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An agent-based model of information management in the Chinese pig sector: top-down versus bottom-up

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Abstract
In this paper, we argue that information management theory may benefit from agent-based modelling as a method to investigate the relationship between system level (top-down) and agent level (bottom-up) behaviour, when agents' behaviour cannot fully be managed because the agents are autonomous. The Chinese pork sector serves as case. We describe context and design decisions for a conceptual model, focussing on the alleged link between information provision and product quality attained. A multi-level perspective is required: the top-down information management measures, the variation in individual farmer behaviour, and the interaction structures with supply chain partners, governmental representatives and peer farmers.

Keywords
Multi-level information management; agent-based simulation modelling; pork sector; China.

Problem introduction
Policy makers tend to overrate the effectiveness of top-down information management measures in a population of autonomous individuals who pursue their own goals (bottom-up). Our research interest is to investigate what insights agent-based simulation models can give in the discrepancy between the two levels, i.e. top-down sectoral level or bottom-up individual level. More precisely, to investigate:

(a) the effect of top-down information management related measures on a population of heterogeneous, autonomous actors, i.e. changing demand requirements;
(b) whether certain characteristics of the individuals in the population make a difference to that effect, i.e. their embeddedness in social and business networks, their perception of the information they receive and their ability to take action upon this information.

Of this general problem the present study takes one instance: the case of the Chinese pork sector, where the government has targets and requirements, but where the majority of producers consists of individual farmers who act on their own authority.

A recent example from the Chinese pork sector was reported in the China Daily (ChinaDaily, 2010). With the intention of increasing pork quality and safety, government officials 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 at this time of year, this caused a strong dissatisfaction among the town residents. An intervention was made at governmental level, but at agent-level the individual shop owners reacted in an unforeseen way, resulting in an undesirable public reaction.

Impact of the two levels: top-down versus bottom-up
The impact of the dynamics between the two levels can be very different within different contexts. We illustrate this by comparing the Dutch and the Chinese agri-sector, that both have a two-level structure but with a different mix of top-down versus bottom-up.

In the Dutch agri-sector, the government stimulates but does not enforce individual farmers in changing farm practices, not even when the government has an interest by those changed practices. Farmers are autonomous entrepreneurs. They must comply with the law, but what the government wants is not their primary concern. They have legal information management obligations, for example ensuing from quality and safety regulations, but the incentive to comply comes from their chain partners. These exclude them from delivery if they do not meet the requirements, and give them a financial reward if they deliver products of certain quality in time. This chain controlled incentive mechanism is supported by information systems that help a farmer calculate production alternatives, and to compare his own farm management with that of other farmers. The information systems also help to administrate and report legally required data, thus supporting both government and farmer. There is no direct government involvement, except for laying down the legal framework.

In China, the situation is different. There has been a centralized style of government for many centuries. Responsibilities are person-based rather than rule-based within in a multi-layered hierarchical structure. Individual nodes lower in the hierarchy receive administrative guidance from above, for instance from local governments. Communication between functional units at the same level, for example from province to province, has traditionally been very limited (Jahiel, 1998). The chain controlled incentive mechanism as in the Dutch situation is also present in China, but the chain partners involved have to answer to the (local) government as well. Information management as in tracking and tracing requirements is a theme in the governmental white paper on food safety (China, 2007), but supportive information systems are not yet regular tools for average chain partners.

Agent-based modelling as a method
Gilbert (Gilbert, 2008) defines agent-based modelling (ABM) as a computational method that enables a researcher to create, analyze and experiment with models composed of agents that interact within an environment. Agents are either separate computer programs, or, more commonly, distinct parts of a program that are used to represent social actors – individual people, organizations such as firms, or bodies such as nation-states. Agents are

heterogeneous, they pursue their own goals (based on local interactions and bounded rationality) and they can make autonomous decisions. They are reactive (responding to their environment) and social (responding to other agents).

ABM is becoming popular in the social sciences because it allows representing individual behaviour as a conjunction of reasoning (decision making), personality and values (Gilbert, 2008), (Phan et al., 2007), and that they are responsive to the environment and to other agents. Especially the latter property makes ABM suitable for social science applications, because it allows to include simulation of the effect that one agent's behaviour affects the others, and that social networks matter. For our research, this is very relevant, a reason why we use ABM as a method for modelling our case study.

An additional reason to choose ABM as a method is because of its suitability for modelling multi-level systems with autonomous elements (Epstein, 2006), (Miller et al., 2007). The multiple levels in our model are system level, agent level, and interaction level, a distinction which is applied in state-of-the-art ABM research (Dignum, 2004):

- System level describes both the institutional environment (system) that influences the availability of information, and the structure that facilitates the information exchange between agents.
- Agent level describes the characteristics of the population of agents that exchange the information. Differences between agents can be represented individually.
- Interaction level describes the interactions that occur between agents, leading to (information) exchange events.

Objective of the study

As stated before, our research interest is to investigate what insights agent-based simulation models can give in the observed discrepancy between the two levels of sectoral information management. This paper should clarify (1) why that observed discrepancy is the consequence of a research gap in information management theory; (2) why agent-based modelling is an appropriate method to provide answers to fill that research gap, and (3) why the case study at hand forms a suitable instance of the problem to investigate the observed discrepancy by means of the proposed method of agent-based modelling.

This paper presents the theory, and describes the case context and design decisions needed to arrive at a conceptual model that serves as a basis for an agent-based model. The conceptual model focuses on the alleged link between information provision and product quality attained, for which a multi-level perspective is needed: the top-down information management measures, the individual variation in behaviour between farmers, and the interaction structure that they have with supply chain partners, governmental representatives and peer farmers.

In later stages of the research, the model will be used for simulation experiments which are impractical or impossible in the real world. These experiments will give insight in the relationship between top-down informing behaviour on the one hand, and product quality attained at farmer level on the other. The simulation results will show emerging properties at system level as a result of the actions of individual agents. These emerging properties will give insight in how the behaviour of the system and the individual behaviour of agents depend mutually on each other. These insights are valuable contributions to the theory of multi-level information management.

Methodology

Figure 1 shows a schematic representation of the central research framework for this study, designed after Mitroff (Mitroff et al., 1974). The large black oval in the figure indicates the scope of the present paper: a conceptual model is deduced from theory, together with insights from a case study, and parameterized using survey data. In later stages of the research, a computer model is built based on the conceptual model. A 'base' agent-based model is developed and implemented, which is inspected by means of sensitivity analysis before it will be used for further experiments. The base-ABM will be repeatedly adapted to explore selected what-if scenarios by means of simulation runs. The results from these consecutive ABMs are analyzed and evaluated, after which validation by experts - from both ABM and the case study domain - further refines them. Ultimately, the results will be interpreted to contribute to the theory.

The elements of the conceptual framework of Figure 1 are explained and justified in the remainder of this paper.

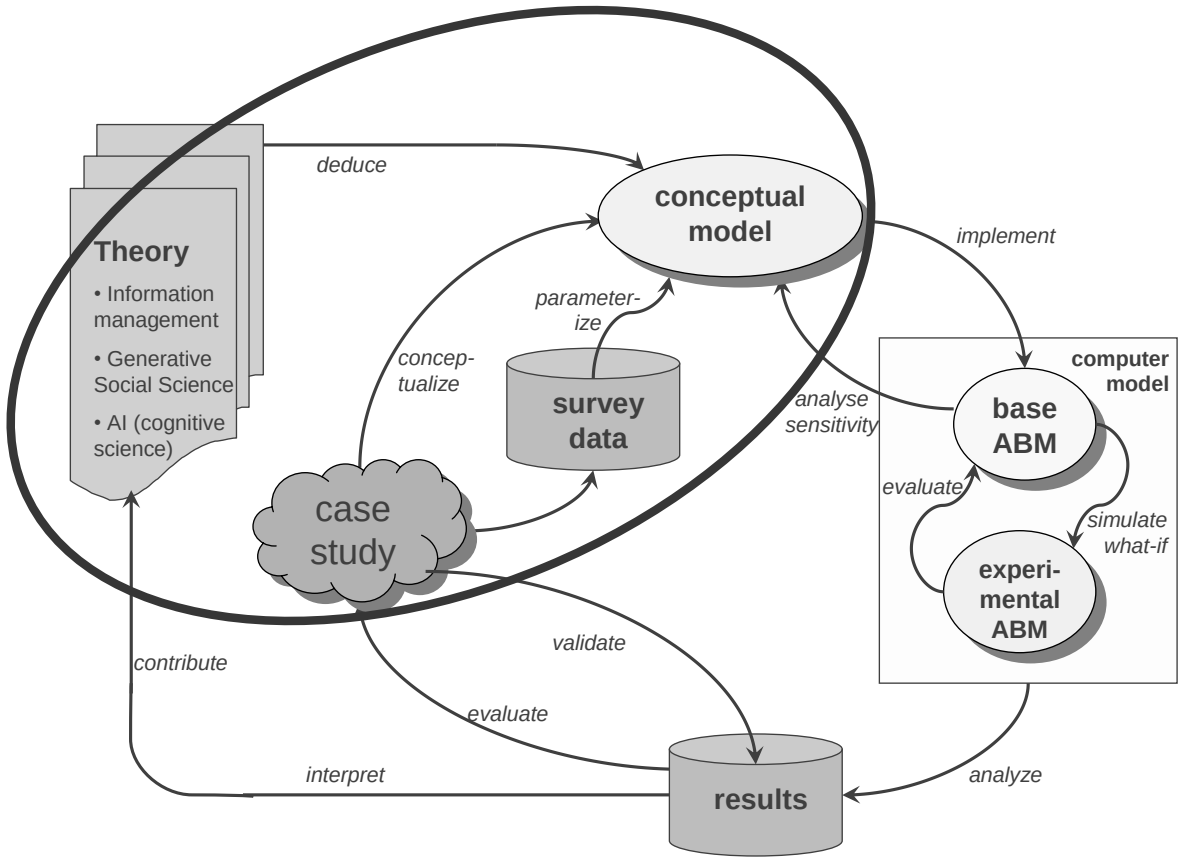

Figure 1: Research framework. The large black oval indicates the scope of the present paper. The other elements of the research framework are addressed in future research.

Theory

The focal theories for this research are on the one hand information management, and on the other hand the founding theories of agent-based models: generative social science and artificial intelligence.

Information Management

The academic discipline of information management involves designing and simulating with models that represent relevant information flows needed to manage the object of study. Up to

now, information management theory has known a normative approach: information management models usually depict a priori designed flows of tasks, procedures and responsibilities. The background of this normative nature is that the discipline is relatively young, and that experiences from pioneering researches have condensed into useful, practical guidelines, often published in handbooks (Laudon et al., 2009).

However, not much is known regarding the suitability of these prescriptive models when applied in situations other than the original. Little research has been done to measure the actual effectiveness of applying such models (Maltz et al., 1996; Hamill et al., 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 (Cross et al., 2004). This is especially true in rural communities (Isaac et al., 2007; Lyon, 2000). In the field of knowledge-based systems, traditionally a distinction is made between explicit and tacit knowledge. The latter of the two often functions as the cement in an organization, but is very hard to bring to the surface (Turban et al., 2007). Brown gives many examples of why tacit information seems more important than explicit information management models, and that 'communities of practice' are of vital importance for learning in an organization (Brown et al., 1995; Brown et al., 2002).

Concluding, information management as a research field is currently in need of models that integrate prescriptive models with models that describe actual behaviour (Dimitriadis et al., 2005; Huang et al., 2003; Stevenson et al., 2007). These should include system level models, models of individual actors who are part of the system, as well as models of the interaction structure between individual actors. This boils down to a multi-level system view.

The strong points of ABM as a method match the requirements of this type of models that integrate a multi-level view in an information management domain.

Generative social science and Artificial intelligence
ABM originates from basically two other theories or research disciplines: artificial intelligence, focusing on the cognitive aspect of agents (Jennings et al., 1998; Dignum, 2004), and generative social science, focusing on the patterns of agent interactions (Epstein et al., 1996; Epstein, 2006; Gilbert, 2008). The former school's results are useful for the development of e.g. robots who can perform tasks that require cognitive skills. The latter serves researchers who are interested in the behaviour of populations of relatively simple agents (e.g. ants or birds), and to investigate emerging properties of these populations.

A current challenge in ABM research is to combine elements from both schools. This implies a trade-off between developing agents' cognitive aspects versus maintaining simulation power. This is where our research is situated. Agents are driven neither by mere cognition, nor do they exhibit pure population behaviour as ants in anthills. They have social needs, that may very well be population-determined. These trigger cognitive actions, which result in agents' behaviour.

Along this line of reasoning, our farmers take decisions not only based on economic arguments, but also for a variety of other reasons. Personality attributes like openness, conscientiousness or ambition (Costa et al., 1992) and cultural attributes like the importance of in-group relationships (Hofstede et al., 2005) further influence the decision to act upon information received, or not.

Suitability of case study
As a case study, we model Chinese pig farmers who run a family business and earn a living out of pig farming. The choice for this case study was made because it has characteristics that are very attractive for an agent-based simulation model with the purpose of investigating the layers in a multi-level approach. These characteristics are:

- *Clear top-down strategies*. China has clear targets in these times of economic growth: both pork volume and quality must increase. To this end, information (i.e. advice and training) needs to be spread among the target population, many of which are farmers. Especially for quality targets, product information also needs to be managed for tracking and tracing purposes.
- *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.
- *Success of strategy depends (also) on person delivering it.* Governmental measures are carried out by provincial livestock bureaus (LB), who delegate to county bureaus who 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.
- *Bottom-up behaviour: population of autonomous individuals.* The population of pig producers consists of many farmers who, on average, have relatively small pig numbers. But together, they are responsible for a large share of production: an estimated 80% according to the literature ((Fabiosa et al., 2005; Pan et al., 2002), which will have changed but 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 computers and internet) appear to be insufficiently available for any chance of success.
- *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 depends on the social network, the personal situation and idiosyncratic attributes of the farmers.
- *Enforcement is problematic.* Processors (like slaughterhouses) should check and register whether farmers have followed certain rules. However, technological support to make these checks watertight 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 even cause sweeping changes in behaviour. The hog cycle (Harlow, 1960) is an iconic example in this respect.

Exploratory case study + survey data
In the spring of 2006, we interviewed 40 stakeholders throughout the pork sector in China. Half of the interviewees were pig farmers in Greater Beijing and two high pork production provinces, Anhui and Sichuan. The other half were representatives of slaughterhouses, processing companies, feed sellers, a pork dealer and an LBO, from the same areas. These

interviews gave us a qualitative understanding of the pork chain(s), the issues stakeholders had to deal with, and the role of information management.

Later in 2006, survey data were collected by survey teams for 223 Chinese farmers in provinces Sichuan and Anhui. The survey concerned farmers' information management practices, supply chain partner relationships, peer relationships, services, governmental institutions experiences, farm data and personality-related questions.

The conceptual model we present here is based on the insights from theory, and on what we learned from our exploratory case study. It is assumed that improving information provision to individual farmers will increase the sector's average product quality. The conceptual model takes the perspective of the pig farmer, and forms the basis for our ABM. It contains only those elements that are relevant for answering our research questions. The survey data are used in this paper to justify the conceptual model, and in later stages of the research for parameterization of the ABM.

Conceptual model

In the environment of the farmer, three main sources of information are present: (governmental) livestock bureau, social network and business network, the latter being supply chain partners who buy the farmers' pigs and feed sellers who offer them feed. Based on this information, the farmers make decisions for their farm practices in order to achieve the best result. The farmer's motivations, abilities and actions affect the degree to which the information is actually applied, leading to a higher quality end product.

Informing behaviour of the government

The livestock bureau is a governmental institute that implements national policy at provincial level. It delegates to county bureaus who send out their officials to the 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 frequently enough.

Social network of farmers

Many farmers live in close-knit rural communities: their market linkages are embedded in relationships. We learned from our qualitative interviews that they 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.

Business network of farmers

As was mentioned earlier, China's pork chain is dominated by many small-scale pig farmers whose downstream chain partners are individual intermediaries ('pork dealers'). From the qualitative interviews, we learned that farmers sometimes have an agreement with a local slaughter with minimal capacity, 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, whose pigs are sold in the wet markets. Or they deliver to larger slaughterhouses who 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 pork dealer. But not all farmers manage to have these contacts.

Motivations, abilities and actions of farmers
For every decision to change something, there is an underlying motivation, related to satisfaction with the current situation. Satisfaction in its turn is related to personality characteristics: it depends on a farmer's personality whether for example a certain income is satisfactory or not. Abilities of a farmer also determine his motivation to change something: some farmers have more skills to get things done than others. Actions clearly indicate the inclination to change.

Survey results to justify conceptual model
Regarding the justification of the elements in our conceptual model, selected descriptive survey results are presented below. Further analysis will be done in later stages of the research, when parameterization of the conceptual model is required.

Informing behaviour of the government
Table 1 gives an overview of visit frequencies by LBO as reported by the farmers themselves.

	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 1: frequency of visits of Livestock Bureau representatives as reported by the farmers in provinces Anhui and Sichuan.

The data in table 1 indicate that one third of all farmers never receive a visit; that about half 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 the response in Anhui and in Sichuan, so it seems fair to generalize these outcomes for other provinces as well.

	medical services		***training (pig raising, quality, hygiene)***		***inform about rules/regulations***		***inspection on farm***	
Service/activity by	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Not offered to me:	12	5	46	21	63	28	56	25
Offered but not aaccepted:	53	24	36	16	40	18	25	11
LBO:	122	55	85	38	111	50	134	60
Independent vet:	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: Results of answers to the question: Were the following services offered to you, if so: by whom?. The results were aggregated in columns 'medical services'(3 values) and 'training'(4 values)..

The farmers were also asked what services were offered to them by either LBO, an independent veterinary service provider, or a company. Table 2 shows the results. The results were slightly aggregated for columns 'medical services' (3 values) and 'training' (4 values).

The LBO comes out as most important to the farm for all types of services. The LBO offers medical services, inspects the farm and informs about rules and regulations for 50-60% of the farmers. A large group of farmers either never receives any services, or prefers to do them themselves: in total, they form about one third of all surveyed farmers. Companies are relatively present when it comes to offer training services (18% of all farmers), which is almost as much as the LBO does. These companies are often feed companies, interested in contracting farmers to buy their feed more regularly.

Social network of farmers
We asked the farmers what information they exchange with whom, i.e. what issues they discuss with others. Their responses were aggregated in table 3.

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 3: Summary of data that show what issues farmers discuss with whom.

The table 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. Farmers organizations form another platform for interaction and exchanging information.

Business network of farmers
Table 3 shows the most important business connections for buying their pigs, as reported by our farmers.

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

Table 3: Overview of farmers' answers to the question "who is your main pig buyer?".

About half of our farmers indicate that they deal with 'pork dealers', individuals who contact them and who come to take their pigs. 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 smaller. There are slight differences between Anhui and Sichuan, but the overall picture is very similar in both provinces.

Motivations, abilities and actions of farmers
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 the pig house, how much investments those involved, and whether they could get a loan for it. Also we asked them the reason why they did it. From our 223 farmers, 77 had changed their pig house during the previous five years, and succeeded in raising the money for it. As the reasons why they changed their pig house, 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.

Concluding remarks regarding conceptual model
We presented and justified the conceptual model that should form the basis of our ABM. Regarding the business and social network, the survey data are in line with the general picture of the Chinese pork sector: the majority of farmers has a pork dealer, i.e. an intermediary buyer. Only a minority has direct contacts with slaughterhouses. This is worthwhile because it requires no profit to be earned by the intermediary, but not all farmers manage to have these contacts.

Apparently, there is a substantial part of the pig farmer population not within direct reach of the LBO, as the case study and survey data demonstrate. This justifies the case for our ABM, where we wish to experiment exactly with those situations where high level measures do not arrive at the target population through the regular channels. For our surveyed pig farmers, the LBO is the main source of information. Companies are second in providing training services to farmers. From the exploratory interviews, we learned that these are often feed companies, and sometimes processing companies, who see an interest in contracting farmers.

It is important to include motivations, actions and abilities of farmers as drivers for their decision making process: the data indicate that farmers *do* take the initiative to change something about their situation, and that they had their motivations for making that choice. Additional data analysis will allow us to deduce a set of decision rules that reflect the agents' behaviour.

Finally, our model should facilitate person-to-person contact between our agents, because farmers do discuss relevant issues with family and friends.

Conclusion
In this paper, we argue that information management theory has a lack of insight in the relationship between system level and agent level behaviour, in situations where the agents' behaviour cannot fully be managed because the agents are autonomous. We conclude that this lack of insight is the consequence of a lack of methods that can describe both the system and its elements; information management is well stocked with prescriptive theory but has a dearth of descriptive methods in addition.

We showed that the case study at hand forms a suitable instance of the problem. Despite the hierarchical relationships between government and small-scale farmers in China, preliminary data analysis demonstrates that farmers have considerable individual freedom to collect information and follow government advice, and also that their personal networks play a large

role. This article is the first one from an ongoing research project, and the research cycle has not yet been executed full circle, so that it cannot yet be asserted just how far agent-based modelling can inform the case study.

We showed that agent-based modelling seems to fit the requirements as a method to investigate the relationship between top down information management and individual agent behaviour. As such, it will be a welcome addition to the methods at the disposal of information management researchers. Full authority over individual agent behaviour is a fiction even in a dictatorial system, let alone in any system in non-dictatorial circumstances such as supply networks or industry sectors. Therefore, descriptive modelling of such systems holds promise.

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