quality of farmers' knowledge lead to their adopting higher quality markets? *(research question 2)*	• *increase knowledge quality* (how to represent?) • *quality of a market* (how to represent?) • *adopting* (by what decision mechanism?) • *higher* (how to measure?)
How effective is it for a government to impose a policy decision on the farmer population? *(research question 3)*	• *government* (how to represent?) • *policy decision* (how to represent?) • *impose* (how?) • *effective* (how to measure?)

Table 8.1: Required concepts and relationships to define per research question.

ments concern representation of results, for example: how can 'emerging result of market choices' be represented as a simulation experiment outcome.

Table 8.2 further summarizes Table 8.1. It presents per concept or mechanism the assumptions for which to find empirical support from literature. Numbers refer to sections.

8.4 Assumptions

The assumptions for the model are treated in line with Table 8.2. For each concept or mechanism, selected literature is presented, from which relevant findings are summarized into assumptions to guide the ABM design.

8.4.1 Influence structure

Farmers are not alone. They have family, friends and peers. They have their direct suppliers, like feed suppliers, and their direct customer, being a slaughterhouse or processing company (called 'market' here). There are governmental bodies that provide a legal framework, sector organizations, certification institutes, veterinarians, and banks. There are consumers who buy the meat, cit-

Concept / mechanism	Assumptions to derive from literature
Influence structure 8.4.1	What personal, peer and sector level influences do farmers experience when making decisions?
Decision mechanism 8.4.2	What mechanism adequately describes the decision making process of farmers; what is relevant for their market choice?
Knowledge use 8.4.3	How do farmers collect and apply knowledge while making decisions?
Knowledge type 8.4.4	What kind of knowlege is involved in pig farmers' market decision making?
Exchange mechanism 8.4.5	What connections exist between farmers and other actors in the field; in what way do they exchange knowledge with each other?
Markets 8.4.6	What are farmers' options; what are markets' quality requirements & price mechanisms?

Table 8.2: Overview of concepts for which to find empirical support; numbers refer to sections.

izens who have concerns, and NGOs. For an overview of stakeholders and their structural relationships, see (Hofstede et al., 2004, p. 16).

Arens et al. (2012) describe the influences German pig farmers experience. Their findings include that farmers' intrinsic motivation is the most important driver, and that it is influenced by 'role model farmers', for instance successful, widely known farmers, as well as by educational activities. Alarcon et al. (2013) studied British pig farmers. The farmers indicate that they highly value what they hear from other farmers, even though these tend to 'tell only the good things, not the bad things'. They perceive the veterinarian as the most trusted information source on disease control.

In order to manage their farm successfully amidst these many stakeholders, farmers need to recognize opportunities and acquire required knowledge and other resources. Scholten et al. (2013) summarize the constraints within which farmers need to operate. They introduce the concept 'livestock farming with care', which integrates four principles of sustainability: *health* (healthy and safe for animals and humans), *customized care* (from the individual animal's perspective and integrity), *no nuisance* (from an environmental and societal perspective) and *credible performance* (from an economic and public prospect). The first three translate into requirements for the farmer: the processing company or slaughterhouse may not accept his product if he disregards the rules. The fourth one is a requirement in the sense that a farm needs to be economically viable or it cannot survive.

Relevant for model design:

a) Farmers experience influence from peers and other actors in the field.
b) Role model farmers and educational activities influence farmers' intrinsic motivation.
c) Peers are perceived as a reliable source of information.
d) The veterinarian is perceived as a reliable source of information.
e) Farmers can only opt for a market if they qualify for what it requires.
f) Any decision is subordinate to keeping the farm economically viable.

8.4.2 Decision mechanism

An often used theory to describe behaviour is the theory of planned behaviour (TPB) (Ajzen, 1991, 2011). It states that attitude toward behaviour, subjective norms, and perceived behavioural control together shape an individual's behaviours. The TPB has been applied in studies that involve decision making of farmers, for instance regarding the use of climatological information by Iranian farmers (Sharifzadeh et al., 2012), regarding the intention of Dutch dairy farmers to take action with respect to cow foot health problems (Bruijnis et al. 2013), and regarding English pig farmers' decision-making process for disease control (Alarcon et al., 2013). Sharifzadeh et al. found that farmers often did not use climatological information at all, even though considerable effort was made to make this information available to them, and that 'attitude' toward use of information was the most prominent driver for farmers' behaviour. Bruijnis et al. found that the most important driver for farmers to improve dairy cow foot health was cost-effectiveness, and that feed advisors and foot trimmers were most influential. Alarcon et al. report that pig mortality, a 'feeling of entering an economically critical situation', animal welfare concerns and a 'feeling of despair' were drivers for pig farmers to take action. Also they found that lack of awareness was a barrier, as well as difficult access to current scientific research output.

Although these three studies all applied the TPB to farmer decision making, the outcomes are highly dependent on their design. Only drivers and barriers that were taken into account could be reported as influential. Nevertheless all studies demonstrate that farmers do have different attitudes that influence their behaviour, that information use (and access to information) makes a difference, that there is social influence from peers and other actors in the field, and that economic aspects (cost-effectiveness) are important.

Farmers need to manage their farm in such a way that continuity is ensured. To that end, a minimum requirement is for the farm to be economically viable. Farmers have a management plan and periodically reconsider their options. Simon introduced the concept of bounded rationality: people do not weigh all their options like a Homo economicus, but are constrained by time, resources, personal circumstances or cognitive abilities; they use a satisficing rather than an optimizing approach to make decisions (Simon 1957). There is ample evidence from sociology that farmers' decision behaviour is influenced by behaviour and norms from other people such as family, peers and friends (Commandeur, 2006; de Rooij et al., 2010; Ambrosius et al., submitted). Socializing is an important driver for farmers' decision behaviour. Jager and Janssen (2012) elaborate on this idea also in their 'consumat' approach in consumer studies.

Relevant for model design:

g) Farmers are heterogeneous decision makers, influenced by attitude.
h) There is social influence; some actors in the field are more influential than others.
i) Information use makes a difference with respect to decision making.
j) Farmers do not always use information that is available to them.
k) Economic aspects are driving forces for farmers to take action.
l) Farmers have bounded rationality.

8.4.3 Knowledge use

Anthropologist Paul Richards intensively studied farmer behaviour in various agricultural contexts (Richards, 1989, 1993), especially in cases where taking action, or 'performance', is associated with knowledge and technology. He argues that farming has a technical dimension (use of skills, tools, knowledge and techniques to accomplish certain ends), a social dimension (management and control of e.g. the labour process), and an economic dimension (how to be productive according to market conditions). It makes little sense to talk about technology without context ('an axe in the hand of a tree feller is a different tool than an axe in the hands of a confused, deceived lover'). Richards makes use of the term 'situated action', introduced by Suchman (1987), to argue that "every course of action depends in essential ways on its material and social circumstances". Not only the intrinsic characteristics of tools and artefacts, but the process of using them to make something, including knowing-that and knowing-how, are needed to perform. And: no single individual has complete knowledge of all steps involved in a specific process, but knowledge is divided over a team of individuals involved in that process.

Relevant for model design:

m) Knowledge has multiple dimensions (technological, social, economic).
n) Knowledge resides over multiple individuals, and is exchanged between individuals.
o) Knowledge is not absolute. It is dependent of subject, time and situation.

8.4.4 Knowledge type

Schulze et al. (2006b) apply the framework of explicit versus tacit knowledge (Nonaka and Takeuchi, 1995) to describe information use by German pig farmers with respect to market coordination. They state that pork production employs primarily explicit knowledge, such as development of pig prices and state-of-the-art disease treatment, often provided on an on-going basis by producer associations or publicly subsidized institutions. Pork production strongly depends on good animal health and biological performance indicators such as daily weight gain and feed conversion efficiency.

Arens et al. (2012) describe the use of information regarding health management on German pig farms. They mention: prices, costs, product quality, expected supply and demand, orders and delivery dates. They further find that farmer's competence, information quality and frequency of use are influential factors.

Alarcon et al. (2013) investigate what kind of knowledge and information is involved in British pig farmer's decision making from the perspective of disease control. The farmers indicate that it is hard to come by reliable information. Scientific knowledge is hardly accessible or incomprehensible to them; they do not trust knowledge coming from commercial sources because they suspect conflicts of interest.

Relevant for model design:

p) Explicit knowledge is more predominant in spot markets than implicit or tacit knowledge.
q) Types of knowledge are: prices, costs (e.g. disease treatment), product quality (e.g. weight gain, feed conversion efficiency), expected supply and demand, orders, delivery dates.
r) Information access is not always easy. Information may be unavailable, or not comprehensible.

8.4.5 Exchange mechanism

Richards' notion that knowledge is distributed over multiple individuals within a community (see 4.3) is shared by the theory of diffusion of innovations (Rogers, 1962, 2003). In the context of this article, an innovation could be a novel technology, idea, or practice known to some farmers, which allows them to supply to certain markets. Adoption would mean that the innovation not only becomes known to a farmer, but that the farmer also decides to act upon it. Diffusion is the process by which an innovation spreads through the community. There is a social component to this theory in the sense that individuals may influence each other as to whether or not to adopt the innovation. Brudermann et al. (2013) studied farmers' decision processes with respect to adopting photovoltaic installations. They identified that economic considerations dominate the decision making process, and that socio-dynamic factors are particularly important in the information collection process prior to the decision to adopt or not.

Relevant for model design:

s) Knowledge diffuses through a community by an exchange mechanism.
t) Individuals may influence each other during the exchange.
u) Socio-dynamic factors are important when collecting information prior to adopting.
v) Knowing something does not necessarily imply acting upon it.

8.4.6 Markets

Market choice matters to a pig farmer. This choice is influenced by the terms and conditions of the available markets, and also depends on how the relationships between farmers and markets are coordinated. Decision-oriented organization theory addresses the need for coordinating between decision makers at firm level (McCann and Galbraith, 1981) or at supply chain level (Lazzarini et al., 2001).

Schulze et al. (2006b, 2007) use this theory to position empirical results from their study on decision behaviour of pig farmers with respect to market coordination. Two coordination models are predominant in the main pork producing countries: spot markets and contract farming. Spot markets are preferred in many European countries where pork production chains are comparatively loosely organized in short-term agreements. Those allow easy change of buying and selling behaviour - although often there is a long-term relationship with a limited number of livestock dealers or slaughterhouses. In other important pork producing countries (United States, Brazil, Denmark, Spain) contract farming prevails, making the farmers dependent on centralized decisions from processors. Schulze argues that the spot market is favourable for German farmers because they can keep their entrepreneurial freedom, and transactions remain transparent.

The main driver for market coordination is price. Output or performance control mechanisms (such as carcass grading systems) are used to communicate expected qualities to farmers, and rewards are immediate and dependent on market success. Intrinsic motivation, and exchange of tacit knowledge, is more necessary for other types of market mechanisms with a higher degree of coordination, as are group identity, loyalty and commitment. Schulze praises the extrinsically motivated, explicit-knowledge-oriented characterization of German pork production, because of its high autonomy, high flexibility and high incentive intensity. The situation for Dutch pork farmers is similar to that of the Germans.

Relevant for model design:

w) The predominant market coordination mechanism of Dutch and German pork production is the spot market.
x) Price is the main driver of the spot market mechanism.
y) Markets communicate expected qualities to farmers by means of output control mechanisms, in terms of explicit knowledge.

8.5 Model description

8.5.1 Design choices

In line with Gilbert's middle-range criterion, the model needs to be sufficiently rich to represent the real-world situation and to answer the research questions, but also parsimonious enough to be interpretable. For every item collected from the literature in section 8.4, design choices were made. They are listed in Table 8.3.

Representation of knowledge

An example of how the literature findings result in design choices, see Table 8.3, is the representation of knowledge in the model. Based on the literature findings, we reasoned as follows. Knowledge plays a role in farmers' decision making process (i). Knowledge has multiple dimensions (m), but is mainly explicit knowledge (p) of different types (q) that has a different value to different people at different times (o). Not all knowledge is available to all people (r) and if it is available it is not always used (j): knowing something is not the same as acting upon it (v). Knowledge is exchanged with other people (n) and diffuses through a population (s). It comes either from an independent, trustworthy source (like the veterinarian), who can also explain it when it is incomprehensible scientific knowledge (r), or it comes from peers (c). Having the right knowledge plays a key role for market entry (e).

Based on these characteristics, we modelled knowledge as a collection of information items, or info-items for short, of which each farmer has a private collection. Info-items are represented as triplets of id, type, and value. *Id* is meant to distinguish info-items from one another and to indicate their age. *Type* is the abstract dimension to which the info-item belongs. *Value* refers to the value that this info-item has for its current owner. For example, [24, B, 40] represents an info-item with id 24, of type B, which has a value of 40 to its owner. A farmer can exchange info-items under certain conditions with peers in his network (the size of which is a model parameter). When a farmer exchanges an info-item with somebody else, the new owner receives a copy of the info-item, but its value diminishes. This is to reflect the fact that farmers cannot simply copy knowledge and skills from each other, but instead have to build up some expertise for themselves. New info-items are brought into the system by 'the institution', an abstraction of the veterinarian or any other independent information source, at a certain rate that is a model parameter. Info-items become obsolete over time by age, reflecting the dynamic nature of regulations, knowledge, and appropriate skills.

Markets are mainly defined by a collection of quality criteria. These are expressed in terms of the same types and values as the info-items. Markets may require minimum values for selected information types. Each market thus represents a certain quality; markets together cover the available quality spectrum.

Collected from literature	Design choices for the ABM
Influence structure (8.4.1) • Farmers experience influence from peers and other actors in the field (a) • Role model farmers and educational activities influence farmers' intrinsic motivation (b) • Peers are perceived as a reliable source of information (c) • The veterinarian is perceived as a reliable source of information (d)	• Farmers are connected with peers with whom they can exchange info-items; no distinction between family, neighbours or friends • Connections change at random • Other actors (government, bank, veterinarian, feed supplier, etc.) are abstracted to 'the institution' • Farmers can be educated (= receive info-items) by connected peers or by the institution
Decision mechanism (8.4.2) • Farmers are heterogeneous decision makers, influenced by attitude (g) • There is social influence; some actors are more influential than others (h) • Information use makes a difference with respect to decision making (i) • Farmers do not always use information that is available to them (j); information access is not always easy (r) • Economic aspects are driving forces for farmers to take action (k); any decision is subordinate to keeping the farm economically viable (f) • Farmers have bounded rationality (l) • Farmers can only opt for a market if they qualify for what it requires (e)	• There is randomness involved in farmers' decision behaviour • Social influence is proportional to the number of connections that an agent has • Farmers do not use all info-items they have when making decisions • Decisions are based on info-items • Economic aspect: make sure that farmers have a minimal income • Bounded rationality: farmers consider only one option for improving their market at every time step • Farmers need to qualify for a market in terms of minimal values for required info-items
Knowledge use (8.4.3) • Knowledge has multiple dimensions (technological, social, economic) (m) • Knowledge resides over multiple individuals, and is exchanged between individuals (n) • Knowledge is not absolute. It is dependent of subject, time and situation (o)	• Info-items have multiple dimensions, i.e. types • Info-items can reside with more individuals and can be exchanged • The value of info-items differs per farmer and changes after exchange • Info-items can become obsolete • Info-items are 'in use' or not

Knowledge type (8.4.4)	
• Explicit knowledge is more predominant in spot markets than implicit knowledge (p) • Types of knowledge are: prices, costs (e.g. disease treatment), product quality (e.g. weight gain, feed conversion efficiency), expected supply and demand, orders, delivery dates (q)	• Info-items each have a type, representing a knowledge dimension, best suitable to represent explicit knowledge • The types are abstract in the model, and can be filled in for a specific application. This makes the representation suitable for a pig farmer case as well as e.g. a housing market case
Exchange mechanism (8.4.5) • Knowledge diffuses through a community by an exchange mechanism (s) • Individuals may influence each other during the exchange (t) • Socio-dynamic factors are important when collecting information prior to adopting (u) • Knowing something does not necessarily imply acting upon it (v)	• There is an exchange mechanism between connected farmers; new knowledge comes in through the institution • Socio-dynamic factors are the connections that exist between famers; these are partly dynamic • A decisions is based on priorly collected knowledge • Farmers act upon info-items only if their values reach a required minimum
Markets (8.4.6)	
• The predominant market coordination mechanism of Dutch and German pork production is the spot market (w) • Price is the main driver of the spot market mechanism (x) • Markets communicate expected qualities to farmers by output control mechanisms, in terms of explicit knowledge (y)	• The market mechanism reflects the spot market: ad hoc 'bargains', no fixed contracts • Farmers evaluate a market through an expected price mechanism • Markets set quality requirements in terms of minimum values for certain types of info-items

Table 8.3: Design choices based on collected relevant findings from literature (see section 8.4).

Abstraction

The trade-off between capturing the richness of the real world and maintaining clarity in the ABM behaviour requires making choices on what to represent explicitly and what to aggregate into a generic representation. Some design choices are more general than what the literature findings suggest. In those cases, the gain of maintaining clarity in the model outweighed the cost of sacrificing representation power. For example, the conceptual richness of farmers collecting information, deciding what to do and acting upon it has been modelled partly by randomization. Randomly assigning info-items with random values to farmers is the abstract generalization of modelling the variation of deliberate choices that each farmer makes based on personality and circumstances, the specific details of which are not our primary concern.

8.5.2 ODD protocol

To describe the ABM, we present a concise ODD (Overview, Design concepts, and Details) protocol. It was first introduced in the ecological individual-based modelling community and is now more commonly used by ABM modellers in general to communicate model specifications (Grimm et al., 2006, 2010).

General purpose

The model aims to investigate the emerging range of quality market shares, in a knowledge-rich sector, as the joint outcome of agents' market choices. Decisions are based on multi-dimensional knowledge which agents collect and exchange within their network, brought into the system by an independent source ('institution'). The model is generic: agents, products and markets are applicable to multiple domains. In our case, the agents are farmers selling pigs to meat quality markets.

Entities, state variables and scales

Agent types and their main attributes:
Farmers: *current market*: market to which farmer currently supplies and qualifies for; *friends*: other farmers in network (to exchange info-items with; *info-items*: private collection of triplets [id, type, value] (see 8.5.1); *number of pigs*: amount of product a farmer has for sale; *wealth*: farmer's earnings.
Markets: *quality*: a list of criteria with required minimum values for info-items of selected types; *price*: the price this market currently pays (represented by three price constituents, see price mechanism); *last price*: last price of this market, by which farmers evaluate the market; *total supply*: total amount of farmers supplying to this market;
Institution: *info-items*: all available info-items, with maximum value, to be handed out to farmers at a supply rate (*ISR*).

Spatial resolution: The model is not spatially explicit.

Temporal resolution: 1 time step is the time needed for pigs to mature, which is about 6 months. The simulation length is adjustable; standard runs last 2000 steps. The first 100 steps are neglected.

Process overview and scheduling

Figure 8.2 illustrates the model cycle of one time step. The steps are explained as follows, starting after the 'tick' (a new time step).
Adjust network: Farmers pick one new friend among friends' friends, or a random friend if this fails. When the average number of friends per farmer within the population (*NFR*) becomes too high, friends are dropped at random.

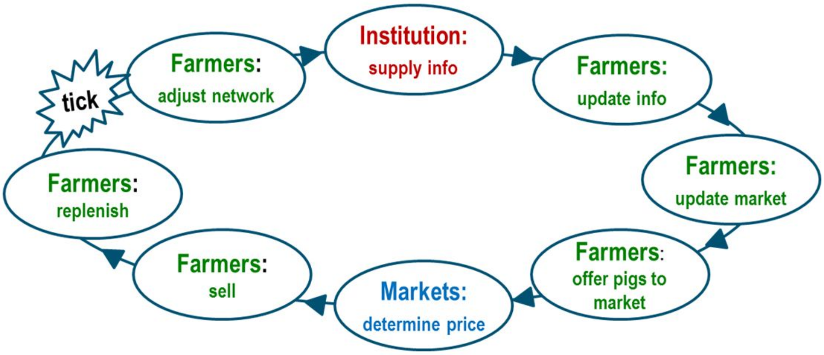

Figure 8.2: The model cycle; one time step in the simulation.

Supply info: The institution creates one new info-item and adds it to the collection of info-items. It supplies a random number of farmers with a random info-item, according to the information supply rate *ISR*.
Update info: Each farmer evaluates one random market. If its expected price (i.e. *last price*) is higher than his current market's price, and he qualifies for it, he will change market. If not, he keeps his current market, if he still qualifies, because due to loss of information that may no longer be the case. If all else fails, the commodity market remains, that has no requirements but farmers do not get paid anything either.
Offer pigs to market: Offer pigs to the market; now *total supply* becomes known.
Determine price: Markets can determine their actual price based on a fixed part (the base price) and an elastic part, dependent on total supply.
Sell: Farmers receive money (based on the actual price) for their pigs.
Replenish: Farmers buy new pigs (at a fixed price). They buy a random number between 1 and maximum capacity, maximized to what they can afford.

Model parameters

ISR: the information supply rate at which the institution supplies new information to farmers ([0,100]).
NFR: the number of friends, a population average, expressed per farmer. On population level the friend ratio equals *NFR* at all times. Individual farmers have various numbers of friends, changing over time.
thr: the value-threshold ([0,100]); any info-items with a value lower than *thr* will be disposed of, so that only high-valued items remain.
kch: the keep-chance by which info-items currently in-use (i.e. used to qualify for the current market) are protected from disposal ([0,100]).
shock-at: the time step at which a shock is introduced, after which a market

closes and the degrading factor becomes active. If *shock-at* is larger than the run length, there is no market degradation.
degrading: when the shock occurs, the degrading factor [0,100] defines the percentage of farmers allowed to keep a closed market as their current market until they voluntarily leave (after which they cannot return).
network: farmers' static connections (non-numeric, a list of other farmers). They also have a dynamic network of friend connections, controlled by *NFR*. Static connections could be interpreted as family relationships.
markets set: the range of available quality markets (non-numeric). Each market is defined as a list of 3 price constituents followed by requirements on various types. There is no limit to the number of types.
random seed: defining randomization in the model, saved for all runs, thus allowing for reproducibility.

Design concepts

Emergence

- The outcome of the model (range of market shares) is emergent.
- Total supply is emergent. The price a market pays depends on total supply, which is calculated after all farmers made their decision.

Adaptation

- Farmers opt for one new market at every time step and evaluate it based on its price, which is an emergent property.
- Farmers adjust their network by gaining a new friend (where friends' friends have priority) and dropping friends at random when the *NFR* is too high. New friends offer an opportunity to gain new info-items.
- Markets' actual price depends on total supply. Farmers who choose a market with little supply (a niche market) receive higher price, even if the market's base price is low.

Objective

- Farmers have no other objective than to earn as much money as possible.

Learning

- Farmers do not change their decision behaviour. But they learn in the sense that their collection of info-items changes, reflecting experience and skills. The longer they live, the more likely it is that they will qualify for a new market.

Prediction

- Farmers use an estimated price, i.e. its last price, to evaluate a new market.

Interaction

- The institution interacts with farmers at random to supply an info-item.
- Farmers interact (exchange info-items) with farmers only within their network (both static and dynamic).
- Implicit interaction occurs because total supply determines a market's actual price.

Stochasticity

- Most agent's choices involve some randomness. This is an abstraction of the variation in a population of agents who make deliberate choices that we do not explicitly model.
- The order in which agents carry out tasks within one time step is random.
- All randomness is controlled by a random seed that is registered, so simulation runs are reproducible.

Observation

- Main observable is the amount of farmers supplying to each market at each time step in the simulation. Simulation data are summarized during analysis, but detailed data can be inspected when desired.
- Another observable is the Gini-coefficient, a system-level measure of the distribution of wealth over a population; it is calculated from each farmer's individual wealth (Cowell, 1995).
- Other observables are farmers' wealth, networks, and information items.

Initialization

In the simulation runs, input parameters of interest are systematically varied, dependent of the research question. The main input parameters that are kept constant are: number of farmers (100), number of institutions (1), number of time steps (2000), total number of information items (100), average amount of initial information items per farmer (20).

Input data

The model does not use any external data. Input parameters of interest are systematically varied between runs, dependent of the research question, see the description of simulation experiments in section 8.6.

Sub models

Info-item exchange mechanism: When farmers exchange info-items with other farmers (or the institution), new info-items are combined with the old ones. That occurs according to Table 8.4:

New info-item is...	Condition:	Resulting value:
not yet present	–	$random[0, newvalue]$
already present	$newvalue > oldvalue$	$randomvalue[oldvalue, newvalue]$
already present	$newvalue < oldvalue$	old value remains

Table 8.4: Calculating an info-item's new value after exchange.

Price mechanism: The model adopts a standard price mechanism from economics (Perloff, 2009). The pig price is calculated for each market according to Equation 8.1:

$$price = b + c * e^{-kQ} \tag{8.1}$$

where *b* equals the base-price for that market (i.e. the price, related to market quality, suppliers still receive when supply is endless), *c* is a constant related to the price at low supply, and *k* is a measure for price elasticity (i.e. how the price changes when the quantity changes). *Q* stands for total supply, an emergent property at each time step. Each market has its own *b*, *c*, and *k* associated with it.

Market qualification mechanism: To evaluate whether a farmer qualifies for a market, his info-item values are compared with the market's required minimum values per selected type. A farmer may have several info-items of the same type. The farmer considers the average value of his 5 highest information items per type to see whether he meets the market requirements. This value of 5 is the default *information window* value.

8.6 Simulation experiments

For each research question a simulation experiment was defined. These experiments have been described in previous studies, two of them using preliminary versions of the current model. The purpose of re-doing the experiments is that we examine them more closely now by means of additional multi-level analyses. The three experiments are:

- **Experiment 1**: How much impact does knowledge exchange between farmers have on the emerging result of all their individual market choices? This experiment is described in detail in (Osinga et al., 2012), using a preliminary version of the current model. The experiment studies the effect of different network topologies between farmers (their static network) in combination with a population average *NFR* connections (dynamic network) and different market sets on the respective market shares. Also the rate at which new information enters the world (*ISR*) was varied.

- **Experiment 2**: Does increasing the quality of farmers' knowledge lead to their choosing for higher quality markets? This experiment is described in detail in (Osinga et al., 2013), using a preliminary version of the current model. The experiment studies whether it is rewarding to dispose of low-valued info-items, so that the average quality of remaining info-items increases. Therefore, all info-items that have a low value (according to a value threshold *thr*) are disposed of. Also, the effect of extra protecting info-items that are 'in use' for supplying to the current market is studied (by applying a chance *kch* that an in-use item is saved from disposal).

- **Experiment 3**: How effective is it for a government or sector as a whole to impose a policy decision on the farmer population? This experiment is described in detail in (Osinga et al., 2014), using the current model. The experiment studies what happens when the lowest quality market is no longer an option, referring to what happened in the Netherlands when retailers decided in May 2014 that they wished to respect animal welfare concerns and that they would only accept meat of good farming star quality from now on (Pig Progress, 2014). Two different market closure policies are tested: sudden death (*SD*) versus graceful degradation (*GD*).

For this article, all experiments were re-run with the current comprehensive model, which comprises all elements that were available in previous model versions. When the model element can be ignored for an experiment, parameters controlling it are given neutral values. When the model element is of particular interest for an experiment, parameters controlling it are systematically varied. Osinga et al. (2013) describe some methodological aspects of safeguarding model outcomes when using successive model versions. We determined the number of runs for each experiment with help from a convergence test introduced by Troitzsch, which entails visual inspection of graphs plotting the differences between successive average observables against increasing run numbers Troitzsch (2014). On top of the production runs, we also did runs for local sensitivity analysis, most extensively in Experiment 2. Table 8.5 shows how parameters of interest were varied per experiment. Things from Table 8.5 not mentioned yet in the ODD are explained below:

- **Network topologies** of their static networks were tested in populations of 100 farmers. Topology *ring10d* consists of 10 disjoint ring-wise connected clans; *clan10-2d* consists of 10 disjoint clans, where each clan member is connected to 2 random other clan members; in *tree1-10* one agent is connected to 10 others who are separately connected to 9 others; *isolated* means that there are no connections at all.

- **Market sets**: requirements are always expressed in terms of abstract types A, B, C and D with range [0,100].

  - *ext-diff8*: 4 low and 4 high quality markets. The low ones require 10 on A, B, C, D respectively and none on the three other types, base price 10; the high ones require 80 instead of 10 and have base price 80. (Experiment 1)

- *ext-same8*: the same markets as *ext-diff8*, but all base prices are 50. (Experiment 1)
- *unif-inc8*: 8 uniformly increasing markets. Market 1 requires 10 each on all four types A,B,C,D with base price 10. Market 2 requires 20 with base price 20, and so on up to 80. (Experiment 1)
- *rand-inc8*: 8 random values for A, B, C, D where the average of each market's requirements is increasing from 10, 20, up to 80; the average is also the base price. (Experiment 1 and 2)
- *unif-inc4-low*: the same as *unif-inc8*, but consisting of only 4 markets, requiring 20, 30, 40, 50. Base price equals requirement. (Experiment 3)
- *unif-inc4-hi*: the same as *unif-inc4-low*, but now requiring 20, 40, 60, 80. (Experiment 3)

For the markets from Experiment 1 and 2, the price constant always equals 200 + the base price. For Experiment 3 markets, the base price equals the requirement and the price constant is always 200. Price elasticity for all experiments is 0.1.

- **Policy**: In Experiment 3, a shock (*shock-at*) is introduced at t=400 (on a run length of 800). With policy Sudden Death (*SD*), the *degrading* factor is set to 0, meaning that at the shock farmers are forced to leave the lowest market immediately. With Graceful Degradation (*GD*) policy, the *degrading* factor is set to 100, meaning that at the shock the lowest market is no longer available as an option, but farmers who already supplied there can keep this market until they leave it voluntarily, after which they cannot return.

The total number of parameter sets in Experiment 2 is calculated as follows. All parameters were varied one-at-a-time. Parameters *thr* and *kch* were also varied together. The sensitivity analysis involved 21 one-at-a-time variations (11 variations of *kch* with *thr* fixed to 0; 11 variations of *thr* with *kch* fixed to 0; 1 double removed), and 9 *thr-kch*s combinations that were varied together, which adds up to 30 different *thr-kch* combinations. For 9 other parameters, we chose values slightly higher and slightly lower than the base value. These were: *ISR*, *NFR*, *number of farmers*, *run length*, *maximum value for info-items*, *number of different info-items*, *information window*, *pig price*, *number of pigs capacity*. In conclusion: every *thr-kch* combination was run with the base value and 18 other values, making a total of 19*30=570 combinations.

8.7 Results and multi-level analysis

Each experiment yielded results similar to the ones already described in previous studies. For this article, we are especially interested in multi-level analyses, where an observed pattern can be inspected with help of individual-level data, something the previous studies of these experiments did not yet allow.

	Experiment 1	Experiment 2	Experiment 3
(Static) network topology	*ring10d*; *clan10-2d*; *tree1-10*; *isolated*	*ring10d*	*isolated* (only *NFR* effect)
Market sets	*ext-diff8*; *ext-same8*; *unif-inc8*; *rand-inc8*	*rand-inc8*	*unif-inc4-low*; *unif-inc4-hi*
ISR (information supply rate)	10; 50; 90	50	25; 50; 75; 100
NFR (nr of friends population average)	0; 0.5; 1; 3	1	0; 1; 3
thr (value-threshold)	0	0, 10,..,100 (*kch*=0/*thr*=0)	0
kch (keep chance		10,20,..,90 (combined)	
policy	n/a; shock after end of run time	n/a; shock after end of run time	*SD*; *GD* shock at t=400
Total nr of parameter sets	4*4*3*4 = 192	(11+10+9) * 19 = 570	2*4*3*2 = 48
Runs per set	32	32	128

Table 8.5: Variations in parameter values per experiment, total number of parameter sets and total runs per set.

8.7.1 Visualization of results

Figure 8.3 shows two sample results, each visualising farmers' joint market choices over time for one particular run, with markets aggregated into high, medium, low and commodity market segments. Although this information is very detailed, it is already summarized over all farmers.

Separate visualisations of a single run lack conciseness to evaluate the effect of specific parameters (e.g. *ISR* and *NFR*) on the emerging market choices. For this purpose, we used graphs as depicted in Figure 8.4, visualizing the joint market choices of all farmers, again aggregated into three market segments and the commodity market, averaged over all runs of this parameter combination, and averaged over time. By placing parameter combinations as bars below each other in a coherent order, any change in effect of parameter combinations can be visually observed. In comparison with Figure 8.3 this graph has a higher level of abstraction in the sense that the course over time is no longer visible.

The sensitivity analysis results from Experiment 2 were visualized by graphs showing on the vertical axis the relative sensitivity of each parameter when *thr-kch* had values as specified on the horizontal axis. The other parameters were according to Table 8.5. For each market share such a picture was created. Figure

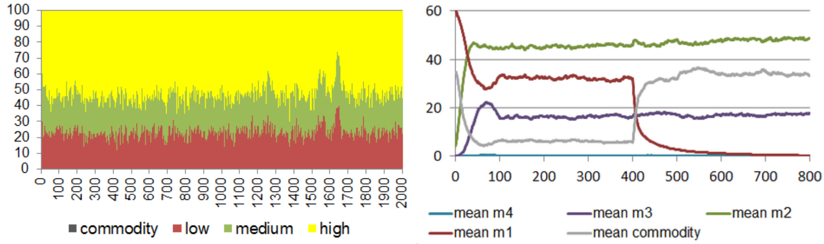

Figure 8.3: Two sample results. Farmers active over time at (aggregated) markets during one run. Left: Experiment 1 (cumulative; an information-rich situation, no visible commodity): market set *unif-inc8*, network topology *ring10d*, *ISR* of 90, *NFR* of 3. Right: Experiment 3 (poorer: no friends, high demanding markets): market set *unif-inc4-hi*, *ISR* of 75, *NFR* of 0, policy *GD* at time t=400.

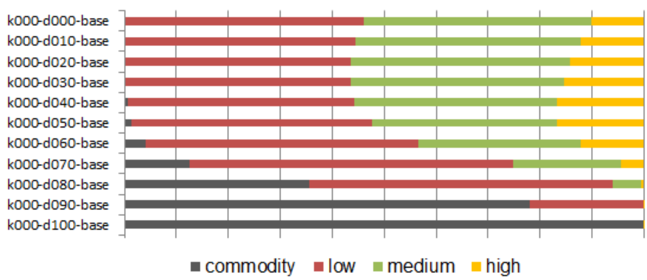

Figure 8.4: A sample result from Experiment 2. Joint market choices, aggregated into market segments high, medium, low and commodity, averaged over all runs and averaged over time. This is the base case scenario (see Table 8.5) of the combinations with value 0 for *kch* (so: no special protection for in-use items) and all 11 variations for *thr* (anything of lower value is disposed of).

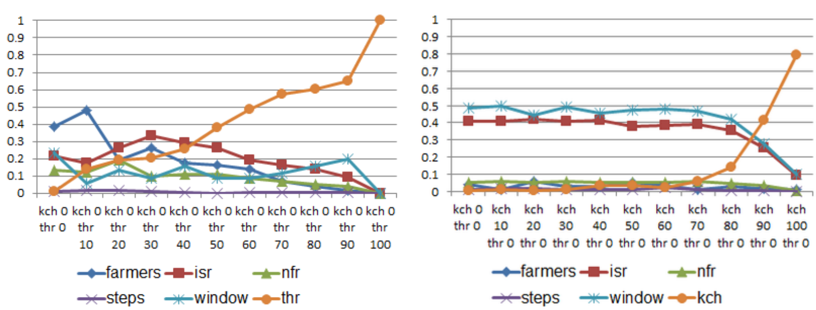

Figure 8.5: Sensitivity analysis for Experiment 2. The relative sensitivity of parameters (vertical axis) for each *thr-kch* combination that is shown on the horizontal axis, for commodity (left) and high markets segment (right).

8.5 shows the commodity and high-markets segments. Both are one-at-a-time variation samples.

8.7.2 Results after multi-level analysis

The added value of the re-runs with the comprehensive model was (a) to increase confidence in the results obtained before because of higher run numbers, and individual inspection of 'outliers'; (b) to inspect system-level patterns, identified but not understood before, at individual level. We illustrate per experiment what insights one or more of these multi-level analyses adds to our results already obtained. When applicable, we highlight the role of info-items, i.e. knowledge.

a) Experiment 1: analysis of multiple runs

Our focus of Experiment 1 is on the analysis of multiple runs of the same scenario. The main findings of Experiment 1 are similar to what was found in the earlier studies. In summary: information turnover (*ISR*) has a consistently huge effect: the higher the *ISR*, the more markets are within reach. Only when there is little information in the system (i.e. *ISR* is low), there is an effect of varying *NFR*: the more friends, the more markets become within reach. There is no clear effect from network topology, except for *isolated*, which consistently performs worst. Lack of network topology effect is partly due to influence from *NFR* (with higher *NFR*, the dynamic network overshadows the static network). Varying market sets has a minimal effect. Niche markets remain attractive despite high requirements, even with low base price, because the price-constituent that depends on total supply makes the market attractive with few competitors.

Added value of performing more runs: We gained confidence in these outcomes now that they also appear with sufficient runs (sufficient according to Troitzsch' convergence test). We did inter-run analysis to find out how stable our outcomes are. Secondly, we inspected 'outliers', because the benefit from ABM is that outliers are especially interesting to understand a phenomenon (Squazzoni et al., 2013). The inter-run analysis entailed visual inspection of result graphs. Troitzsch (2014) argues that in simulation studies the effect size is more important than the significance of the effect (because by increasing the run numbers, one can make any effect significant), and that eye-judgment is a good indicator for an effect. Sorting the same result graph scenario by different sorting order gives various visual inspection opportunities. Figure 6 shows an extract from a sample result graph (to the left). By eye-judgment, the inter-run variation is small. Also, there are no real 'outliers', but only 'extreme cases' in a pattern that is quite stable. This appears to be true for most of our scenarios. The arrow in the figure indicates one of those extreme cases: this run seems to produce a slightly higher market share for both black (commodity) and green (medium segment), relative to the other runs. On the right hand side, this extreme case is shown as individual run over time. We repeated this particular

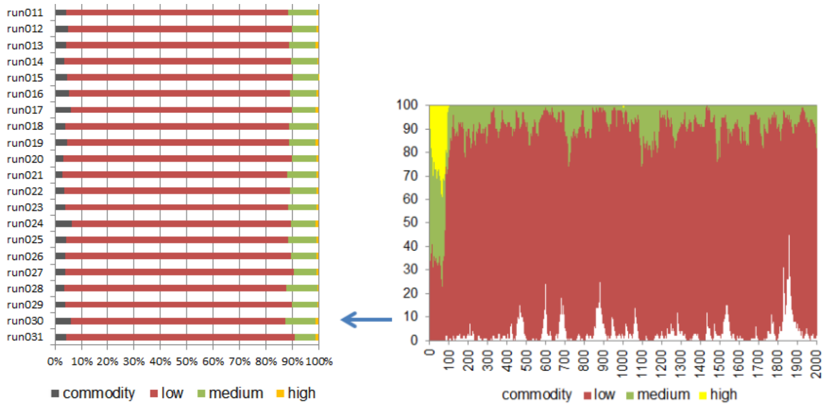

Figure 8.6: Left: Extract from sample inter-run variation inspection graph (scenario *rand-inc8*, *clan10-2d*, *ISR* 10, nfr 30) from Experiment 1, sorted from the right hand side by high, medium, low and commodity segment. The arrow points at an 'extreme case'. That one is shown as single run over time in the right graph. Individual farmer data inspection brought no further explanation for the extreme case deviations.

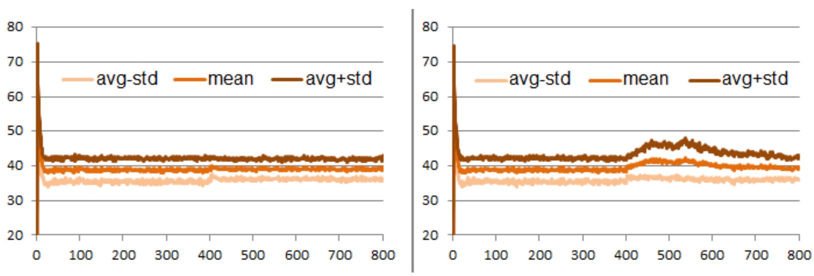

Figure 8.7: (Experiment 3). The Gini-coefficient over time for two different policies (shock at t = 400) of the same scenario: *NFR* 3, *ISR* 50, low-markets, *SD* policy (left) and *GD* policy (right). The 'bubble' (right) is present in a number of scenarios, most clearly in those with low-markets sets.

run, but now recording individual farmer data, so that we could inspect them. We found various individual differences in farmers' info-items, pointing in opposite directions, which did not lead to an explanation for the extreme case deviations other than that they seem to be coincidental.

b) Experiment 2: individual-level inspection of pattern (*'boomerang'*)

We use Experiment 2 to see what individual multiple-level analysis can do when a pattern appears for which we have a theory. The main findings of Experiment

2 are, in summary: Farmers reach higher quality markets with higher *thr* and *kch*, up until moderate values. The influence of *thr* is in most situations stronger than that of *kch*. Sensitivity results provide additional insight: For the commodity market segment, when *thr* is not dominant, other parameters such as the number of farmers and the *ISR* are. A 'boomerang' effect emerges, named after the shape of the graph: when *thr* is high, and only high-valued info-items remain, the level of quality markets decreases again. This effect is visible in Figure 8.4.

We have a theory about this emerging boomerang effect. Initially, with a thr-value up to about 30, it seems profitable to maintain high-quality information only. Although it seems contradictory that 'throwing away info-items' can lead to higher-quality results than keeping them, the theory is that quality pays off during exchange with other farmers. When other farmers also have only higher-quality information, the exchange will - on average - be more profitable than when they run a risk to receive a low-valued info-item. On the other end, when *thr* gets a value higher than about 70, farmers can no longer maintain their quality-markets segments because they cannot afford to lose anything; they become too vulnerable then. The sensitivity analysis results indicate that the *thr* parameter is dominantly responsible for farmers' market choices, which is not in conflict with this theory.

Added value of inspecting individual-level data for boomerang-pattern for which we have a theory: To test whether our theory holds, we repeated re-runs of scenarios representative to test the boomerang, meanwhile recording individual farmer-data. First, we checked whether it is true that exchange with other farmers initially leads to higher-quality info-items when *thr* increases. For several scenarios we plotted for an arbitrary farmer in an arbitrary run the number of info-items and the total value for each type of info-item over time. This showed indeed that although the number of info-items for that farmer decreases, the value per type of info-item is maintained. Next, we checked whether it is true that farmers lose too much info-items when *thr* gets too high. By a similar inspection, this theory also holds.

c) Experiment 3: individual-level inspection of pattern (*'Gini-bubble')*

Experiment 3 also shows an emerging, unexplained pattern. Again we apply multi-level analysis to find out more about this pattern. In general, the main findings of Experiment 3 are, in summary: When only the end result counts, there is no difference between policies *SD* and *GD*. However, looking at the time of transition, with *GD* policy farmers can stay away from the commodity market for a longer time. This is especially true in information-poor situations. Both policies respond differently in the transition period right after the shock, but either way the markets balance out into a new equilibrium, which depends on the other parameters. Plots of the Gini-coefficient show that, only with *GD* policy and most prominently in scenarios with relatively low-demanding markets, there is temporarily a higher wealth inequality right after the shock (see Figure 8.7). Without inspecting individual-level data, we have no means to explain the cause of this bubble and who the temporarily rich farmers are.

Added value of inspecting individual-level data for Gini-bubble pattern for which we have no theory: By repeating some of the runs, meanwhile recording individual farmer data at the time of the bubble, we could track down the relatively rich farmers. It appears that these are all farmers on market 1: the closing market. With *GD* policy, market entry is closed for other farmers, but farmers already on that market can stay if they want. This results in a decreasing number of competitors. The price mechanism ensures a relatively high price for the remaining farmers, which makes them relatively rich. However, all farmers at some point have to leave this market when they no longer qualify for it (because of info-items becoming obsolete). This eventually happens to all of them within 100 time steps after the shock.

8.8 Expert validation

Our simulation results give us outcomes and patterns emerging from our model's behaviour. Additional multi-level analysis gives us explanations for these outcomes or patterns. We have shown that these explanations are valid in model terms: given the assumptions and mechanisms of our model, we can explain this behaviour. What we wish to know next is whether these outcomes, patterns and explanations have any relevance with the real world. Are these outcomes plausible in reality, and would domain experts deem our explanations acceptable?

To this end, we conducted expert validation. We interviewed 9 expert representatives from the following areas: animal science (pigs), pig production economics, pig sector innovation, pig farmer sociology, pig meat processing business, business economics, agent-based modelling, and systems modelling (the latter two both with experience in pig sector domains). Most experts covered at least two of these disciplines. All experts were interviewed face-to-face during one hour. We introduced them to the model by means of pictures (10 minutes), showed them result graphs like those in this article, asked them to reflect on these, and then asked them to reflect on the explanations that our own model and analyses had taught us. All interviews were recorded and qualitatively analysed. The most important outcomes are summarized in Table 8.6.

Per element the links with reality that experts came up with are given, including an indication of how often this particular link was brought up or agreed with among the team of experts. It happens that experts mention or agree with more than one such link.

8.9 Discussion

This research entailed an entire modelling cycle (see Figure 8.2). The model's assumptions were grounded in literature, and the selection and abstraction steps to build the ABM were carefully chosen. During development, we verified our model and its results in such a way that we had great confidence in our model's behaviour. Still, what we discussed during expert validation sessions provoked lively discussions with our consulted experts, indicating that ABM modelling of the pig sector is not straightforward, but both challenging and promising. Things to discuss boiled down to four major categories: regarding our assumptions, model parameters, resulting patterns and methodology.

8.9.1 Assumptions

Information items. The multidimensional (ID, type, value) info-items worked well for our consulted experts. They could understand the concept. As for *type*, they could reason with us about what kinds of types were applicable, and that there can be several info-items per type. As for *value*, we heard more than once that it should be possible to not only downgrade but also *up*grade an info-item's value other than by repeated exchange. In relation to this, we have been thinking about including another dimension to info-items that specifies the sender of the info-item. Different senders may imply different values to the receiver, perhaps related to the link strength that may be calculated or inferred.

Institution. Our model of knowledge appears to be authoritative, with an 'institution' to bring knowledge to farmers (and depreciate its value!). However, the institution is an abstraction. Its role is to create knowledge and to make sure it enters the population at a specified rate. It can just as well be interpreted as a 'source of innovation': a farmer who gets a visit from the institution could be a farmer who finds something innovative and spreads it through the community.

Commodity market. The model assumes that farmers who have nowhere else to go resort to the commodity market, for which they do not get paid. This was meant to be an 'escape', to allow the simulation to continue. This is not a realistic assumption. In reality, when farmers cannot supply their product anywhere, they turn to the export (commodity) market, but they will certainly get paid a (low) price. In our model it is possible to stay on the commodity market for a longer time. In reality, this will never happen: if they had no other choice, they would quit farming instead.

Market segments. Experts considered the market share outcomes for our simulated farmers 'too positive'. Some graphs show a lot of yellow (like Figure 8.3). In reality, the large majority of pigs in the Netherlands is destined for the commodity market. Only 2% is organic, and the remaining part is for the intermediate segment, consisting of various market concepts such as good farming star. However, this does not imply that our model should be changed. It only implies that the market sets may be initialized according to more realistic requirements and associated price parameters.

Market choice based on information. An important model assumption is that farmers' behaviour is solely determined by their collection of info-items. Experts were critical about this: a farmer does not have that much decision freedom, an example being the organic segment for which there is currently a 'waiting list'.

Element	Links with reality (according to the experts)	n
Experiment 1: The general outcomes: - *information is more important than network structure* - *the more information is present, the higher quality markets are reached*	Yes, information in itself (the more, the better) is beneficial for farmers' performance.	9
	Yes, so is exchange. The Netherlands has an extremely well organized knowledge infrastructure for pig farmers.	3
	Most farmers are member of a study club (of say 40): they share information with each other, invite speakers, etc.	4
	In smaller groups (of say 6), they are willing to share even business information with each other. They want to learn from each other (typical for the Dutch). And it pays off.	2
	Even isolated farmers get on-farm visits from suppliers, veterinarian, accountant, so info reaches them anyway.	1
	Farmers are heterogeneous; there's much variation in farmers' personalities, capabilities to innovate, make a profit	2
Experiment 2: The general outcome: *it pays off to keep only high-quality or in-use information, instead of maintaining* all *information*	No. Farmers do not 'lose information' (*thr*). It builds up.	
	Maybe. Protection for in-use info is imaginable (*kch*)	3
	Maybe. It seems plausible that knowledge becomes obsolete because it needs to be continuously renewed.	3
	Maybe. If we assume that the human brain has limited capacity, then it is plausible that we lose information.	2
	Partly. Only for technical, not managerial knowledge. For a new rule, e.g. obligatory air scrubber to reduce emissions, updated knowledge is required; the old is outdated.	2
	Partly. Only if market requirements change equally dynamically. Not the case in the model, but true in reality.	2
	Only if 'information' includes investments and business inputs as well. If you don't have them, you fail.	2
	Yes, making decisions and changing behaviour requires some *slack* (seemingly unnecessary knowledge). Without it, farmers are no longer flexible to innovate.	2
	Yes, pig farming that includes managing breeding sows is highly knowledge-intensive. Farmers must continuously update their knowledge to compete.	2
Experiment 2: Notable pattern: *the 'boomerang'*	No. The boomerang has no counterpart in reality.	6
	No. To end up with only high-quality information you can't afford to lose or you'll go bankrupt isn't plausible.	6
	Yes: it is a rat-race to keep up, knowledge-wise (breeding sows). Historic example: a European country's pig production performance collapsed after economic downfall.	1

Experiment 2: Explanation: *high quality exchange pays off*	Yes. It is plausible that info exchange is more effective if everybody's knowledge is of higher quality level.	3
	Indifferent, no strong opinion.	6
Experiment 2: Explanation: *too efficient = too vulnerable*	Yes, that could be the case.	3
	No. That is weird.	6
Experiment 3: The general outcome: *no long-term difference between SD vs. GD policy, but transition matters*	Yes for *GD*: this is how it usually happens, with a long (5, 10 year) transition period.	6 5
	Yes for *SD*: can happen when acute crisis (e.g. swine fever).	3
	No for *SD*: can't think of an example where this happened.	4
	It would have been more realistic to close the high market instead of the low one. This currently happens to the organic segment.	3
	Transition period usually has an end term, too. That is more realistic than to let it 'phase out'.	3
Experiment 3: Notable pattern: *the 'Gini-bubble'*	Yes. During a transition, there is temporarily a differentiation among farmers. Some manage to make a profit out of the situation.	5
Experiment 3: Explanation: *some transition farmers are temporarily rich*	Yes. I can think of at least one example to illustrate this: farmers have a product for which the market closes, but demand is still there. With fewer competitors, they can make a profit.	6
	Yes. Alternative explanation: some farmers may decide to quit farming after the transition period. They have lower costs and are temporarily rich.	6
	No. If demand is still there, it means that customers will get it from the world market. A few Dutch farmers won't change the world price.	3
	A transition may require a new skill. Those who transit need to learn this. Those who don't may have a benefit because they can still manage-by-routine.	1
	Government may compensate if transition is too sudden. Sometimes those farmers receiving it may profit.	1

Table 8.6: Summarized results of 9 experts' validation: links with reality they mention for all experiments' outcomes, notable patterns and explanations. The third column indicates the number of experts who mention this link.

Market switching. Switching markets is not without costs, nor without memory. Our agents are memory-less, except for the fact that they remember their current market, and can check markets' last price. Also, their info-items collection reflects a history: it changes only gradually over time. But it is indeed possible that farmers repeatedly switch markets. In reality, this is not the case.

There is path dependency involved, because of lock-in: a farmer has invested in many respects to be able to supply to another market segment. Those investments prohibit him from switching back right away. These things can be incorporated in our model by including 'transaction costs' for market switching, or by forcing the farmer to stay on his current market for a minimum amount of time.

Time scale. There are some inconsistencies with how we treat time. One time step in our model represents one pig growth process to maturity: about 6 months. By the same model cycle, our farmers reconsider their market every 6 months as well. In reality this is a strategic choice, which occurs once every 5 or 10 years at the most. However, *considering* a new market may happen more often than actually *changing* market. It depends on the case how to agree upon a consistent time scale. In our case, a solution could be to maintain the time step of 6 months, but to restrict market switching (e.g. allow no switching, or only to a market that is, requirements-wise, close to the current market). Only once every 10 time steps (5 years) farmers may actually make a major switch. On a side note: our simulations last for 800 or 2000 time steps, which is unrealistically long for real life. However, model-wise, we are interested in the stability of the outcome over time, so for the simulations it is better to take a long time horizon.

Market closing. There are some issues about market closing: if it is closed, is demand still there? In our model, only market entry is restricted but being on a market-to-be-closed is no different from being on a real market. Our price mechanism does not change the price parameters for a closing market. So in our model: yes, demand is still there, and the price responds in the same way. In reality, it is plausible that the price parameters of a market-to-be-closed would change as well.

Price mechanism. The price mechanism was generally considered adequate by the experts. However, some argued that the part of the price that is supply-related should be allowed to become negative, to indicate that farmers can actually lose with respect to their costs. This seems realistic, but requires a different price mechanism. Changing a mechanism is a more fundamental model change than changing a parameter or a value.

8.9.2 Model parameters

ISR. Our simulation results together with the expert validation indicate that *ISR* is a useful parameter. It serves its purpose, and simulation results achieved through this parameter seem plausible.

NFR. The number-of-friends parameter is also a good one, with similar argumentation.

Network typology, or static network, can go: *NFR* can create connections, and the structure of these connections is not important according to our own results.

Market sets seem to be functional, assuming the current price mechanism. Their values could be adapted to better reflect realistic market segments, but model-wise they are fine.

The *thr* and *kch* parameters are hard to recognize for experts. The whole concept of 'losing information' is questionable in reality, despite the fact that there are some valid arguments in favour of it. We might consider using this mechanism only for information of certain type, as some experts suggested: technical, but not managerial knowledge. We could also make the parameters individual-based: each agent gets his own threshold value.

SD and *GD*. Policy parameter *SD* is a very artificial one according to some experts. Still, it can serve as a base case to compare other policies with. Contrarily, *GD* is recognized by most experts as a plausible policy. Suggestions to actively end transition periods can be taken into account. It might be interesting to see what happens if the high market closes instead of the low one.

8.9.3 Resulting patterns

Two notable patterns from our simulation results were the 'boomerang' effect and the 'Gini-bubble'. The Gini-bubble is recognizable in the real world by experts, but the boomerang effect was considered strange. Most experts could not link this to a counterpart from reality. We may conclude that this pattern is too artificial. However, our boomerang pattern has an interesting parallel in the world of (sports) team cooperation: research in this area indicates a 'too-much-talent-effect' (Swaab et al., 2014). This means that a team consisting of exclusively top-players performs less well than if a few sup-top players were added to the team. Their explanation is that with only top-players there is too little intra-team coordination. Regarding our own model, there were a few experts who did say that having some *slack* is important to maintain the flexibility to innovate, where slack is interpreted as seemingly unimportant knowledge. It may well be that our pattern's behaviour is too artificial at its extreme, but it seems plausible that 'having some slack' is a necessary factor even in those extreme situations.

CHAPTER 8

8.9.4 Methodology

After applying expert validation to evaluate our model results and explanations, can we now assert that our model is valid? It was built based on assumptions that were carefully chosen. Next, we ran our simulations and looked for interesting patterns. We then tried to explain these patterns in terms of our own model: its assumptions and mechanisms. Our experts could draw parallels between certain outcomes and reality. Some of their parallels concerned an explanation from reality that could never be true for our model, because our model did not contain the elements for that explanation. This is the case for the suggestion that the Gini-bubble could be caused by farmers who quit farming:

in our model, farmers do not have the behavioural option to quit farming, so this can never be 'the' explanation. Fortunately, there were also parallels that did concord with our model. The explanation that diminished competition is beneficial for the stay-behinds, assuming that demand is still there, fits with how we could explain this phenomenon in our own model's terms. For the Gini-example, this means that our model outcomes, the observed Gini-pattern, the individuals responsible for it, and the explanation of how this happened are all plausible, 'imaginable' in reality.

Validation of agent-based models is a recognized challenge (Moss, 2008; van Vliet, 2013). Our model is not as abstract as a purely theoretical model. It is - for example - not a model of the prisoners' dilemma, for which all theoretically possible options and outcomes can be listed, tried and checked, after which we can call the model validated. The model is not a facsimile model either, because there is no one-to-one match with reality. We did not model real farmers of whom we have data that we can use for validation (the extent at which that is even possible is another subject of discussion). Our model is middle-range: it shares characteristics with a real life situation, it has been sufficiently abstracted by making its behaviour as transparent as possible without losing the properties of interest, but it has not become purely theoretical. This means that neither theory nor real-world data can be used for definitive validation. We are of the opinion that expert validation is the highest level of validity we can obtain for a model like ours. If the experts are well chosen, their validation can make the model plausible. This is sufficient for a middle-range model.

8.10 Conclusion

The ultimate objective of this study was to gain insight in the multi-level relationship between knowledge-rich decision behaviour of individuals and the emerging market shares on sector level, relevant for the manageability of a sector consisting of autonomous suppliers. We explored this by means of an ABM, used to carry out three experiments, each investigating specific research questions. Multi-level analysis, which comes natural to an ABM, addressed the fact that the sector has multiple levels and that explanations from individual level can help to explain emerging patterns on sector level in model terms. We used expert validation to evaluate our results and explanations with respect to their relevance for the real world. Important drivers in the current model are its price mechanism, and the role of information as a proxy for behaviour.

With respect to research question 1, 'Does information exchange affect market choices?', we may conclude that there is a positive effect. Simulation results consistently show this outcome, and the experts agree that this is plausible in reality. They also agree with the conclusion that network structure is subordinate to the availability of knowledge. In a country like the Netherlands, where the knowledge-infrastructure for farmers is very efficient, network structure is of secondary importance. Multi-level analysis for this experiment entailed inspecting multiple runs of the same scenario. The inter-run variability was small, indicating a stable model result. There were no real outliers, only extreme cases. Analysis of those did not provide any additional insights.

For research question 2, 'Does increasing knowledge quality lead to higher quality market choices', the outcome is not so clear. Simulation results show a distinct effect when knowledge quality increases by 'throwing out' low-valued information. Initially, that works well, but there is a limit to this efficiency. Multi-level analysis by inspecting the actual individuals' info-items confirmed our theory that exchanging information within a network of farmers who all have only high-quality information helps farmers to increase their knowledge quality, which allows them to choose higher markets. The experts confirmed that this is plausible. On the other end of the spectrum this effect backfires ('boomerang'). Our theory was that high efficiency makes vulnerable and causes lack of flexibility to innovate. This theory is not recognized by the majority of our experts, presumably because this end of the spectrum is too artificial to allow for comparison with real life. There is, however, reason to believe that some *slack* knowledge is required to have the flexibility to innovate, where slack is interpreted as seemingly unimportant knowledge.

The third research question, regarding the effect of a policy intervention, applying *GD* policy yielded a final outcome very similar to the outcome after applying *SD* policy. This indicates that *policy doesn't matter* if only the end result counts. However, the transition itself does matter, and this is also representative of reality. With respect to the Gini-bubble, the temporary inequality during transition time, multi-level analysis revealed that the farmers on the market-to-be-closed are the cashers. Experts did not come up with one solid explanation from reality for this phenomenon, but they provided various plausible explanations. A plausible explanation that is in line with our model assumptions is: fewer competitors on a closing market for which there is still demand leads to a temporarily higher income.

A secondary aim of this article was to communicate the methodology of ABM to researchers of similar domain areas: an information-rich sector consisting of many individual decision makers where multi-level analysis of both the sector and the individuals helps to gain insight in phenomena of interest. In the ABM modelling community it is not common practice to explicitly describe all modelling steps (apart from providing the ODD). This article gives a transparent overview of the modelling process as we applied it. An important driver for design was parsimony of modelling to keep the model's behaviour transparent. Strength of our approach is its explicit separation of levels, and the application of multi-level analysis and expert validation. We recommend this for other ABM applications as well.

As a final question: What did we learn from this ABM exercise? Regenerating patterns which we try to get to the bottom of by inspecting individual agents' behaviour at that point is definitely fruitful, as two illustrations in this case have shown. The alternative of saving all individual simulation data is unattractive. It might be physically possible to analyse all data through grid computing and data mining tools, but pattern-based inspection of individual agents is cheaper in all respects and may well produce similar results. By finetuning the model's mechanisms and its level of abstraction, we expect to be able to make output that is even more plausible to the experts' opinions. Already the model has shown its purpose as a valuable means of communication. The model can be used to explore what-if scenarios for multi-level knowledge-rich domains within the limits of our model assumptions.

Preface to Chapter 9

General discussion

Op een dag liepen de eekhoorn en de olifant door het bos. De zon scheen en ze hadden het over boomschors, motregen en bemoeizucht.

Onder de eik bleef de olifant staan.

'Denk je dat ik door de eik heen kan lopen?' vroeg hij.

'Nee,' zei de eekhoorn. 'Hij is te dik.'

'Dik is geen reden,' zei de olifant. 'Mist is soms heel dik. En molmsoep.'

'Maar hij is ook te groot,' zei de eekhoorn.

'Te groot...' zei de olifant schamper. 'De woestijn is groot. En de lucht. De lucht is nog veel groter... en daar lopen jij en ik dwars doorheen, eekhoorn!'

'Hij is te zwaar,' zei de eekhoorn.

'Dat is ook geen reden,' zei de olifant.

'Waarom niet?' vroeg de eekhoorn.

Dat kon de olifant zo gauw niet bedenken, maar het was geen reden, dat wist hij zeker.

One day the squirrel and the elephant were walking in the forest. The sun was shining and they were talking about bark, drizzle, and meddlesomeness.

The elephant stood still under the oak tree.

'Do you think I can walk through the oak tree?' he asked.

'No,' said the squirrel. 'It's too thick.'

'Thick is no reason,' the elephant said. 'A fog can be thick. And mould soup.'

'But it is also too big,' the squirrel said.

'Too big...' the elephant said, scornfully. 'The desert is big. And the sky. The sky is even bigger... and we're walking right through it, squirrel!'

'It is too heavy,' the squirrel said.

'That's no reason either,' said the elephant.

'Why not?' the squirrel asked.

The elephant found that hard to answer, but it was no reason, he was fairly certain of that.

Chapter 9
General discussion

In this final chapter we answer our research questions and reflect on what we learned. In Chapter 2, we structured our thesis chapters according to Hevner's relevance, design and rigour cycles. Figure 9.1 shows the deliverables from our work. To the left is the relevance cycle, where we include the insights we learned from the expert validation that we performed in the synthesis chapter (Chapter 8). Apart from evaluating our results, the experts also provided us with many useful reflections on our assumptions and mechanisms, many of which return in the discussion sub-section of this chapter. In the design cycle in the middle we present the three models of our work: the pilot study model from Chapter 3, the pork cycle model from Chapter 4, and the final model covering four chapters (Chapters 5-8). The final model was introduced in Chapter 5, extended with a mechanism to increase knowledge quality in two ways (Chapter 6) and extended with another mechanism to model two intervention policies (Chapter 7). In the synthesis chapter (Chapter 8), we used the same model without further extensions again to repeat our experiments from the previous three chapters, and to increase the level of analysis. To the rigour side of the figure we present the scientific insights we found (depicted as a diagram) and also the methodological and practical insights we gained (depicted as tools).

In the remaining sections we answer our research questions (including scientific insights), discuss our findings (with much help from insights from experts), present our methodological toolbox, and end with a conclusion.

9.1 Research question 1

What is the relationship between sector-level knowledge management measures (top-down), actions of individuals, and the system behaviour resulting from these actions (bottom-up) in the context of a sector of autonomous suppliers, specifically applied to the case of pig farmers?

Before answering this main question, we answer its two sub-questions. To keep the text readable, we avoid using the names of specific parameters. For more detailed explanations we refer to the respective chapters. Each sub-question is first answered separately, after which we answer the main question.

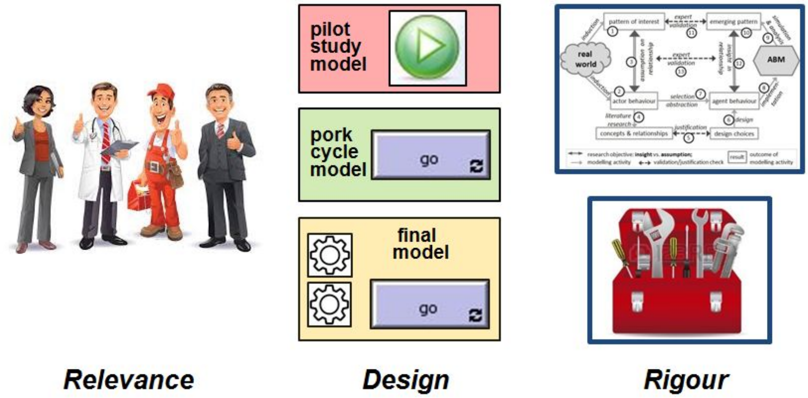

Figure 9.1: The deliverables from this thesis according to Hevner's relevance, design and rigour cycles (see also Chapter 2): experts' views regarding the relevance of our work, three models, and scientific and methodological insights.

9.1.1 Sub-research question 1a

What is the effect of agent-level variations with respect to knowledge management on total system behaviour?

Agent-level variations refer to experimenting with those agent attributes that make the population heterogeneous, and see what the effects are on system level (**bottom-up**). We applied 'agent-level variations with respect to knowledge management' in the cases from Chapters 3, 4, 5, and 6. We varied the amount and quality of information, which directly affects knowledge management. We also varied network structures, which are a prerequisite for knowledge exchange (in those cases where that is an option), so these variations also affect knowledge management. In the case of Chapter 6 we varied system-level parameters to filter out high-quality information. These variations can still be considered to be at agent-level, because each farmer's collection of personal information (a heterogeneous property) is filtered according to these parameters, which results in an altered but still heterogeneous collection of info-items. We revisit all cases where agent-level variations were an issue.

Pilot study (Chapter 3)

- We varied how many farmers receive a visit from the information providing agent (20% versus 100%): a measure of how much information farmers have. The effect on quality level is present in all scenarios, but most salient in situations where the higher quality markets are attractive because of high demand there.
- Farmers are heterogeneous with respect to their 'openness' attribute (static),

which co-determines their satisfaction threshold (i.e. the probability that they will change market) and the probability that they will aim for a higher quality market. This heterogeneity affects how farmers eventually distribute themselves over quality markets. The mechanisms by which this happens are concatenated and depend on each other by many parameters, each with their own heterogeneous influence, which makes it difficult to say with confidence what their contribution to the outcome is.

Case: pork cycle (Chapter 4)

- Each farmer possesses information (a numeric value, static throughout the simulation), from which the accuracy is derived with which he determines his expected price. Farmers' expected prices therefore range from naïve to perfect. Naïve means that they take the previous price; perfect means that they take the price mechanism's equilibrium price. This heterogeneous agent-level property determines whether the pork cycle emerges.

Case: markets model & multi-dimensional information (Chapter 5)

- Farmers are heterogeneous with respect to the number of info-items they have (dynamic during the simulation, because of exchange), the value those items have for them (also dynamic), their current market (dynamic), and their network (both static and dynamic). Of these, we varied the number of info-items present in the system, static network topology, and dynamic network. Most influential for the result is amount of information in the system, followed by dynamic network, both causing an increase in quality market shares. There was hardly any effect from network topology.

Case: increasing quality of information (Chapter 6)

- We varied quality-increasing parameters, meaning that farmers maintain only info-items of high quality (in our experiments evaluated by two different ways to assess quality), initially resulting in slightly increasing quality market shares. This seems strange at first: farmers have less knowledge (they lose low quality info-items), so how can they perform better than before? This can be explained because of their exchange events with others. Since all farmers have higher-valued info-items, info-item exchanges are more profitable than before: the probability that farmers receive a high-valued info-item from their peer has increased. This initially increasing effect does not last: for higher values of quality-increasing parameters, the effect on quality market shares decreases. The resulting graph from this effect (first increasing, then decreasing market shares) is boomerang-shaped, which is why we name it in our further analyses the ***boomerang effect***.

- Sensitivity analysis shows that the amount of information in the system is among the most influential parameters, for low values of the quality-increasing parameter, especially on higher market segments.

Synthesis: repeating experiments (Chapter 8)

- The repeated experiments for the cases relevant for this sub-research question (Chapter 5 and Chapter 6) give similar outcomes, and increase confidence in these outcomes. Multi-level analysis shows that the boomerang effect happens indeed because farmers are losing too valuable information when the quality of their info-items becomes too high.

Answer for sub-research question 1a (bottom-up, agent-level)

From all our experiments where we varied agent-level properties, we conclude that they have in almost all models an effect on system behaviour that is according to expectation. For some properties we could or did not measure the effect (heterogeneity in the pilot study, remaining heterogeneous attributes in the other cases). For network topology, there is hardly any effect. When increasing info-quality the effect has a tipping point (boomerang effect). In general we can say that, in all our models, system behaviour responds accordingly when agent-level properties are varied.

As for plausibility, experts confirm that more information and more network connections contribute to higher performance, and that these effects are more important for higher market segments. Experts do not recognize the boomerang effect: this is a model outcome that does not seem plausible in reality. Experts do acknowledge that increasing information quality may be efficient: leading to higher performance, resulting in higher quality market shares. However, only to some extent, and only for certain types of knowledge: technical knowledge, not managerial knowledge. The necessity of having some slack, i.e. seemingly worthless knowledge, is generally acknowledged.

9.1.2 Sub-research question 1b

What is the effect of system-level interventions on agent behaviour and total system behaviour?

Interventions at sector level are changes from a **top-down** perspective that concern the sector as a whole. Such interventions were applied three times: changing demand volumes (pilot study case Chapter 3), changing market requirements (case of Chapter 5), and closing a market (case of Chapter 7). We revisit all these occasions.

Pilot study (Chapter 3)

- The intervention in the pilot study is: changing the required demand per quality class. Demand is varied as a system parameter, indicating how much each buyer agent in the model (one for every quality class) can purchase from farmers. We do see a change in farmers' satisfaction and consequently farmers moving to other quality classes, when demand changes. This is especially true in information-rich situations when higher quality classes come within reach.

Case: markets model & multi-dimensional information (Chapter 5)

- The intervention here is to vary the market sets. Market sets differ with respect to requirements they set and associated price parameters. Changing the market set essentially changes demand. These changes are not dynamic, but treated as a parameter: once initialized, a market set remains static throughout the simulation. We varied 4 market sets: two sets of 'extreme markets' setting only low and high requirements, and two market sets with increasing requirements. We also varied the associated base price farmers would receive at these markets (either increasing with requirements, or the same base price regardless of requirements). We saw only modest variations in outcome. One interesting phenomenon was that 'niche markets' appeared to be attractive even if their base price was lower than their requirements justified: the supply-dependent part of the price compensated for the low base price. (A niche market would only last until other farmers discovered it).

Case: policy interventions (Chapter 7)

- The intervention in this case is to close one of the available markets (the one with lowest requirements). This happens either by *sudden death* or *graceful degradation* policy. We see that policy does not matter for the final outcome: in both cases the low market eventually disappears and the remaining markets find a new balance, dependent on the other parameters of the model. The time of transition does matter: farmers are able to stay away from the dump market (which is an ultimate resort in the model) a bit longer, especially in information-poor situations.

- We see an emergent pattern that we call the ***Gini-bubble***, indicating a difference in wealth equality in the population at the time of the transition, only for graceful degradation policy.

Synthesis: repeating experiments (Chapter 8)

- The repeated experiments for the cases where we varied system-level properties (Chapter 5. and Chapter 7) give similar outcomes, and increase confidence in these outcomes. Multi-level analysis for the Gini-bubble pattern shows that the farmers who linger on the closing market are the ones who are - temporarily - very rich, thus responsible for the emerging Gini-bubble.

Answer for sub-research question 1b (top-down, system-level)

A system-level intervention such as demand change or closing a market has an effect on the population: farmers adapt, choose different markets, and a new balance of market shares emerges. The new balance depends on the other parameter settings. In an information-poor situation, farmers have limited options to make the move to higher quality markets; in information-rich situations, more farmers are able to move to higher quality markets. The policy experiment shows that the type of transition has no lasting effect on the final outcome, which makes a farmer-friendly alternative (graceful degradation) the preferred policy. During the transition period, we see temporarily deviating wealth distribution (the Gini-bubble) for the graceful degradation policy situations.

The fact that a new market balance appears after an intervention is deemed plausible by our experts, because this is indeed what happens in reality. Experts confirm that interventions are usually made according to graceful degradation policy: including a (usually long) transition period. Sudden death policy only occurs in times of acute crisis, e.g. a swine fever outbreak, and is never a preferred policy. Most experts can provide explanations for the Gini-bubble in the sense that they have seen farmers profiting during a transition period. Not all explanations they provide are possible in terms of our model. A plausible explanation that agrees with our model is that farmers experience less competition on a market for which there is still demand, which results in a higher price for their product.

9.1.3 Answer for research question 1 (bottom-up vs. top-down)

In conclusion, we can say that there is indeed an interacting relationship between sector level knowledge management measures and actions of individuals. Both when individual properties and when system-level properties were varied, this resulted in responsive behaviour that can be explained in model terms, and that is to some extent also plausible in reality.

Most interesting are the cases where an unexpected pattern emerges. This happened twice: the boomerang and the Gini-bubble effect. Multi-level analysis showed in both cases what the relationship is between the pattern (which is by definition at system level) and the individual level. For the boomerang effect, this explanation is valid in model terms, but not plausible in reality. For the Gini-bubble, the explanation is valid in model terms as well as considered plausible in reality.

9.2 Research question 2

How suitable is agent-based modelling as a method for representing a real-world case of sectorial knowledge management?

Before we answer this research question, we bring to mind the process framework we used in Chapter 8, synthesis, depicted here as Figure 9.2. We consider this framework a scientific deliverable from our work. At the end of Chapter 2 we concluded that Hevner's research framework is helpful to distinguish between relevance, design and rigour cycles, but that Hevner does not

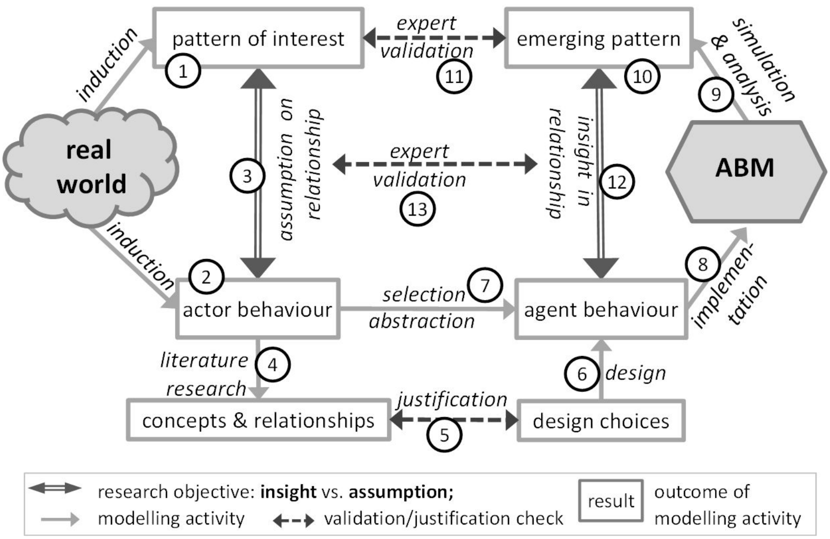

Figure 9.2: Process framework of multi-level agent-based modelling as, a scientific deliverable from our work. The numbers indicate a possible research chronology. For details, see Chapter 8.

highlight the process of how to alternate between his three cycles. Our Figure 9.2 show a possible chronological ordering of research activities. Also, the two levels (sector and system versus actor and agent level) are clearly present in our figure, as well as the interaction between the two.

Sub-research question 2a addresses the selection and abstraction we applied to model our agent behaviour (number 7 in Figure 9.2). For this behaviour we made design choices (number 6) based on assumptions grounded in literature (number 5) of how to represent relevant concepts and mechanisms. The sub-research question concerns these representational issues with respect to knowledge management, and the representation of the two levels in the system.

Sub-research question 2b is about validity: how relevant are our models and results for the real world. This concerns the arrows in Figure 2 labelled with numbers 11 and 13. In the figure, the vertical arrow on the left (number 3) indicates the assumed relationship between an observed pattern from the real world and observed actor behaviour in the real world. The vertical arrow on the right (number 12) indicates the same relationship but now in the model, the difference being that model and agent behaviour can be inspected. Our experts assessed (number 11) the plausibility of our main simulation outcomes, the emerging patterns themselves (number 10), and the explanations (number 13) we found for these patterns in model terms (number 12).

9.2.1 Sub-research question 2a

Representation: *How well does the design of the agent-based model permit representing knowledge management and representing the multiple levels of the real-world case?*

Before we can answer sub-question 2a, we must define the representation power of what we consider 'representing knowledge management' in our research. In our view this representation power comprises the following elements: what 'knowledge' represents and how this is expressed, how new knowledge is created and how it diffuses through the population either from outside or within a peers-network, what the main knowledge-based decision and the incentive for that decision is, what the relationship is between knowledge and behaviour towards that decision, how time is represented, and whether the two (actor and sector) levels are present. In Table 9.1 we summarize these elements for all our models - i.e. the models presented in Figure 9.1: the pilot study model, the pork cycle model, and the final model. In the following sections we provide additional details and explanations regarding this table where needed.

	Pilot study model	**Pork cycle model**	**Final model**
Knowledge name	Information units	Info-items	Info-items
Knowledge represents	***Quality level*** of pigs; ***Price*** indicator for pigs	***Informedness*** of farmer	***Type***: range of knowledge categories ***Value***: how skilled, educated, informed farmer is; relevance
Knowledge expressed as	Single number [1,100]	Single number [0,100]	Multi-dimensional: (id, type, value [0, 100], in-use [y/n]
Generation of knowledge	At initialization: LBO is assigned 100 unique information units	At initialization: random info-items per farmer	Institution creates at initialization 100 random info-items; each time step 1 new one
Knowledge lifetime	No limit (standard runs last 30 time steps)	No limit	Obsolete by age, or by value, protected by in-use
Knowledge diffusion (from outside)	LBO hands out copies of its 100 information units to random farmers	No (knowledge is a static property)	Institution hands out random copies of its info-items to random farmers
Knowledge diffusion (peers)	On demand exchange; within dynamic network	No (no network)	Always exchange; within static and dynamic network
Main decision	Change target quality & quality level	Restock or not	Change quality market

Incentive for main decision	Internal; personal circumstances, satisfaction	Internal; personal expected price	External; previous market price
Time step represents	1 month; 1/6 of farmers may sell pigs (on demand)	1 month; 1/6 of farmers sell pigs	6 months; all farmers sell pigs
Relation between knowledge and (summarized) behaviour	If satisfaction < threshold → Change target quality → (Make more friends) → Change quality level	Informedness → Accuracy → Expected price → Restock or not	Poll 1 new market → If better expected price & criteria match info-items → Change quality market
Multi-level representation	Present; dense model inhibits inspection	Present; mostly implicit	Present; model allows multi-level inspection

Table 9.1: Comparison of the three models with respect to knowledge management and multiple levels. The arrow (→) indicates the order within the behavioural mechanisms.

Table 9.1 - Additional details for pilot study model

- Farmers can only exchange information units with other farmers from their network. They generate a network if they choose to spend time on making new friends (time not spent on other behavioural options). Exchange happens only if a farmer explicitly chooses to do this (and it costs time, again).
- A farmer's satisfaction level (affected by how well he sold his pigs in the previous round) rises or drops. When it drops below his threshold level, which partly depends on his personal 'openness', he may decide to change quality class. Downgrading is always possible but implies less income. Upgrading can only happen if quality level suffices. If quality is insufficient, the farmer may choose to increase quality (one of the four behaviours in his action repertoire). This takes time which he cannot spend on other behaviours (e.g. to make new friends). Increase quality means that he picks one of his friends and exchanges an information unit with this friend. If he receives a new information unit, his quality level increases by 1. His quality level will also increase if the LBO happens to visit him, but he cannot control when this happens.

Table 9.1 - Additional details for pork cycle model

- A farmer's info-items represent how informed he is. This is a proxy for accuracy, on scale [0,1], by which he is able to determine his expected price, so accuracy and expected price are also static for every farmer throughout the simulation.

- A farmer's info-units, hence his accuracy, hence his expected price will be the basis for his decision to restock or not. If the expected price is good, the probability that he will restock is higher than when the expected price is low. The better informed he is, the more accurate his decision, the less chance the sector runs to end up in an over- or undersupply situation, of which the farmer experiences the consequences.

Table 9.1 - Additional details for final model

- Knowledge is expressed as 'information items', or info-items for short, a farmer attribute. Each farmer has a list of info-items. An info-item is multi-dimensional: it consists of 4 parts (id, type, value, in-use - the last one is only actively used in Chapter 6). A farmer can have several info-items of the same type, each with their own id and value.
- A farmer's info-items represent his knowledge and skills in a very broad sense, the range of which is determined by the available types. The value can represent various things: how skilled or how educated or how informed the farmer is for this particular piece of knowledge, or how relevant this piece of knowledge is for him.
- Each time step, all farmers exchange knowledge, unless they have no friends: they exchange one info-item with each friend in their network. They received some network connections during initialization and dynamically change connections during the simulation. They may receive a new info-item, or one they already have. Either way, the info-item's value for the receiver changes.
- Each time step, all farmers will sell their pigs, but first they must determine at which market. Each farmer polls one new market per time step (bounded rationality), whose last price is a driver for the farmer to change market, but only if he can meet this markets' requirements. Those requirements are expressed in terms of required values on selected types of info-items. If there is a match, the farmer will change. If not, he will stay. Only if he cannot stay (because he no longer qualifies) he seeks further. To determine whether there is a match with a market, the farmer will take the average value of his 5 highest info-items per type (also reflecting bounded rationality).

Table 9.1 - Additional details for multi-level representation

- For all three models there is a clear distinction between agent level and system level. In all cases, only agents and their behaviour are modelled, and system level behaviour emerges.

- The pilot study's multi-level representation is limited in the sense that there are only 10 agents, and that the system-level outcomes are hard to interpret because they depend on so many parameters and mechanisms.
- The pork cycle model is very parsimonious regarding the two levels: the agents' representation is minimal, and the outcome is a fluctuating pattern for which we used Fourier transformation to determine whether it is periodic. There is no explicit relationship anymore between pattern and individuals.
- The final model has the richest multi-level representation: the outcome is farmers per market set, so the more markets we define, the more fine-grained the results can be (and we can choose to aggregate them again, as well). The model allows us to record individual data up to the granularity we need. This means that for any pattern in the outcome we can do re-runs of the model and record individual data to the level we need, as detailed as that of one farmer in one time step.

Answer for sub-research question 2a

We see that representation power is different for each model. The pork cycle model differs the most from the other two. It has the simplest representation power: knowledge refers to only one single, static number. There is no exchange, no new knowledge. Knowledge represents 'how informed the farmer is'. It could implicitly mean much more (ability, skill), but since the number is a proxy for accuracy and expected price, it makes sense to limit its representation to those farmer qualities that result in being able to predict the price he expects to get for his pigs, on which he bases his decision.

The knowledge representation power is highest in the final model. Several types of knowledge can be distinguished. For every type of knowledge, personal values are associated. Instead of combining all this into one number, knowledge can be differentiated and personalized in this model. This has much more representation power than both other models.

There are similarities between the way knowledge is represented in the pilot study and in the final model. In both cases, the LBO (or the institution) is the source of new knowledge, and new knowledge can be obtained from exchange with friends. The relationship between knowledge and behaviour is different: in the final model, farmers do not seek for higher quality but simply check whether they match a market's criteria (driven by its price). In the pilot study model, the personal circumstances of the farmer (satisfaction, depending on his 'openness') drive a farmer to act.

Both in the pilot study and the pork cycle model farmers have an intrinsic motivation to act. In the pilot study model, satisfaction triggers farmers to change quality class. In the pork cycle model, their expected price (dependent on a personal attribute) is an important ingredient for their decision to restock.

This intrinsic motivation is implicit in the final model, where farmers are driven by an external factor (price).

All models succeed to some extent to represent knowledge management and multiple levels of a real world case. The pilot study model's focus is on representing heterogeneity in individual behaviour, but does not allow for easy multi-level inspection. The pork cycle model is most implicit with respect to representation power but succeeds in creating a sector-level pattern based on agent-level behaviour. The final model is richest in representing knowledge and best allows inspection of the relationship between sector and agent level.

9.2.2 Sub-research question 2b

Validity: *Do the evaluated simulation results lead to increased understanding of the interdependence of emerging system behaviour and individual agent behaviour in the real-world case?*

Validity and plausibility have been explicit issues in our synthesis chapter (Chapter 8), where we used expert validation to determine what our research outcomes mean to the real world. Sub-research question 1a already answers this question per pattern, per case, indicating whether the pattern is considered plausible by consulted experts.

An interesting issue is: what is actually our starting point? In Figure 2, the 'pattern of interest' in the real world has number 1 assigned to it. This is also where we started our quest, years ago: the pattern of emerging quality market shares. Can we gain insight in this pattern through our agent-based modelling exercises? Can we manipulate that pattern by changing something for individuals? Can we manipulate it by intervening at sector level? Are our model outcomes representative for phenomena in the real world? Our cases show that this is indeed plausible, at least for some of the things we tried. As the answer we gave under sub question 1a demonstrates: we could make the full cycle for this pattern a number of times - regenerate it with the agent-based model, relate it to what happens at individual level, and link it back to the real world.

However, the most exciting moments for us were the patterns that emerged unexpectedly in our agent-based model. A boomerang! A Gini-bubble! We had no real world phenomenon in our minds that triggered us to look for these patterns. Yet the patterns appeared, and we started reasoning the other way around - could we perhaps link a real world phenomenon to our model's emerged pattern? To some extent, and with some reservation, we could do this, at least for the Gini-bubble. This exercise was useful because it caused lively debates with experts - if not useful, it was at least inspiring. It was also useful, because it made us question our model's behaviour, and inspired us to think about model changes. The discussion section contains some of these ideas.

9.2.3 Answer for research question 2

With respect to knowledge management, our answer to sub-research question 2a shows that our models' representation power differs per model. Dependent on the aim of the model, representation power can be kept deliberately modest (as in the pork cycle model), or can be high (as in the final model with respect to representing different types of knowledge). There is no end yet to the possibilities: our model could still be extended to represent e.g. more heterogeneity in farmers' decision behaviour. We believe that representation power of agent-based models makes them sufficiently suitable to represent a real-world case, as long as the model has a well-defined purpose.

As for how representative these models are for the real world in terms of validity: we also discussed in the synthesis chapter that 'plausible' is not the same as 'validated'. We are happy if an expert confirms that our artificial pattern and the explanation we provide for it in model terms has a counterpart in the real world, but - even if we have an explanation that does not contradict with our model - we have no guarantee that this is indeed the explanation that makes our model valid, and hence that the model is representative for the real world.

9.3 The agent-based modeller's toolbox

As a spin-off from our work, we would like to present the collection of modelling insights and methods that helped us analyse our model data. The methods were not invented by us but proved to be useful in the context of our research. This emerging agent-based modeller's toolbox may also be helpful to other agent-based modellers in our field.

We use the terms 'rich', 'dense', 'sparse' as follows: A rich model is a model that contains a large number of concepts and mechanisms to represent the real world. By a dense model, we mean that its accessibility is inhibited: it does not allow structural analysis in such a way that we can still interpret results. Sparse (or: parsimonious) means that the number of concepts and mechanisms is kept as little as possible in order to keep the model transparent, i.e. such that our levels of analyses can explain its behaviour.

- *'A too rich model behaves like a black box' (pilot study).* Although it is tempting to represent a realistic case in all its richness, be aware that the denseness of the mechanisms may obscure the relationship between inputs and outcomes.

- *'Less is more' (pork cycle, final model).* Parsimony in modelling pays off when it comes to analysing model behaviour (we reinvented the known adage KISS: 'keep it simple, stupid').

- *Fourier transformation is useful to determine periodicity (pork cycle).* Methods that are common in other disciplines may show their worth in novel applications. Fourier transformation, usually applied to analyse frequencies in (sound) waves, is also applicable to the pork cycle.

- *Heterogeneity can be achieved by a random element (pork cycle, final model).* When there is variation in a population, but the details of this variation are not of our concern, assigning a random value is the sparsest way of modelling this variation.

- *Summarizing simulation results as bar charts (Chapter 5 and 6).* Visualizing many simulation runs in order to see the course of the changes in outcome can be achieved by representing each run as a bar chart and sorting them in the order or interest. We created a Python program for this.

- *Post-processing results (Chapter 5).* To quantify differences between various simulation experiments, pairwise comparison can be applied and counted and recorded (we used Python). For details we refer to Chapter 5.5.

- *Automatize batch simulation processing.* For our last experiments, we created a Java program to process the data during the runs into the format we desired, based on specifications read from file. This was useful both from a processing point of view and for archiving experiments.

- *Record full data or summarize data during runs.* The same Java program also allowed us to choose for full data recording if we had reason to do this, e.g. to inspect pattern causes.

- *Verification of model versions the way we did it (Chapter 6).* When extending an existing model, such as we did in the case of Chapter 6, it is helpful to explicitly verify that the newly added mechanism does not change model outcomes when applied to the 'old' cases. For details we refer to Chapter 6.5.

- *Local sensitivity analysis (Chapter 6).* The local sensitivity analysis approach as we applied it is not difficult to do and helpful for investigating the relative influence of parameters.

- *Troitzsch' test (Chapter 7 and 8).* To determine whether the number of simulations is sufficient, we can recommend Troitzsch' approach. For details see Chapter 7.7 or (Troitzsch 2014).

- *Multi-level analysis (Chapter 8).* Multi-level analysis addresses the core of agent-based modelling: to inspect patterns in terms of individual behaviour, as this thesis demonstrates, especially in Chapter 8.

- *Expert validation (Chapter 8).* Expert validation is a good method to assess the plausibility of an agent-based model's results, as we claim in this thesis. Apart from plausibility assessment of results, most experts give valuable advice and comments that help ground the work as well.

9.4 Discussion

The discussion section is structured around our knowledge management paradigm, model assumptions and mechanism, and simulation and analysis related issues. If not otherwise specified, the discussed issues concern the final model of the last three cases.

9.4.1 Knowledge management paradigm

Knowledge representation - Types

Our final model's knowledge paradigm - representing knowledge as a collection of info-items of different types and with different values per owner -may raise a discussion of what exactly these knowledge types can be. We gave examples such as: health, hygiene, management of pigs, housing issues, feeding issues. These are all - indeed - things for which a farmer can collect distinct pieces of knowledge. He can then increase these pieces' value when he repeatedly hears them, develops them, or gets experienced in them. The fact that the types remain abstract makes the model powerful - it could be anything. But, as one expert asked: can it also be infrastructure? Investments? Money? Steel? Theoretically, the answer is: yes, the model can probably handle that. But in the context of our case, knowledge management is not about these things.

Knowledge owner - Institution

The representation of the institution (LBO) seems 'authoritative': the wise, learned official owns all knowledge and gives it to farmers as he pleases. But we would like to emphasise that the event of the institution visiting a farmer could equally mean that new knowledge enters the population at that instant. We could interpret it as: the farmer has a new idea which can start spreading. The institution is important, however, to control how often new ideas enter the population. In this interpretation, that parameter can express the innovativeness of a population.

CHAPTER 9

Knowledge downgrading and knowledge exchange

In our final model, knowledge downgrades as soon as it enters the population. When a farmer repeatedly hears the same thing, its value can only become higher if the info-item was offered with a higher value. If it was offered with a lower value, its value does not increase at all. This is not entirely satisfactory. Perhaps knowledge should be allowed to upgrade for the pure sake of repeatedly hearing something, no matter its value. It is also imaginable that upgrade occurs under other circumstances, for example if the sender has a higher status than the receiver. Currently, we did not model this.

Losing knowledge

Our experts were most puzzled about the fact that we let farmers lose info-items, especially in the case of Chapter 6 (where we introduce mechanisms to increase the quality of remaining knowledge). Still there are plausible explanations of why losing knowledge is a real possibility. Most important is that in knowledge-intensive domains, like managing breeding sows, knowledge needs to be kept up-to-date and continuously renewed. Updating knowledge implies that other knowledge 'gets old'. In less knowledge-intensive domains, it seems that losing knowledge is plausible in case of technical knowledge, but not managerial knowledge. "I don't suddenly forget how to take care of my pigs". Translating this back to the model: we might consider to change the losing mechanisms in such a way that it only applies to information of a certain type.

9.4.2 Model assumptions and mechanisms

Market criteria

After having lost info-items, it sometimes happens that farmers no longer qualify for their current market. This seems to make more sense if the reason why they no longer qualify is not because they have lost crucial information (an example of reality being that they lost e.g. a certification), but because market criteria have changed. Experts acknowledge that this is realistic, especially for new market concepts. "There is always something extra that we also have to do", farmers complain, according to our experts. In model terms, it is not an easy adjustment to change market criteria dynamically, but it is an idea worth investigating.

Price as a driver is too strong - path dependency & lock-in

Experts agreed about the price mechanism in our final model, but they criticized the assumption that "the price determines all". Especially that our farmers can theoretically switch back and forth as much as they like if only the price is better elsewhere meets resistance. And they have a point. In reality, farmers do not switch market like that, but there is path dependency involved. Switching market requires preparation, investment, and happens only once or twice in a farmer's lifetime. If he has just invested to move to another market, he will not backtrack anymore, because of lock-in. It is worth investigating how often the farmer agents in our model actually make a switch, because, also in the model, their collection of info-items constrains their options, and this collection changes only gradually over time.

Dump market

The term 'dump market' that we used in the cases of most of our earlier-written chapters encountered resistance with the experts. (The dump market in our models sets no requirements, but farmers do not get paid anything either). However, meat is not treated like vegetables: there is always the world market, or commodity market, that does pay something. It is true that meat gets downgraded, for example if there is oversupply for a certain (higher) quality, then a processing factory downgrades this to other available quality, or ultimately to commodity. In some of our model outcomes, farmers keep supplying to the dump market for a longer time. This would never happen in reality, experts assure us, because a farmer would rather quit farming if he received no money for his product than to let that happen again. For this reason we changed the dump market's name in our synthesis chapter to 'commodity market', but the model still pays them no revenue there.

Market shares could be more realistic

A majority of Dutch pork meat is produced for the commodity market; the other market segments are actually very small. Our model can accommodate this by giving realistic values to the market set that is defined at the start of the simulation. It would also make sense to limit the volume of certain markets.

Commodity market and 'level playing field'

Many experts referred to the fact that Dutch or European farmers need to comply with Dutch or European regulations that do not hold for farmers in other parts of the world, even if they produce for the commodity market (as the vast majority of Dutch pig farmers do). This means that there is no 'level playing field': famers need to meet criteria for which they receive the same price as farmers from other countries who were not restricted by these requirements. However, in terms of knowledge management, it may still pay off: if a farmer has more knowledge (needed to meet more criteria), he is most probably also a more efficient producer than the foreign farmer who did not need to have all this knowledge, so his production costs are lower. Dutch pig farmers are indeed known to be among the most efficient producers in Europe, second after the Danes (Hoste, 2013).

What happens to demand when a market closes

Another interesting question in relation with the graceful degradation policy intervention case of Chapter 7 is: what happens to demand if a market closes? Is there still a demand - but then, is that market really closed? In model terms, this is clear. With graceful degradation policy, when a market closes, only market entry closes, newcomers are not admitted. But those remaining on the market can stay - and receive a price, so implicitly this means that there is still demand. In reality, this is not so clear. Because there is always the world market: if a market closes and lowest quality is no longer available by the rules, 'somebody with demand for lowest quality' will turn to the world market to import it instead of be willing to pay a higher price to the few remaining suppliers.

This has similar implications for our Gini-bubble pattern, which emerges because farmers who remain on the lower market become temporarily very rich - since demand is still there but there are less competitors. Experts deemed it plausible that this happens, but not to the extent that these rich farmers' income visibly affects the Gini-coefficient. If the price would be that high in reality, all higher segment farmers would offer their meat to that market as well, no matter how high its quality (and the price would soon drop). In our model, that is not possible because we closed market entry.

From this respect: we might have tried to close the highest market instead of the lowest. This would have been a realistic scenario as well, because there is currently an entry barrier for the organic segment. Closing the highest market does not have the world market escape. Also, in reality, if a market closes, it is realistic to assume that demand changes accordingly, and that something should change about the price parameters as well.

Pork cycle model's assumptions

We did not discuss the pork cycle model with our experts. They did confirm that the pork cycle still exists, but that governmental interventions (like buying excessive supply and freezing it for a couple of years) have not happened in recent years, at least not in Europe. With respect to the assumptions of how the farmers behave in our pork cycle model (restock or not based on price expectation): in the Netherlands, it is no option to 'not restock' if you have a pig farm. In China this may still be possible - most famers have crops and pigs: if the pig price is high you purchase piglets and feed them the crops, and if not, you don't get the piglets and sell the crops.

9.4.3 Simulations and analyses

Model - sensitivity analysis and interaction effects

We applied local sensitivity analysis - using a commonly accepted method - in our case from Chapter 6. We simultaneously varied the two parameters responsible for increasing the quality of farmers' info-items (thr and kch). The others were one-at-a-time variations. One-at-a-time variation assumes that parameters are independent. Except for thr and kch, we did not include other interaction effects in our sensitivity analysis, effects that are the result from combined, not necessarily independent parameters.

It is, however, very plausible that there are indeed interaction effects present in our model. A few of our experts, those with a strong modelling background, also suggested this. To investigate this we could consider to perform global sensitivity analysis that also cover interaction effects. There are global sensitivity methods available that we could use, for example those including stratified methods such as Monte Carlo (Jansen et al., 1994), applied in (Burgers et al., 2010), or Latin hypercube simulation (Helton and Davis, 2003).

Multi-analysis: inter-run variability and outlier-inspection

In the synthesis chapter, we performed inter-run variation analysis and outlier analysis for the case of Chapter 5, but it turned out that there were no real outliers in that experiment. Also inter-run variation did not yield exciting results. So although the idea was appealing, there are no worthwhile results to report from this exercise, and we lacked the time to repeat this for another case that turned out to have actual outliers to inspect.

Multi-level analysis: why do farmers leave?

We did another kind of multi-level analysis that we did not report in the case chapters, addressing the question: Why would farmers leave a high market at some point? In our model, farmers can leave a market (1) because they see a better opportunity - price - elsewhere, and (2) because they no longer meet the requirements for their current market due to loss of info-items becoming obsolete. We were curious how many times these two situations occur. We analysed (manually) in one run how many times the first 10 farmers left the high segment for a lower market, and for what reason. It turned out that this happened 17 times voluntarily (reason 1), and 145 times forced (reason 2). Generalizing this would mean that farmers leave a high market because they no longer qualify in roughly 90% of the cases. In our model 'no longer qualifying' is apparently a strong driving mechanism to leave a high market.

9.5 Future work

The discussion section already contains several pointers for future work. In summary, our ideas include to extend info-items with an extra attribute which refers to the sender of the info-item. The value-change of that item for the receiver depends on how important its sender is - which can be derived from e.g. his number of connections or his performance.

Other ideas are to differentiate between information types and mechanisms by which they become obsolete. As experts indicated, we could apply this to certain types of information only: technical knowledge, which has a limited lifecycle, becomes obsolete, but managerial knowledge of basic activities remains. Another interesting idea is to let market criteria change dynamically instead of defining them once at the beginning of a simulation. Finally, to model an intervention of closing a high market instead of a low one could be a nice alternative to compare with what we already did.

In broader terms, we are thinking of extending the model in a social direction, to make it more interesting with respect to heterogeneity of agents: we could divide agents over groups and let agents' behaviour depend more on behaviour of members of their group. Behaving according to norms could be part of this group behaviour. Culturally embedded aspects could be translated into model parameters that allow for comparison between pig farmers' behaviour in various cultural contexts.

9.6 Plausibility and validation

We concluded for research question 2 that our model outcomes are plausible in some occasions, but we do not consider them validated. Is validity perhaps too strong a claim for middle-range agent-based models like ours, and is plausibility not sufficient? We argued earlier in this thesis that agent-based models are not suitable for making predictions, but suitable for exploring possibilities. Our reference discipline is information management, in a context of knowledge diffusion through a population. In this discipline, validation is not part of the research process at all. It is more common practice to explore a new method, and make plausible that this method can be of use. Seen in this tradition, we believe that our research fits in very well: by modelling the object of information management, the sector, we have already provided added value to what is common practice. Given the current state of development of our work, we cannot yet aim for validity. This is no problem, as long as we can see a route ahead of us that could lead there eventually. We see many possibilities to continue, as addressed in the Future Work sub-section, and we do believe that agent-based modelling is a method worth adding to the toolbox of the information management modeller.

An alternative approach for expert validation as a means to validate is to use role-play or gaming simulations, to strengthen the empirical basis of a model. Gilbert (2008) advocates that empirical validation is as important as sensitivity analysis. Meijer applied a chain-game to validate his work with real traders (not actors) in the mango supply chain (Meijer et al., 2009). This experience gave him valuable insight additional to the model and its behaviour.

Hommes (Hommes et al., 2008; Hommes, 2011) used a lab experiment to act out the pork cycle: participants had to forecast expected prices during 50 time periods. After each forecast, a computer model calculated the equilibrium price out of their forecasts, and gave this as feedback to the students (telling them that their forecast was 'too high' or 'too low'). The experiment showed that the equilibrium price can be influenced, for example it can be pushed up if the participants are given too much positive feedback. This results in a 'wrong' equilibrium price, which is likely to happen in economic reality as well - if feedback is provided by stakeholders (such as pension funds) who benefit from a higher equilibrium price. The experiment showed something else: the theory says that expectations should be independent, but this may not be the case in reality. Although participants in the experiment did not know what the others' forecasts were, their own line of forecasts was not independent - they did not switch forecasting strategies all the time but pursued certain forecasting strategies once they had used them before, and thus exhibited path dependency.

This implicit coordination between forecasts, together with the price-pushing effect of positive feedback, caused periodic oscillations such as in the pork cycle to occur.

Our own work could also include role-playing to find additional empirical insights to help us with model development. We could act out our final model with a group of participants who each have a collection of info-items that they can exchange under certain conditions, let them behave according to a set of rules, and see what unanticipated mechanisms might develop there.

9.7 Conclusion

In retrospect, this PhD thesis can best be characterized as a heuristic process. When we started out, the general goal was clear: to investigate what the possibilities are of agent-based modelling as a method in our knowledge management domain, and what we could learn from studying the multi-level aspect. What we would discover was not fixed from the beginning. We advanced case by case, not sure where this would lead, but making progress all the same. The current thesis adds coherence to those cases and articulates what we learned over the years, but it is not an end point. We can think of many ways how to continue the present line of cases - we feel we have only just begun.

To study the multiple levels in knowledge management is an ambitious aim. Our cases contribute to that aim as individual patches contribute to a quilted blanket. We investigated a collection of patterns, agents and mechanisms, giving colour to some of the patches. However, there are many uncoloured patches left. Nevertheless, we are positive about what our contribution yields. Epstein (2006) challenges agent-based modellers with his adage *grow it to show it*: we must consider the very fact that our models can reproduce behaviour simply 'according to expectation' an achievement in itself. That they also produce unexpected patterns which we can unravel in terms of individual behaviour gives added value. We expressed that value when we answered our research questions: in the context of knowledge management, agent-based models are suitable to investigate the relationship between system level and agent level and vice versa. They also allow for the representation of real-world cases. We recommend agent-based modelling as a method. We believe that continuing this line of research is promising for any discipline where complex adaptive systems are objects of study, of which knowledge management and information management are examples.

To illustrate that we are indeed talking about complex adaptive systems, we take a repeating example from our cases: that of obligatory group housing for breeding sows. This regulation became effective as of January 2013 and involves investments to the pigs' housing, but also requires changes in farmers' management style. Already during my mini-traineeship in 2007, I heard Dutch farmers being preoccupied with this new regulation. However, the first signs regarding this issue stem from much longer ago: my co-promotor Gert Jan Hofstede was already in 1984 studying "the deleterious effect of tethering breeding sows" (Cronin et al 1984). Apparently, a society needs 30 years before it is ready to adopt ideas that first entered the debate so long ago. The idea needs to develop, diffuse, and it requires a tipping point before it is adopted by society. Usually the regulation follows societal acceptance.

How generally applicable is our work? Our first model was of Chinese pig farmers, we then abstracted to Dutch pig farmers, and we claim that the final model is useful for other knowledge-rich supplier-market domains as well. We learned that Dutch pig farmers are specific in the sense that they are entrepreneurial, that there is a rich knowledge-infrastructure, and that they are individualists, but willing to learn from each other if that can make them better. Dutch society is also specific: in no other country is pressure on farmers due to demand from society to produce more animal- and environment-friendly as high a factor as in the Netherlands (Hoste, 2013). For future work, also culturally embedded aspects could be translated into model parameters that allow for comparison between pig farmers in various contexts (Hofstede et al., 2010a).

Returning to my choir analogy from the Introduction, I would like to refer to certain music where, at first sight, little seems to happen. I am thinking of the 90-minutes lasting meditative choral music *Kanon Pokajanen* by Arvo Pärt, and the non-choral *Canto Ostinato* by Simeon ten Holt. An unsuspecting listener might label this music at first as 'long lasting profound tones, sounding all alike' (Kanon Pokajanen) or 'just a lot of continuous thrumming on the piano' (Canto Ostinato). In contrast, somebody who is willing to sit down a while and immerge himself in this music, after some time discovers that even the slightest variations in harmony are able to cause an incredible effect. In the Canto Ostinato, these are the moments when harmony 'ends on its feet' in full splendour, which has a glorious impact upon the listener. In the Kanon Pokajanen, a long-awaited modulation, after a patient build-up, is experienced as a marvellous event when it finally occurs. As an expert in this field I can confirm various reportings of this effect, and I can add that the same experience is sensed by the singers themselves. In relation to this thesis: we compared our work to colouring patches of a quilt that still needs many more pieces before it becomes a sizeable blanket. However, the power of agent-based models is that seemingly unimportant changes over time can be the beginning of something more substantial than we could have imagined beforehand. Perhaps later, in hindsight, we appear to have been at the start of a new era: an era when agent-based modelling of complex adaptive systems belongs to the core activities of studying information management. We are eager to reach that tipping point.

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English summary

Complex adaptive systems research is concerned with studying *systems* (meaning: the whole thing, consisting of several parts) that are *adaptive* (they can adapt behaviour in response to a situation) and *complex* ('the whole is more than the sum of its parts'). Complex adaptive systems are characterized by *multiple levels* of behaviour: the behaviour of individual components and the behaviour of the entire system. In this thesis we study this relationship by means of *agent-based models*. By modelling individuals (agents) and their behaviour only, and simulating their behaviour over time, we generate *emerging* patterns: we did not explicitly put them in. We give our individual agents their rules of behaviour; we let the system create conditions in which the agents can operate; they act according to those rules and conditions; and together they create system-level patterns that we can study. We try to understand these patterns by reasoning back to individual level (multi-level analysis).

The objective of this thesis is to study what the complex adaptive systems domain of knowledge management at individual level implies for knowledge management at sector level, and vice versa. We explore this relationship by means of a series of agent-based modelling cases of situations where suppliers are matched with available markets. The objective is relevant in the sense that including a multi-level perspective in knowledge management (1) adds insight in the field of knowledge management, and (2) evaluates agent-based modelling as a candidate method for the toolbox available to knowledge management researchers. To address that second issue, we highlight methodological aspects of our research throughout the thesis to help us evaluate how suitable agent-based modelling as a method is to represent multi-level knowledge management.

Our notion of *knowledge management* combines elements from the academic fields of information management and knowledge management. We combine the technological 'data'-oriented meaning of information management and the behavioural notion of knowledge management, such as in knowledge sharing and learning. In this thesis, both the terms 'information management' and 'knowledge management' refer to the same. Knowledge management has not been studied before by means of agent-based modelling, as far as we know.

Knowledge is defined as everything a supplier needs to know to match the entrance criteria set by a market segment, as perceived by that supplier, and instrumental in his decision making process. We leave implicit that this required knowledge is of heterogeneous nature. It represents factual knowledge, e.g. regarding requirements with respect to the product itself and the manufacturing process of the product. It represents skills and know-how that require experience to build up. It represents personal capabilities. It represents constraints to a supplier's options, for example access to financial resources needed to invest. It represents the available 'action repertoire' that a supplier has at his disposal, enabled or constrained by factors beyond our concern. It also represents that the supplier knows how to operationalize this knowledge to behaviour. From our modelling perspective, our definition of knowledge assumes that all these issues are a joint concept. Throughout the thesis, the terms 'information' and 'knowledge' are used interchangeably, meaning the same thing.

All cases in our successive simulation studies are taken from the pig sector: we model pig farmers who take the decision of what quality market to supply their pigs to. To be able to decide which market to choose requires that the farmer has all relevant knowledge at his disposal, and that he has the flexibility and means to actually take that decision. During the simulation he is gathering that knowledge, receiving some, sharing some with other agents, which continuously changes his options spectrum. The farmers apply *bounded rationality* when they make a decision: instead of optimizing all alternatives to find the best one, they use a *satisficing* approach to find a market that fits their need and for which they qualify.

The secondary aim of this thesis is to pay attention to methodological issues. These include finding the balance between what to include in the model; how to represent it in such a way that it is still clear which results were caused by which behaviour; how to develop and extend such a model while ensuring that former model results are still comparable with new ones; how to handle results from multiple runs and the sensitivity of model parameters to those results; and validity issues, i.e. whether results have any relevance for the real world.

The thesis is set up in three parts. *Part I* concerns the general introduction, defining model concepts and posing the research questions (Chapter 1), and a chapter to introduce the methodology (Chapter 2). The pilot study (Chapter 3) also belongs here. *Part II* subsequently describes four cases (Chapters 4-7), each investigating a specific issue of our problem domain. *Part III* is the synthesis part. It starts with a synthesizing chapter (Chapter 8) that connects the last three cases with each other; better grounds them in literature; repeats the experiments more thoroughly; adds multi-level analysis; and performs expert validation. The last chapter is the general discussion (Chapter 9), answering the research questions, reflecting on the research in the discussion, and ending with a conclusion.

The **research questions**, each of them having two sub-questions, are:

1. What is the relationship between sector-level knowledge management measures (top-down), actions of individuals, and the system behaviour resulting

from these actions (bottom-up) in the context of a sector of autonomous suppliers, specifically applied to the case of pig farmers?

   a) What is the effect of agent-level variations with respect to knowledge management on total system behaviour?

   b) What is the effect of system-level interventions on agent behaviour and total system behaviour?

2. How suitable is agent-based modelling as a method for representing a real-world case of sectoral knowledge management?

   a) *Representation*: How well does the design of the agent-based model permit representing knowledge management and representing the multiple levels of the real-world case?

   b) *Validity*: Do the evaluated simulation results lead to increased understanding of the interdependence of emerging system behaviour and individual agent behaviour in the real-world case?

We further highlight each research question and present our results, starting with the sub-questions.

Sub-question 1a. *Agent-level variations* refer to experimenting with those agent attributes that make the population heterogeneous, and see what the effects are on system level (bottom-up). We applied this in the pilot study (Chapter 3) and three cases (Chapters 4, 5, and 6). We varied the amount and quality of information in the system, which directly affects knowledge management. We also varied network structures, which are a prerequisite for knowledge exchange (in those cases where that is an option). In general, we can say that, in all our models, system behaviour responds accordingly when agent-level properties are varied. We could let patterns emerge out of modelling individual behaviour only (pork cycle pattern, Chapter 4). More information leads to higher quality market shares, as long as there is a minimum number of network connections (Chapters 3, 5). Network typology appears to be of secondary importance (Chapter 5). Varying the quality of information leads to a tipping point in our model behaviour that we call the *boomerang effect* (named after the shape of its graph): increasing the quality a little is effective at first, but increasing it too much is deteriorating (Chapter 6). As for plausibility, experts confirm that more information and more network connections contribute to higher performance, and that these effects are more important for higher market segments. Experts do not recognize the boomerang effect: this is a model outcome that does not seem plausible in reality. They do acknowledge that increasing information quality may be efficient: leading to higher performance, resulting in higher quality market shares. However, only to some extent, and only for certain types of knowledge: technical knowledge, not managerial knowledge. The necessity of having some slack, i.e. seemingly worthless knowledge, is generally acknowledged.

Sub-question 1b. *Interventions at sector level* are changes from a top-down perspective that concern the sector as a whole. We applied these in three ways: changing demand volumes (pilot study Chapter 3); changing market requirements, essentially also a demand change (cases Chapters 5); and closing the lowest market by two different policies - one without and one with a transition period (case Chapter 7). We studied how our agents respond to these interventions. The results show that farmers adapt, choose different markets, and a new balance of market shares emerges. The new balance depends on the other parameter values. In an information-poor situation, farmers have limited options to make the move to higher quality markets; in information-rich situations, more farmers are able to do that. The policy experiment shows that the type of transition has no lasting effect on the outcome, which makes a farmer-friendlier alternative (with transition period) the preferred policy. When a policy with transition period is applied, we see an unexpected pattern emerge: a temporarily deviating wealth distribution (we refer to this pattern as the *Gini-bubble*). The fact that a new market balance appears after an intervention is deemed plausible by our experts, because this is indeed what happens in reality. Most experts can provide explanations for the Gini-bubble in the sense that they have seen farmers profiting during a transition period. Not all explanations they provide agree with our model. A plausible and concordant explanation is that farmers experience less competition on a market for which there is still demand, which results temporarily in a higher price.

Answer to research question 1. In conclusion, we can say that there is indeed a relationship between (top-down) sector level knowledge management measures and (bottom-up) actions of individuals. Both varying individual properties and varying system-level properties result in responsive behaviour that can be explained in model terms, and that is to some extent plausible in reality. Most interesting are the two cases where an unexpected pattern emerges: the boomerang and the Gini-bubble effect. Multi-level analysis (inspecting the pattern on individual agent level) gave an explanation in both cases. For the boomerang effect, this explanation is valid in model terms, but not plausible in reality. For the Gini-bubble, the explanation is valid in model terms as well as plausible in reality.

Sub-question 2a. Answering this question requires reviewing how knowledge management and the multiple levels were represented in the models of the successive cases. Representation of knowledge management comprises various elements that differ per model. All models succeed to some extent to represent knowledge management and multiple levels of a real world case. The focus of the pilot study model (Chapter 3) is on representing heterogeneity in individual behaviour, but does not easily allow multi-level inspection. The pork cycle model (Chapter 4) is implicit with respect to representation power but succeeds in letting a sector-level pattern emerge based on agent-level behaviour. The final model (Chapters 5-8) is richest in representing knowledge and best allows inspection of the relationship between sector and agent level.

Sub-question 2b. Validity and plausibility have been explicit issues in our synthesis chapter (Chapter 8), where we used expert validation to determine what our research outcomes mean to the real world. This question concentrates on the following issue. We can observe patterns in the real world, and *assume* a relationship between a particular pattern and associated actor behaviour (real world relationship). We can also observe patterns in our models, and *inspect* the relationship between a pattern and associated agent behaviour (model relationship), and present explanations for it. How *plausible* is the model relationship, and the explanation we provide, for the real world relationship, according to experts? And if it is plausible, how *valid* can we then call our model results? We draw the line at plausibility, and we do not conclude that our models are therefore validated.

Answer to research question 2. Representation power appears to differ per model. Dependent on the aim of the model, representation power can be kept deliberately modest (as in the pork cycle model), or can be rich (as in the final model with respect to representing different types of knowledge). We believe that representation power of agent-based models is sufficiently suitable to represent a real-world case, as long as the model has a well-defined purpose. As for validity, we have no guarantee that a plausible explanation for a pattern is indeed the explanation to make our model valid, and hence that the model is representative for the real world. Is validity perhaps too strong a claim for middle-range agent-based models like ours, and is plausibility not sufficient? Agent-based models are known to be not suitable for making predictions, but suitable for exploring possibilities. Our reference discipline is information management: in this discipline, validation is not part of the research process at all. It is common practice to explore a new method, and make plausible that this method can be of use. Seen in this tradition, we believe that our research fits in very well: by modelling the object of information management, the sector, we have already provided added value to what is common practice in our discipline.

Conclusion. We conclude that studying the multiple levels in knowledge management is an ambitious aim. Our cases contribute to that aim as individual patches contribute to a quilted blanket. We investigated a collection of patterns, agents and mechanisms. We gave colour to some of the patches, but there are many patches left uncoloured. Nevertheless, we are positive about what our contribution yielded. We recommend agent-based modelling as a method. We believe that continuing this line of research is promising for any discipline where complex adaptive systems are object of study, of which knowledge management and information management are examples. For future work, we intend to polish our knowledge and skills, and continue to expand. Possible directions of research include extending the model in more social directions: let agents' behaviour depend more on behaviour of members of their group (e.g. how norms could be part of this group behaviour). Also culturally embedded aspects could be translated into model parameters that allow for comparison between pig farmers' behaviour in various cultural contexts.

Nederlandse samenvatting

Onderzoek op het gebied van complex-adaptieve systemen (complex adaptive systems) houdt zich bezig met de studie van *systemen* ('het geheel' dat uit verschillende onderdelen bestaat) die *adaptief* zijn (ze kunnen hun gedrag aanpassen aan de situatie) en *complex* ('het geheel is meer dan de som der delen'). Complex adaptive systems kenmerken zich door gedrag op *meerdere niveaus (multiple levels)*: het gedrag van de individuele componenten en het gedrag van het systeem als geheel. In dit proefschrift bestuderen we deze relatie met behulp van *agent-gebaseerd (agent-based) modelleren*. Door alleen individuen (agenten) en hun gedrag te modelleren, en dit gedrag te simuleren als functie van de tijd, genereren we *emergente* patronen: we hebben ze er niet expliciet ingestopt. We geven onze individuele agenten hun gedragsregels, we laten het systeem bepaalde omstandigheden creëren waarbinnen de agenten hun gang kunnen gaan, de agenten gedragen zich volgens deze regels en binnen deze omstandigheden, en gezamenlijk creëren ze patronen op systeemniveau die wij kunnen bestuderen. Die patronen proberen we te begrijpen door terug te redeneren naar het niveau van het individu (multi-level analyse).

Het doel van dit proefschrift is te onderzoeken wat het individuele niveau van kennismanagement - een complex adaptive systems domein - betekent voor kennismanagement op sectorniveau, en vice versa. We werken deze relatie uit met behulp van een serie agent-gebaseerde modellen van gevalsstudies die betrekking hebben op situaties waarin toeleveranciers gekoppeld worden aan beschikbare markten. Het doel is relevant in de zin dat we door het aannemen van een multi-level perspectief in kennismanagement (1) inzicht kunnen toevoegen aan het vakgebied van kennismanagement, en (2) kunnen evalueren of agent-gebaseerd modelleren een geschikte methode is om toe te voegen aan de gereedschapskist van kennismanagement-onderzoekers. Vanwege dat laatste leggen we door het hele proefschrift heen de nadruk op methodologische aspecten van ons onderzoek, zodat we beter kunnen beoordelen hoe bruikbaar agent-gebaseerd modelleren is als methode voor het representeren van multi-level kennismanagement.

Onze invulling van het begrip *kennismanagement* combineert elementen van de academische disciplines informatiemanagement en kennismanagement. We combineren de technologische, 'data'-georiënteerde betekenis van informatiemanagement met het gedragsaspect van kennismanagement, zoals bij leren en het delen van kennis. In dit proefschrift verwijzen de termen 'informatiemanagement' en 'kennismanagement' naar hetzelfde. Kennismanagement is niet eerder bestudeerd met behulp van agent-gebaseerde modellen, voor zover wij weten.

Kennis wordt gedefinieerd als alles dat een toeleverancier moet weten om aan de entree-eisen te voldoen die een marktsegment stelt, in zijn eigen perceptie, en voor zover instrumenteel voor zijn beslisproces. We laten verder impliciet dat deze vereiste kennis heterogeen van aard is. De kennis omvat feitenkennis, zoals bijvoorbeeld criteria die over het product zelf of over het productieproces gaan. De kennis omvat daarnaast vaardigheden en know-how die groeien door ervaring. De kennis omvat ook capaciteiten die van persoon tot persoon verschillen. De kennis omvat bovendien de beperkingen die een toeleverancier ervaart, bijvoorbeeld omdat hij beperkte toegang heeft tot financiële middelen die nodig zijn om te investeren. De kennis omvat het 'actierepertoire' dat een toeleverancier ter beschikking heeft, gefaciliteerd of beperkt door factoren die voor ons onderzoek verder niet van belang zijn. De kennis omvat tevens de aanname dat de toeleverancier weet hoe hij deze kennis moet operationaliseren tot gedrag. Onze definitie van kennis, opgesteld vanuit een modelleerperspectief, veronderstelt dat al deze zaken hierin meegenomen zijn. In dit proefschrift worden de termen 'informatie' en 'kennis' door elkaar gebruikt, maar ze verwijzen allebei naar ditzelfde begrip.

Alle gevalsstudies voor onze serie simulaties komen uit de varkenssector: we modelleren varkensboeren die de beslissing moeten nemen aan welke kwaliteitsmarkt zij hun varkens willen leveren. Om te kunnen besluiten welke markt hij kiest moet de boer over alle relevante kennis beschikken, en de flexibiliteit en de middelen hebben om die beslissing ook daadwerkelijk te nemen. Gedurende de simulatie verzamelt hij deze kennis, ontvangt soms wat, wisselt wat met andere agenten uit, waardoor hij steeds andere mogelijkheden krijgt. De boeren passen *begrensde rationaliteit (bounded rationality)* toe bij hun beslisproces: in plaats van te optimaliseren en van alle alternatieven de beste te bepalen, stoppen ze met zoeken zodra ze een markt hebben gevonden die voldoet en waar ze voor in aanmerking komen (*satisficing*).

Een aanvullend doel van dit proefschrift is aandacht te besteden aan methodologische aspecten. Hiertoe behoort bijvoorbeeld het zoeken naar de balans tussen wat wel en wat niet mee te nemen in het model; hoe zaken op zo'n manier te representeren dat nog duidelijk is welke resultaten veroorzaakt worden door welk gedrag; hoe een model ontwikkeld en uitgebreid kan worden en tegelijkertijd te waarborgen dat eerdere modelresultaten nog te vergelijken zijn met nieuwe modelresultaten; hoe om te gaan met resultaten van meerdere runs en de gevoeligheid van modelparameters voor deze resultaten; en validiteitsissues, dat wil zeggen: de vraag welke relevantie de resultaten hebben voor de werkelijkheid.

Dit proefschrift is opgezet in drie delen. *Deel I* omvat de algemene introductie, waarin modelconcepten gedefinieerd worden en de onderzoeksvragen gesteld worden (Hoofdstuk 1), en een hoofdstuk om de methodologie te introduceren (Hoofdstuk 2). Het proefmodel (de pilot study) hoort hier ook thuis (Hoofdstuk 3). *Deel II* beschrijft achtereenvolgens vier gevalsstudies (Hoofdstukken 4-7), die elk ingaan op een specifiek aspect van ons probleemdomein. *Deel III* is de synthese. Het begint met een synthese-hoofdstuk (Hoofdstuk 8) dat de laatste drie gevalsstudies met elkaar verbindt, ze beter grondt in de literatuur, de experimenten op een degelijke manier herhaalt, multi-level analyse toevoegt en een expertvalidatie uitvoert. Het laatste hoofdstuk is de algemene discussie (Hoofdstuk 9) dat de onderzoeksvragen beantwoordt, reflecteert op het onderzoek in het discussie-gedeelte en eindigt met een conclusie.

De **onderzoeksvragen**, elk met twee deelvragen, zijn:

1. Wat is de relatie tussen kennismanagement-maatregelen op sectorniveau (top-down), handelingen van individuen en het systeemgedrag dat hiervan het resultaat is (bottom-up) in de context van een sector bestaande uit autonome toeleveranciers, specifiek toegepast op varkensboeren?

    a) Wat is het effect op het algehele systeemgedrag als er gevarieerd wordt op agentniveau met betrekking tot kennismanagement?

    b) Wat is het effect op agentgedrag en algeheel systeemgedrag van interventies op systeemniveau ?

2. Hoe geschikt is agent-gebaseerd modelleren als methode om een situatie uit de werkelijkheid te representeren met betrekking tot kennismanagement in een sector?

    a) *Representatie*: Hoe gemakkelijk laat het ontwerp van een agent-gebaseerd model het toe om het kennismanagement en de meerdere niveaus van de situatie uit de werkelijkheid te representeren?

    b) *Validiteit*: Leveren de geëvalueerde simulatieresultaten een beter begrip op van de onderlinge afhankelijkheid tussen emergent systeemgedrag en individueel agentgedrag in de context van de situatie uit de werkelijkheid?

We lichten nu iedere onderzoeksvraag toe en presenteren onze resultaten, te beginnen met de deelvragen.

Deelvraag 1a. Met *variaties op agentniveau* experimenteren we met eigenschappen van agenten die de populatie heterogeen maken, en kijken we wat de effecten daarvan zijn op systeemniveau (bottom-up). We hebben dit gedaan in de pilot study (Hoofdstuk 3) en drie gevalsstudies (Hoofdstukken 4, 5 en 6). We varieerden de hoeveelheid en de kwaliteit van informatie in het systeem, wat direct invloed heeft op kennismanagement. We varieerden ook de netwerkstructuren tussen agenten, een voorwaarde voor kennisuitwisseling (in die situaties waarin dat gebeurt). Over het algemeen kunnen we zeggen dat het systeemgedrag in al onze modellen volgens verwachting reageerde op de variaties op agentniveau. We kunnen patronen laten ontstaan door alleen het individuele gedrag te modelleren (het varkenscyclus-patroon, Hoofdstuk 4). Meer informatie leidt tot een groter marktaandeel van de hogere kwaliteitsmarkten, als er tenminste een minimaal aantal netwerkverbindingen is (Hoofdstukken 3, 5). Netwerktopologie lijkt van ondergeschikt belang te zijn (Hoofdstuk 5). Variëren met de kwaliteit van informatie leidt tot een omslagpunt (tipping point) in ons modelgedrag dat we het *boomerang-effect* noemen (naar de vorm van de grafiek): een kwaliteitstoename is aanvankelijk effectief, maar als de kwaliteit te hoog wordt verslechtert de situatie weer (Hoofdstuk 6). Wat de aannemelijkheid (plausibiliteit) hiervan betreft, experts bevestigen dat meer informatie en meer netwerkverbindingen leiden tot betere prestaties, en dat dit met name belangrijk is voor de hogere marktsegmenten. Experts herkennen het boomerang effect niet: dit is een modeluitkomst die niet plausibel lijkt te zijn in de werkelijkheid. Ze erkennen wel dat het efficiënt kan zijn de kwaliteit van informatie te verhogen: dit leidt tot betere prestaties en daarmee tot een groter marktaandeel van de hogere kwaliteitsmarkten. Echter, slechts in beperkte mate, en alleen voor een bepaald type kennis: technische kennis, geen managementkennis. De noodzaak voor enige speling (slack), ofwel ogenschijnlijk laaggewaardeerde kennis, wordt algemeen erkend.

Deelvraag 1b. *Interventies op sectorniveau* zijn veranderingen die de hele sector betreffen, gestuurd vanuit een top-down perspectief. Wij deden dit op drie manieren: door het volume van de vraag te veranderen (pilot study Hoofdstuk 3); door de eisen te veranderen die markten stellen, wat in feite ook een verandering in de vraag is (gevalsstudies Hoofdstuk 5); en door de laagste markt te sluiten volgens twee verschillende beleidsalternatieven - één met en één zonder overgangsperiode (gevalsstudie Hoofdstuk 7). We bestudeerden hoe onze agenten reageerden op deze interventies. De resultaten laten zien dat boeren zich aanpassen, andere markten kiezen, en dat er een nieuwe balans in marktaandelen ontstaat. Deze nieuwe balans hangt af van de andere parameterwaarden in het model. In een informatie-arme situatie hebben boeren maar beperkte mogelijkheden om de overgang naar een hogere kwaliteitsmarkt te maken; in informatie-rijke situaties zijn meer boeren daartoe in staat. Het beleidsexperiment laat zien dat de aard van de transitie geen blijvend effect heeft op de uitkomst, zodat het boervriendelijke beleidsalternatief (met overgangsperiode) de voorkeur verdient. Als er een beleid met overgangsperiode wordt gehanteerd zien we een onverwacht patroon optreden: een tijdelijk afwijking in inkomensverdeling (we noemen dit patroon de *Gini-bubbel*). Dat er een verschuiving in markten optreedt na een interventie vinden onze experts plausibel, want dit gebeurt in werkelijkheid ook. De meeste experts kunnen een verklaring geven voor de Gini-bubbel in de zin dat ze sommige boeren wel hebben zien profiteren gedurende een overgangsperiode. Niet alle verklaringen die ze geven zijn in overeenstemming met ons model. Een plausibele verklaring die ook overeenkomt met het model is dat boeren minder concurrentie hebben op een markt waar nog steeds vraag naar is, wat hen een tijdelijk prijsvoordeel oplevert.

Antwoord op onderzoeksvraag 1. Concluderend kunnen we zeggen dat er inderdaad een relatie is tussen kennismanagement-maatregelen op sectorniveau (top-down) en handelingen van individuen (bottom-up). Zowel het variëren met eigenschappen op individueel niveau als het variëren met eigenschappen op systeemniveau levert reactief gedrag op dat we kunnen verklaren in termen van ons model, en dat ook in zekere mate plausibel is voor de werkelijkheid. Het interessantst zijn de twee gevalsstudies waar een onverwacht patroon ontstaat: het boomerang-effect en de Gini-bubbel. Multi-level analyse (inspectie van dit patroon op individueel agentniveau) leverde een verklaring op voor beide gevallen. Voor het boomerang-effect is deze verklaring wel geldig in termen van het model, maar niet plausibel voor de werkelijkheid. Voor de Gini-bubbel is de verklaring zowel geldig in termen van het model als ook plausibel in werkelijkheid.

Deelvraag 2a. Om deze vraag te beantwoorden moeten we eerst nagaan hoe kennismanagement en de beide niveaus gerepresenteerd worden in onze modellen van de opeenvolgende gevalsstudies. Kennismanagement omvat veel zaken die per model op een verschillende manier gerepresenteerd worden. Alle modellen slagen er in zekere mate in om het kennismanagement en de beide niveaus van de gevalsstudie uit de werkelijkheid te representeren. De focus van het pilot study model (Hoofdstuk 3) ligt op de representatie van heterogeniteit in individueel gedrag, maar multi-level inspectie is hier niet eenvoudig. Het varkenscyclusmodel (Hoofdstuk 4) is vrij impliciet wat representatiekracht betreft, maar het kan wel een patroon op sectorniveau laten ontstaan dat gebaseerd is op gedrag op agentniveau. Het laatste model (dat van Hoofdstukken 5, 6, 7 en 8) is het rijkst qua kennisrepresentatie en is ook het krachtigst als het erom gaat de relatie tussen sector- en agentniveau te kunnen inspecteren.

Deelvraag 2b. Validiteit en plausibiliteit zijn nadrukkelijk onderwerp van onderzoek geweest in ons synthese-hoofdstuk (Hoofdstuk 8), waarbij we expertvalidatie gebruikten om te bepalen wat onze onderzoeksuitkomsten betekenen voor de werkelijkheid. Deze vraag draait om het volgende. We observeren patronen in de werkelijkheid en we *nemen aan* dat er een relatie bestaat tussen een bepaald patroon en bepaald actorgedrag (de relatie in werkelijkheid). We kunnen ook in onze modellen patronen observeren, en de relatie tussen het patroon en bijbehorend actorgedrag *inspecteren* (de modelrelatie). Hoe *plausibel* is de modelrelatie, en de verklaring die we daarvoor geven, voor de relatie in werkelijkheid, naar het oordeel van experts? En als deze plausibel is, hoe *valide* kunnen we onze modelresultaten dan noemen? Wij trekken de lijn bij plausibiliteit, en we concluderen niet dat onze modellen daarom ook gevalideerd zijn.

Antwoord op onderzoeksvraag 2. Representatiekracht blijkt te verschillen per model. Afhankelijk van het doel van het model kan deze representatiekracht bewust beperkt gehouden worden (zoals in het varkenscyclusmodel), of rijk (zoals in het laatste model waarin verschillende typen kennis gerepresenteerd kunnen worden). Wij geloven dat de representatiekracht van agent-gebaseerde modellen voldoende toereikend is om een gevalsstudie uit de werkelijkheid te kunnen representeren, zolang het model een welomschreven doel heeft. Wat validiteit betreft, we hebben geen garantie dat een plausibele verklaring voor een patroon ook inderdaad de verklaring is die ons model valide maakt, waardoor ons model representatief wordt voor de werkelijkheid. Is validiteit misschien een te sterke claim voor middle-range ('middengebied-') modellen zoals de onze, en is plausibiliteit niet voldoende? Agent-gebaseerde modellen staan erom bekend dat ze niet geschikt zijn om er voorspellingen mee te doen, maar wel geschikt om verschillende mogelijkheden te verkennen. Onze referentie-discipline is informatiemanagement: in dit vakgebied is validiteit überhaupt geen onderdeel van het onderzoeksproces. Het is gebruikelijk een nieuwe methode te verkennen, en aannemelijk te maken dat deze methode bruikbaar kan zijn. In dit licht bezien geloven wij dat ons onderzoek heel toepasselijk is: door het object van informatiemanagement te modelleren, namelijk de sector, voegen we al waarde toe aan wat gebruikelijk is in ons vakgebied.

Conclusie. We concluderen dat het bestuderen van meerdere niveaus van kennismanagement een ambitieus doel is. Onze gevalsstudies dragen bij aan dit doel zoals individuele lapjes bijdragen aan een quilt-deken. We hebben een verzameling patronen, agenten en mechanismen bestudeerd. Daarmee hebben we sommige vakjes van de quilt kleur gegeven, maar er zijn nog veel open vakjes over. Niettemin zijn we positief over wat we hebben kunnen bijdragen. We raden agent-gebaseerd modelleren als methode aan. We geloven in het voortzetten van deze onderzoekslijn, die wat ons betreft veelbelovend is voor iedere discipline waarin complex adaptive systems object van studie zijn, zoals kennismanagement en informatiemanagement. Voor de toekomst zijn we van plan onze kennis en vaardigheden verder te verfijnen, en gaan we door met ons te ontplooien. Voor mogelijk verder onderzoek denken we aan het uitbreiden van ons model in de richting van sociaal gedrag: laat het gedrag van agenten meer afhangen van het gedrag van de leden van de groep waartoe ze behoren (normen zouden bijvoorbeeld onderdeel kunnen zijn van dit groepsgedrag). Ook cultuurgebonden aspecten zouden vertaald kunnen worden in modelparameters die het mogelijk maken het gedrag van varkensboeren in verschillende culturele contexten met elkaar te vergelijken.

Fryske gearfetting

Yn dit proefskrift giet it oer kompleks-adaptive systemen. In systeem (gehiel fan komponinten, gearstald en oardere neffens in beskaat begjinsel) is adaptyf as de komponinten harren gedrach oanpasse kinne oan feroarjende omstannichheden. We neamme it kompleks as it gedrach fan it gehiel net itselde is as dat fan de som fan de dielen. Skaaimerkjend foar kompleks-adaptive systemen is dit gedrach op ferskate nivo's (multiple levels, dat fan de yndividuele komponinten en dat fan it gehiel). Yn dit proefskrift bestudearje wy de gedrachsrelaasje tusken dizze nivo's mei help fan *agint-basearre modellearjen*. Troch allinnich yndividuen (aginten) en harren gedrach te modellearjen, en dit gedrach te simulearjen as funksje fan'e tiid, generearje wy patroanen dy't *ermergere*, dat wol sizze: út harren sels ûntstean (wy hawwe se der net eksplisyt yn treaun). Wy jouwe ús yndividuele aginten harren gedrachsrigels en litte it systeem beskate omstannichheden kreëarje. Sa ûntstiet der in beheinde romte, dêr't de aginten harren yn gedrage neffens de foarskreaune rigels en omstannichheden, en mei-inoar soargje hja foar patroanen op systeemnivo dy't wy bestudearje kinne. Wy besykjen dy patroanen te begripen troch werom te redenearjen nei it nivo fan it yndividu.

It doel fan dit proefskrift is by it kompleks-adaptive systeem 'kennismanagement' te ûndersykjen wat it yndividuele nivo dêrfan betsjut foar dat op sektornivo, en oarsom. Wy wurkje dizze relaasje út mei help fan in searje agint-basearre modellen fan gefalsstúdzjes dy't situaasjes oanbelangje wêryn taleveransiers keppele wurde oan beskikbere merken. It doel is relevant yn de sin dat wy troch it oannimmen fan in multi-level perspektyf yn kennismanagement (1) ynsjoch tafoegje kinne oan it fakgebiet fan kennismanagement, en (2) evaluearje kinne oft agint-basearre modellearjen in gaadlike metoade is om ta te foegjen oan de arkkiste fan kennismanagement-ûndersykers. Fanwege dat lêste lizze wy troch it hiele proefskrift hinne de klam op metodologyske aspekten fan ús ûndersyk, sadat wy better beoardielje kinne hoe brûksum agint-basearre modellearjen as metoade is foar it represintearjen fan multi-level kennismanagement.

Ús betsjutting fan it begryp kennismanagement kombinearet eleminten fan de akademyske dissiplines ynformaasjemanagement en kennismanagement. Wy kombinearje de technologyske, 'data'-oriïntearre betsjutting fan ynformaasjemanagement mei it gedragsaspekt fan *kennismanagement*, lykas by leare en it dielen fan kennis. Yn dit proefskrift ferwize de termen 'ynformaasjemanagement' en 'kennismanagement' nei itselde. Kennismanagement hat net earder bestudearre west mei help fan agint-basearre modellen, foar safier't wy witte.

Kennis wurdt definiearre as alles dat in taleveransier witte moat om oan de yntree-easken te foldwaan dy't in merksegmint stelt, yn syn eigen persepsje, en foar safier ynstrumentiel foar syn beslútproses. Wy litte fierder ymplisyt dat dizze fereaske kennis heterogeen fan aard is. De kennis omfettet feitekennis, lykas bygelyks kritearia dy't it produkt sels of it produksjeproses oanbelangje. De kennis omfettet dêrnjonken feardichheden en knowhow dy't groeie troch ûnderfining. De kennis omfettet ek kapasiteiten dy't fan persoan ta persoan ferskille. De kennis omfettet boppedat de beheiningen dy't in taleveransier ûnderfynt, bygelyks om't hy beheinde tagong hat ta finansjele middels dy't nedich binne om te ynvestearjen. De kennis omfettet it 'aksjerepertoire' dat in taleveransier ta syn foldwaan hat, mooglik makke of beheind troch faktoaren dy't foar ús ûndersyk fierder net fan belang binne. De kennis omfettet ek de ferûnderstelling dat de taleveransier wit hoe't hy dizze kennis ta gedrach operasjonalisearje moat. Ús definysje fan kennis, opsteld fanút in modelleardersperspektyf, ferûnderstelt dat al dizze saken hjiryn meinommen binne. Yn dit proefskrift wurde de termen 'ynformaasje' en 'kennis' troch inoar brûkt, mar hja ferwize allebeide nei ditselde begryp.

Alle gefalsstúdzjes foar ús searje simulaasjes komme út de bargesektor: wy modellearje bargeboeren dy't it beslút nimme moatte oan hokker kwaliteitsmerk sy har bargen leverje wolle. Om beslúte te kinnen hokker merk hy kieze sil moat de boer oer alle relevante kennis beskikke, en de fleksibiliteit en de middels hawwe om it beslút ek feitlik te nimmen. Ûnder de simulaasje sammelt er dizze kennis, kriget er soms wat, wikselt er wat mei oare aginten út, wêrtroch 't er hieltyd oare mooglikheden kriget. De boeren passe *begrinzge rationalisaasje* ta yn harren beslisproses: yn plak fan te optimalisearjen en fan alle alternativen it bêste út te finen, stopje hja mei sykjen sagau't hja in merk fûn hawwe dy't foldocht en dêr't hja foar yn oanmerking komme (*satisficing*).

In oanfoljend doel fan dit proefskrift is oandacht te besteegjen oan metodologyske aspekten. Hjirta heart bygelyks it sykjen nei de balâns tusken wat men al en wat net meinimt yn it model. En hoe represintearet men saken op sa'n manier dat noch dúdlik is hokker resultaten feroarsake wurde troch hokker gedrach? Hoe kin in model ûntwikkele en útwreide wurde en hoe jout men dêr tagelyk de garânsje by dat eardere modelresultaten noch te fergelykjen binne mei nije? Hoe giet men om mei resultaten fan ferskate runs en de gefoeligens fan modelparameters foar dizze resultaten? Hoe behannelt men de fraach hokker relevânsje modelresultaten hawwe foar de wurklikheid (falidens)?

Dit proefskrift is opset yn trije parten. *Part I* begjint mei in algemiene yntroduksje, dêr't modelkonsepten yn definiearre wurde en de ûndersyksfragen yn steld wurde (Haadstik 1), en in yntroduksje fan de metodology (Haadstik 2). De proefstúdzje heart hjir ek thús (Haadstik 3). *Part II* beskriuwt efterinoar fjouwer gefalsstúdzjes (Haadstikken 4-7), dy't elk yngean op in spesifyk aspekt fan ús probleemgebiet. *Part III* is de synteze. It begjint mei in synteze-haadstik

(Haadstik 8) dat de lêste trije gefalsstúdzjes mei-inoar ferbynt, se better grûndearet yn 'e literatuer, de eksperiminten op in deugdlike manier werhellet, multilevel analyse tafoeget en in ekspertfalidaasje útfiert. It lêste haadstik, de algemiene diskusje (Haadstik 9), jout antwurden op de ûndersyksfragen, refleksjes op it ûndersyk yn it diskusje-part en einiget mei in konklúzje.

De **ûndersyksfragen**, elk mei twa dielfragen, binne:

1. Wat is de relaasje tusken kennismanagement-maatregels op sektornivo (top-down), hannelingen fan yndividuen en it systeemgedrach dat hjirfan it resultaat is (bottom-up) yn de kontekst fan in sektor besteande út autonome taleveransiers, spesifyk tapast op bargeboeren?
   a) Wat is it effekt op it systeemgedrach (as gehiel), wat kennismanagement oanbelanget, as der fariearre wurdt op agintnivo?
   b) Wat is it effekt fan yntervinsjes op systeemnivo op agintgedrach en systeemgedrach as gehiel?
2. Hoe gaadlik is agint-basearre modellearjen as metoade om in situaasje út de wurklikheid te represintearjen, wat kennismanagement yn in sektor oanbelanget?
   a) *Represintaasje*: Hoe linich giet it ûntwerp fan in agint-basearre model om mei it represintearjen fan kennismanagement en de ferskate nivo's fan de situaasje út de wurklikheid?
   b) *Falidens*: Leverje de evaluearre simulaasjeresultaten in better begryp op fan 'e ûnderlinge ôfhinklikens tusken systeemgedrach dat ûntstiet en yndividueel agintgedrach, yn de kontekst fan 'e situaasje út de wurklikheid?

Wy ljochtsje no elke ûndersyksfraach ta en presintearje ús resultaten, te begjinnen mei de dielfragen.

Dielfraach 1a. Mei *fariaasjes op agintnivo* eksperimintearje wy mei eigenskippen fan aginten dy't de populaaasje heterogeen meitsje, en sjogge wy wat de effekten dêrfan binne op systeemnivo (bottom-up). Wy hawwe dit dien yn de proefstúdzje (Haadstik 3) en trije gefalsstúdzjes (Haadstikken 4, 5 en 6). Wy fariearren de mannichte en de kwaliteit fan ynformaasje yn it systeem, wat direkt ynfloed hat op kennismanagement. Wy fariearren ek de netwurkstruktueren tusken aginten, in betingst foar kennisútwikseling (yn dy situaasjes dêr't dat bart). Oer it algemien kinne wy sizze dat it systeemgedrach yn al ús modellen neffens ferwachting reagearre op de fariaasjes op agintnivo. Wy kinne patroanen ûntstean litte troch allinnich it yndividuele gedrach te modellearjen (it bargesyklus-patroan, Haadstik 4). Mear ynformaasje liedt ta in grutter merkoandiel fan de hegere kwaliteitsmerken, as der teminsten in minimum oantal netwurkferbiningen is (Haadstikken 3, 5). Netwurktopology liket fan minder wichtich belang te wêzen (Haadstik 5). Fariearje mei de kwaliteit fan ynformaasje liedt ta in omslachpunt (tipping point) yn ús modelgedrach dat wy it *boomerang-effekt* neame (nei de foarm fan de grafyk): in kwaliteitstanimming is yn it begjin effektyf, mar as de kwaliteit te heech wurdt, wurdt de situaasje wer minder (Haadstik 6). Wat de oannimlikens (plausibiliteit) hjirfan oanbelanget, eksperts befêstigje dat mear ynformaasje en mear netwurkferbiningen liede ta bettere prestaasjes, en dat dit benammen wichtich is foar de hegere merksegminten. Eksperts kinne it boomerang effekt net teplak bringe: dit is in modelútkomst dy't net oannimlik liket te wêzen yn de wurklikheid. Hja wolle der wol oan dat it effisjint wêze kin de kwaliteit fan ynformaasje te ferheegjen: dit jout bettere prestaasjes en dêrmei in grutter merkoandiel fan de hegere kwaliteitsmerken. It giet lykwols mar yn beskate mjitte op, en inkeld foar in beskaat type kennis: technyske kennis, gjin managementkennis. De needsaak foar wat sinterske kennis (slack), oftewol kennis dy't sa op it earste each neat wurdich is, wurdt algemien erkend.

Dielfraach 1b. *Yntervinsjes op sektornivo* binne feroaringen dy't de hiele sektor oanbelangje, stjoerd fanút in top-down perspektyf. Wy diene dit op trije manieren: troch it folume fan de fraach te feroarjen (proefstúdzje Haadstik 3); troch de easken dy't merken stelle te feroarjen, wat feitlik ek in feroaring yn'e fraach is (gefalsstúdzjes Haadstik 5); en troch de leechste merk te sluten neffens twa ferskillende beliedsalternativen - ien mei en ien sûnder oergongsperioade (gefalsstúdzje Haadstik 7). Wy bestudearren hoe't ús aginten reagearren op dizze yntervinsjes. De resultaten litte sjen dat boeren har oanpasse, oare merken kieze, en dat der in nije balâns yn merkoandielen ûntstiet. Dizze nije balâns hinget ôf fan de oare parameterwearden. Yn in ynformaasje-earme situaasje hawwe boeren mar beheinde mooglikheden om de oergong nei in hegere kwaliteitsmerk te meitsjen. Yn ynformaasje-rike situaasjes binne mear boeren dêrta by machte. It beliedseksperimint lit sjen dat de aard fan de transysje gjin bliuwend effekt hat op de útkomst, sadat it boerfreonlike beliedsalternatief (mei oergongsperioade) de foarkar fertsjinnet. As der in belied mei oergongsperioade brûkt wurdt sjogge wy dat'er in ûnferwachte patroan ferskynt: in tydlike ôfwiking yn ynkommensferdieling (wy neame dit patroan de *Gini-bubbel*). Ús eksperts wolle der wol oan dat der him in ferskowing yn merken foardocht nei in yntervinsje, want dit bart yn wurklikheid ek. De measte eksperts kinne wol in ferklearring jaan foar de Gini-bubbel yn de sin dat hja wol sjoen hawwe dat guon boeren profitearje tidens in oergongsperioade. Lykwols binne net alle ferklearringen dy't hja joue binne yn oerienstimming mei ús model. In oannimlike ferklearring dy't ek strykt mei it model is dat boeren minder konkurrinsje hawwe op in merk wêr't noch hieltyd fraach nei is, wat harren in tydlik priisfoardiel opleveret.

Antwurd op ûndersyksfraach 1. Konkludearjend kinne wy sizze dat der yndie in relaasje is tusken kennismanagement-maatregels op sektornivo (top-down) en hannelingen fan yndividuen (bottom-up). Sawol it fariearjen mei eigenskippen op yndividueel nivo as it fariearjen mei eigenskippen op systeemnivo leveret reaktyf gedrach op dat wy ferklearje kinne yn termen fan ús model, en dat ek yn beskate mjitte oannimlik is foar de wurklikheid. It nijsgjirrichst binne de twa gefalsstúdzjes wêr't in ûnferwachte patroan efter wei komt: it boomerang-effekt en de Gini-bubbel. Multi-level analyse (ynspeksje fan dit patroan op yndividueel agintnivo) levere in ferklearring op foar beide gefallen. Foar it boomerang-effekt is dizze ferklearring wol jildich yn termen fan it model, mar net oannimlik foar de wurklikheid. Foar de Gini-bubbel is de ferklearring likegoed jildich yn termen fan it model as oannimlik yn'e wurklikheid.

Dielfraach 2a. Om dizze fraach te beantwurdzjen moatte wy earst neigean hoe't kennismanagement en de beide nivo's represintearre wurde yn ús modellen fan de opinoar folgjende gefalsstúdzjes. Kennismanagement omfettet in protte saken dy't yn ús modellen op ferskate wize werjûn wurde. Alle modellen slagje der yn beskate mjitte yn om it kennismanagement en de beide nivo's fan de gefalsstúdzje út de wurklikheid te represintearjen. De fokus fan it proefstúdzje-model (Haadstik 3) leit op de werjefte fan heterogeniteit yn yndividueel gedrach, mar multi-level ynspeksje is hjir net ienfâldich. It bargesyklusmodel (Haadstik 4) is frijwat ymplisyt wat represintaasjekrêft oanbelanget, mar it kin wol in patroan op sektornivo ûntstean litte dat basearre is op gedrach op agintnivo. It lêste model (dat fan'e Haadstikken 5, 6, 7 en 8) is it rykst kwa kennisrepresintaasje en is ek it krêftichst as it derom giet de relaasje tusken sektor- en agintnivo ynspektearje te kinnen.

Dielfraach 2b. Falidens en oannimlikens ha mei klam ûnderwerp fan ûndersyk west yn ús synteze-haadstik (Haadstik 8), dêr't wy ekspertfalidaasje by brûkten om út te finen wat ús ûndersyksútkomsten betsjutte foar de wurklikheid. Dizze fraach komt del op it folgjende. Wy beskôgje patroanen yn de wurklikheid en wy nimme oan dat der in relaasje bestiet tusken in beskaat patroan en beskaat aktorgedrach (de relaasje yn wurklikheid). Wy kinne ek yn ús modellen patroanen beskôgje, en de relaasje tusken it patroan en it bijhearrend aktorgedrach ynspektearje (de modelrelaasje). Hoe oannimlik is de modelrelaasje, en de ferklearring dy't wy dêrfoar jouwe, foar de relaasje yn wurklikheid, neffens eksperts? En as dizze relaasje oannimlik is, hoe falide kinne wy ús modelresultaten dan achtsje? Wy lûke de line by oannimlikens en konkludearje net dat ús modellen dêrom ek falide binne.

Antwurd op ûndersyksfraach 2. Represintaasjekrêft blykt yn de modellen te ferskillen. Ôfhinklik fan it doel fan it model kin dizze represintaasjekrêft bewust lyts hâlden wurde (lykas yn it bargesyklusmodel), of ryk wêze (lykas yn it lêste model wêr't ferskate typen kennis representearre wurde kinne). Wy leauwe dat de represintaasjekrêft fan agint-basearre modellen foldwaande tarikkend is om in gefalsstúdzje út de wurklikheid represintearje te kinnen, salang't it model in krekt omskreaun doel hat. Wat falidens oanbelanget hawwe wy gjin garânsje dat in oannimlike ferklearring foar in patroan ek yndie de ferklearring is dy't ús model falide makket, wêrtroch ús model represintatief wurdt foar de wurklikheid. Is falidens faaks in te mânske claim foar middle-range ('middengebiet') modellen lykas uzes, en is oannimlikens net genôch? Agint-basearre modellen steane derom bekend dat se net gaadlik binne om der foarsizzingen mei te dwaan, mar wol gaadlik om ferskate mooglikheden te ferkennen. Ús referinsje-dissipline is ynformaasjemanagement: yn dit fakgebiet is falidens alhiel gjin ûnderdiel fan it ûndersyksproses. Dêrfoaroer is it wenstich in nije metoade te ferkennen, en oannimlik te meitsjen dat dizze metoade gaadlik wêze kin. Yn dit ljocht besjoen leauwe wy dat ús ûndersyk tige tapaslik is: troch it objekt fan ynformaasjemanagement te modellearjen, nammentlik de sektor, foegje wy al wearde ta oan wat wenstich is yn ús fakgebiet.

Konklúzje. Wy koncludearje dat it bestudearjen fan ferskate nivo's fan kennismanagement in ambisjeus doel is. Ús gefalsstúdzjes drage by oan dit doel lykas yndividuele lapkes bydrage oan in quilt-tekken. Wy hawwe in samling patroanen, aginten en meganismen bestudearre, dêr't wy in stikmannich fakjes fan de quilt kleur mei jûn hawwe, mar der binne noch withoefolle iepen fakjes oer. Lykwols binne wy posityf oer wat wy bydrage kinnen hawwe. Wy riede agint-basearre modellearjen as metoade oan. Wy leauwe yn it fuortsetten fan dizze ûndersyksline, dy't neffens ús gâns ûnthjittend is foar elke dissipline dêr't kompleks-adaptive systemen objekt fan stúdzje binne, lykas kennismanagement en ynformaasjemanagement. Foar de takomst binne wy fan doel ús kennis en feardigens fierder oan te skerpjen, en sille wy trochgean ús te ûntwikkeljen. Foar mooglik fierder ûndersyk tinke wy oan it útwreidzjen fan ús model de kant op fan sosjaal gedrach: lit it gedrach fan aginten mear ôfhingje fan it gedrach fan'e leden fan'e groep wêrta't hja hearre (noarmen soene bygelyks ûnderdiel wêze kinne fan dit groepsgedrach). Ek kultuerbûne aspekten soene oerset wurde kinne yn modelparameters dy't it mooglik meitsje it gedrach fan bargeboeren yn ferskate kulturele konteksten mei elkoar te fergelykjen.

Preface to Acknowledgements

Op een ochtend schreef de eekhoorn een brief aan de mier.

Beste mier,
Ik wil je iets zeggen, maar ik denk dat ik het beter kan schrijven. Daarom schrijf ik je.
Maar misschien kan ik het je toch beter zeggen.
Eekhoorn.

De wind blies de brief naar de mier. Het was een mooie dag en niet lang daarna stapte de mier de kamer van de eekhoorn in.

'Hallo eekhoorn,' zei hij.

'Hallo mier,' zei de eekhoorn en wreef zich in zijn handen.

[...]

In de verte zong een lijster. De zon scheen door het open raam.

Ten slotte schraapte de mier zijn keel en vroeg: 'Wat wil je mij eigenlijk zeggen?'

De eekhoorn dacht diep na, keek naar de vloer en naar het plafond, zuchtte diep en zei: 'Ik denk dat ik je dat beter kan schrijven.'

'Dat is goed,' zei de mier.

*O*NE MORNING THE SQUIRREL WROTE THE ANT A LETTER.

Dear ant,

I have something to say to you, but I think it's probably better if I write it down. So that's why I am writing this letter.

Then again, maybe it would be better to tell you in person after all.

Squirrel.

The wind blew the letter to the ant. It was a beautiful day and before long the ant was at the squirrel's door.

'Hello squirrel,' he said.

'Hello ant,' said the squirrel, rubbing his hands.

[...]

Far away a thrush was singing. Sunlight streamed in through the open window.

Finally, the ant cleared his throat and asked: 'What was it you wanted to say to me?'

The squirrel pondered for a while, studied the floor and the ceiling, heaved a sigh and said: 'I think it would be better to put it in a letter.'

'That's alright,' said the ant.

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Taking the PhD route the way I've taken it is not something I'd recommend to anyone. Nevertheless, now that it's done, I am as happy as can be. I couldn't have done this without the time it took to mature as a researcher. Nor could I have done it without the life experience I gained over the years, that enables me now to appreciate it even more. And, I couldn't have done it without the many wonderful people that supported me throughout my entire PhD project and beyond. I would like to thank them here.

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I am hesitant at what point I should switch to Dutch, because as soon as I do that, my thank-yous may no longer be understood by any non-Dutch readers. On the other hand, some thank-yous may be better understood by the people for whom they are intended. Let me draw the line here, and let me stress that it is a very arbitrary line.

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it iten dy't eins krekt te dreech foar ús wiene) en troch geregeld te beneammen dat wy alles wurde koene wat wy mar woene. Tankewol, it hat fertuten dien. It docht my goed te witten dat jim grutsk op ús binne en no efkes spesjaal op my. Heit ek noch tige tank foar alle help by it oersetten fan de gearfetting nei it Frysk, want dat hie ik allinnich noait sa moai rêde kinnen.

Myn susters Hinke en Emke, wy ha altyd in soad mei inoar begien west, en ik hoopje dat dat sa bliuwt. Jim binne my leaf, en dêr behelje ik ek graach Bernd, Mirko en de bern yn. Emke, do hast my faker as dast sels wist holpen by it trochhakjen fan knopen, ek wat myn promoasje oanbelanget. Ek sil ik nea ferjitte dat we yn Beijing in grutte tas mei 'goodies' fan dy krigen, wat in teken is fan dyn soarchsumens, al bagatellisearrest dat sels graach fuort. Hinke, hoe fier ast ek fuort wennest en hoe drok jim ek altyd binne, silst nea in jierdei oerslaan. En tank dast dy der allang by dellein hast dasto my faker bellest as ik dy. Dat jim no út Nij Seelân foar my oerkomme taastet my yn it moed.

Myn jonges Jorke, Ids en Hidde wol ik ek tige graach betankje. Ien fan jim hat wolris fersuchte dat ik de ideale baan ha: "Oan it ein fan in lange gong rustich yn in keamerke de hiele dei wat achter in kompjûter sitte dy't hielendal allinnich fan dy is". Jim ha gelyk, it is moai wurk dat ik doch. Mar de lêste moannen ha jim ek sjoen dat ik bytiden net ophâlde koe, dat it thús noch likehurd troch gong. Wat ik moai fûn wie dat jim der mei heit foar soargen dat dat gewoan koe. Jim binne myn grutte kanjers! En ik bin bliid dat we no wer mear tiid ha om jûns ris in DVDtsje te sjen of in spultsje te dwaan.

Sake, do bist de lêste en de leafste. Do hast my yn praktyske sin bystien, mar mear noch hasto mei my meitocht by ferskate stappen yn it ûndersyk. Troch dyn altyd fleurige en muzykale oanwêzigens wiest net allinnich myn klankboerd, mar hast der ek foar soarge dat it hjir thús dochs altyd gesellich bleau, wyls ik, net altyd like gesellich, myn einsprint makke. Yn de wiken dêrnei ha ik jitris ûnderfûn hoefolle asto foar my dochst en om my joust en hoefolle ik fan dy hâld. Ik hoopje dat ik de ferwachtingen wier meitsje kin oangeande alles wêrsto de lêste tiid fan fersuchtest dast 'dat noch nea mei in Doctor dien hiest'.

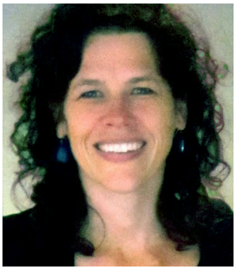
Sjoukje Osinga

About the author

Sjoukje Antje Osinga was born on the 9th of October, 1967, in Blija, a village in the very north of Friesland, The Netherlands. She grew up in Dokkum with her parents and two younger sisters. She attended pre-university secondary education at Oostergo, Dokkum. Her exam subjects included Dutch, English, French, Latin, mathematics, physics and chemistry. She started studying Dutch Language and Literature at the University of Groningen in 1986. After having completed the first year, she specialized with a just launched follow-up study programme within the faculty of Arts: *Humanities Computing*, artificial intelligence from a linguistic perspective. After her third year, she entered a one-year Erasmus-exchange MSc-programme in Louvain, Belgium, entitled *Artificial Intelligence and Cognitive Science* (1989-1990). Her MSc-thesis was on extracting road structures out of multi-seasonal satellite images through a pattern-recognition program, written on a genuine LISP machine. After that, she completed her Groningen *drs*-studies as a trainee at the Utrecht Center for Knowledge Technology, where she wrote her thesis on a hypertext-based knowledge representation tool for KADS, a methodology for developing knowledge-based systems.

As of June 1991, shortly before her graduation in Groningen, she was appointed Assistant Professor at the Applied Information Technology group of Wageningen University, section Knowledge-Based Systems. Her first assignment was to design a new doctoral course, *knowledge-based systems*, which turned out to be well appreciated by the Wageningen students. She took on more teaching responsibility, and was soon involved in many other courses as well. Over the years, she has been a (co-)teacher of nearly twenty different courses. She contributed to various research projects. She became study coordinator for the *Agricultural Systems Science* students. There was always plenty of work to do because the group was structurally understaffed.

After the birth of her three children in 1997-2002, she had the wish to further develop herself as a researcher. In 2006, the opportunity arose to go for half a year to China, with her family. She developed a plan to study the pork supply chain there with respect to information management. She carried out a field study among pig farmers and other stakeholders from the pig sector. She had already entered the then called Mansholt Graduate School in 2005, and started following PhD courses and writing her PhD proposal. Her proposal matured into its final form when she shifted her research focus to *agent-based modelling*. The idea of programming behavioural models from individual farmer perspective, fuelled by her Chinese field study experience, turned out to be the golden combination of both farmer behaviour and information technology. The agent-based modelling approach also re-established the connection with her earlier artificial intelligence studies. In March 2010, her PhD proposal was accepted by the graduate school. From then on, there was a steady research progress through a series of conference papers and articles, which now constitute this PhD-thesis. She plans to keep working in the field of agent-based modelling, both by extending her existing work and through new research projects.



She is married and proud mother of three teenage boys. She likes to sing, mainly in classical chamber choir setting. She is also fond of running.

Publications

Refereed journal articles

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- Osinga S.A., Kramer M.R., Hofstede G.J., 2014. Sustainable animal welfare: does forcing farmers into transition help?. AI & Society: Journal of Knowledge, Culture and Communication, Accepted: 17 January 2014. Published online: 25 February 2014. *Chapter 7 of this thesis*
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- Osinga S.A., Kramer M.R., Hofstede G.J., Beulens A.J.M., 2013. Influence of losing multi-dimensional information in an agent-based model. In: Leitner S., Wall F. (Eds.), Artificial Economics and Self Organization: Agent-Based Approaches to Economics and Social Systems. Springer, Heidelberg. Volume 669 of *Lecture notes in Economics and Mathematical Systems*, pp. 233-244. *Chapter 6 of this thesis*
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- Osinga, S.A., Hofstede, G.J., 2004. What we want to know about our food: consumer values across countries. In: Dynamic in Food Chains: Proceedings of the 6th International Conference on Chain and Network Management in Agribusiness and the Food Industry, Ede, The Netherlands, 27-28 May. Wageningen Pers, pp. 301-309.

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- Osinga, S.A., Hofstede, G.J., Verwaart, T. (Eds.), 2011. Emergent Results of Artificial Economics. *Lecture Notes in Economics and Mathematical Systems* 652, Heidelberg : Springer-Verlag.

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Other

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Sjoukje A. Osinga
Wageningen School of Social Sciences (WASS)
Completed Training and Supervision Plan

Wageningen School of Social Sciences

Name of the learning activity	Department / Institute	Year	ECTS[1]
A. Project-related competences			
Mansholt Introduction Course	Mansholt Graduate School	2005	1
Writing own research proposal	Wageningen University	2010	6
Presentations of research papers:			
• *An agent-based information management model in the Chinese pig sector: top-down versus bottom-up*	Wageningen International Conference on Chain and Network Management	2010	1
• *An agent-based information management model of the Chinese pig sector*	Artificial Economics 2010 Treviso, Italy	2010	1
• *The pork cycle revisited with ABM - applied to a case of Chinese pig farmers*	Artificial Economics 2011 The Hague	2011	1
• *Multi-dimensional information diffusion and balancing market supply: an agent-based approach*	Artificial Economics 2012 Castellón, Spain	2012	1
• *Influence of losing multi-dimensional information in an agent-based model*	Artificial Economics 2013 Klagenfurt, Austria	2013	1
Presentations at various internal research meetings	WUR-INF, Q-PorkChains, WUR-LEI, IP/OP CAS	2010 - now	1
B. General research-related competences			
Quantitative Research Methods	Mansholt Graduate School	2005	2.5
Institutional Economics and Economic Organisation Theory (AEP-20806)	Wageningen University	2007	6
Advanced Econometrics (AEP-50806)	Wageningen University	2007	6
Superpowers in Global Environmental Politics: China and the US	Mansholt & SENSE Graduate School	2007	3
Advanced Programming (INF-30306)	Wageningen University	2008	6
Social and Economic Networks: Models and Analysis	Stanford University (Coursera online course)	2013	3
Workshop Modelling Social Reality	Lorentz Center, Leiden	2014	1

[1] One credit according to ECTS is on average equivalent to 28 hours of study load

Sjoukje A. Osinga
Wageningen School of Social Sciences (WASS)
Completed Training and Supervision Plan

(*Continued*)

Name of the learning activity	Department / Institute	Year	ECTS[1]
C. Career-related competences / personal development			
PhD Competence Assessment	Wageningen Graduate Schools	2005	0.3
Project- and Time Management	Wageningen Graduate Schools	2007	1.5
Organizing conference and editing proceedings	Artificial Economics / Springer Lecture Notes in Economics and Mathematical Systems	2011	3
Programme Committee member of conferences and reviewer of journals related to PhD research	Artificial Economics; several journals	2012 - now	1
Writing research proposals (acquisition) on topics related to PhD research	IP / OP Complex Adaptive Systems; STW	2012 - now	1
Teaching courses at the INF - department related to PhD research (and other courses)	Agent-Based Modelling of Complex Adaptive Systems (INF-50806)	2011 - now	2
Supervising BSc- and MSc-students	Several	2011 - now	2
TOTAL			51.3

[1] One credit according to ECTS is on average equivalent to 28 hours of study load

Epilogue

De mier en de eekhoorn kregen les van de zwaan. Het was aan de oever van de rivier, de zon scheen en zij zaten onder de wilg, in de schaduw van een laaghangende tak.

Het was de tweede les, maar van de eerste les hadden zij niets onthouden.

'Vandaag,' zei de zwaan, 'zal ik het hebben over voorbij.'

Dat vonden de mier en de eekhoorn een goed idee, want daar wisten zij weinig van.

De zwaan trok een ernstig gezicht en zei: 'Alles gaat voorbij.'

Het was heel even stil onder de wilg. Het water in de rivier glinsterde en er was nauwelijks wind.

'Wisten jullie dat?' vroeg de zwaan.

'Nee,' zeiden de mier en de eeekhoorn. 'Dat wisten wij niet.'

THE ANT AND THE SQUIRREL TOOK CLASSES WITH THE SWAN. It was down by the river, the sun was shining and they were sitting under a willow, shaded by a low branch.

This was their second lesson, but they'd already forgotten everything from the first.

'Today,' said the swan, 'I will talk about passing.'

The ant and the squirrel liked that idea, since they didn't know much about it.

The swan put on a serious face and said: 'Everything passes.'

There was a short silence under the willow. The water in the river glimmered and there was hardly any wind.

'Did you know that?' the swan asked.

'No,' the ant and the squirrel said. 'We didn't know.'

Colophon:

Print: GVO drukkers & vormgevers B.V.

Cover illustration and other illustrations: Henk van Ruitenbeek
(The pig illustrating the Part pages is carrying 'the apple of knowledge').

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