



## Research paper

## Diffusion of organic farming among Dutch pig farmers: An agent-based model

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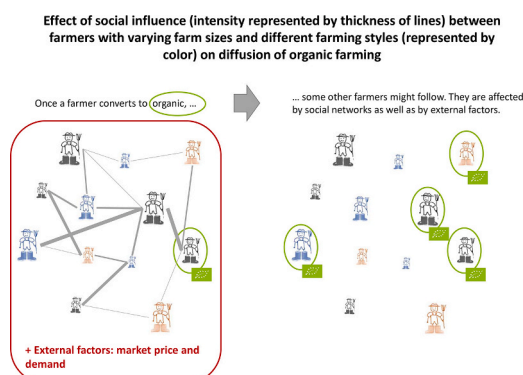
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## HIGHLIGHTS

- Understanding diffusion of organic farming requires a systems approach
- Trend in consumer demand can stimulate or limit diffusion of organic farming
- New entrants influence diffusion of organic farming through their farming style and their peers
- Local interactions can influence diversification of farming styles among organic farmers

## GRAPHICAL ABSTRACT



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## ABSTRACT

**CONTEXT:** Organic farming is an alternative for conventional farming practices with the potential to decrease negative externalities. Yet, in the Netherlands there has been a mismatch between societal preferences and farmer behaviour: despite increasing demand for organic pork meat, farmers feel peer pressure to remain conventional. Therefore, to understand diffusion of organic farming, one needs to consider social dynamics between farmers.

**OBJECTIVE:** The aim of this research is to gain insight in the factors contributing to the diffusion of organic farming, by considering social interaction mechanisms, market price dynamics, and heterogeneity in farming styles.

**METHODS:** We built an agent-based model of pig farmers differing in farm size and farming style (idealists, craftsmen and entrepreneurs) in a social-spatial network. They can convert from conventional to organic farming and back. Farmers can influence one another when they interact. This social influence is based on the social

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identity approach: Farmers who are similar in, among others, farming style converge in attitudes, while dissimilar farmers diverge in attitudes. The conventional meat price is volatile. The organic meat price fluctuates in accordance with supply. An exploratory analysis was performed on social influence parameters. Three social influence scenarios on the likelihood for influence in interaction were selected for local sensitivity analysis. The model run replicated 15 years and started with 16 organic farmers and 1958 conventional farmers. Model results were discussed with Dutch organic pork sector experts.

**RESULTS AND CONCLUSION:** The results of the exploratory analysis are threefold. An increase in the likelihood of influence in interaction increases the number of organic farmers from 44 to 121 and diversifies the organic farmers from 98% idealists to 31% idealists, 49% craftsmen and 20% entrepreneurs. The most influential factor on diffusion of organic farming is the demand for organic pork meat. New entrants stimulate organic farming through a different farming style than their predecessor. Expert discussion on model results confirmed the importance of consumer demand and new entrants for understanding diffusion.

**SIGNIFICANCE:** The social identity approach serves as a helpful framework to capture empirical and sociological knowledge. It reveals that farming styles of entrants contribute to the diversification of farming practices overall. For researchers and policy makers wishing to stimulate alternative farming practices, it is of interest to better understand this mechanism. In addition, we showed that those wishing to understand innovation in farming practices should look beyond farmer decision-making, by including market dynamics through consumer demand.

## 1. Introduction

Intensive farming practices produce cheap food, but are also criticised for impairing animal welfare, and for contributing to climate change, biodiversity loss, poor air quality, soil degradation, stench and the risk of zoonoses (Bergstra, 2013; Coenraads and Cornelissen, 2011; Hendrickson and Miele, 2009; Maassen et al., 2017; Natuur and Milieu, 2017; Stichting Varkens in Nood, 2015). Policy makers and citizens call for alternative, demand-oriented, and less intensive farming strategies, which generate a higher income for farmers and decrease the negative externalities of production (Jansen et al., 2016; Provincie Noord-Brabant, 2017). Farmers' strategic decisions are done with regards to market integration, e.g., enlarge to stay competitive in the international market, or produce for smaller demand-oriented markets like organic. Yet, there has often been a mismatch between, on the one hand, societal and political preferences towards alternative farming strategies<sup>1</sup> like organic, and on the other hand, observed farmer behaviour. In the past, implemented policies had unintended consequences. In the Dutch pork sector, for example, a governmental subsidy for pig farmers to convert to the organic market introduced around the year 2000 resulted in a higher increase in organic supply than the anticipated increase in demand for organic pork meat. Excess supply resulted in dropped farm gate prices, pressure on organic farmers' income, and a damaged reputation of organic farming as a good alternative to conventional among conventional pig farmers (Biologica, 2003). In addition, while organic farming is generally seen by citizens and policy-makers as a viable alternative to conventional farming, farmers feel peer pressure to remain conventional or to defend their choice for alternative farming strategies like organic towards their peers (Alexopoulos et al., 2010; Ambrosius et al., 2015;

Lamine and Bellon, 2009). This shows a friction between societal preferences and farmer dynamics. In order to design an effective support strategy for alternative farming strategies, better understanding of the diffusion of alternative farming strategies is needed, in particular effects of market price dynamics and social interaction among farmers.

### 1.1. Farmer characteristics

Previous research on adoption by farmers of alternative farming strategies or welfare investments focused mainly on farmers' individual considerations, farm and farmer characteristics and/or influence of institutional environment such as policies (Bartkowski and Bartke, 2018; Gocsik et al., 2015b; Kemp et al., 2014; D. C. Rose et al., 2018a; Tuytens et al., 2008). For example, research has focused on the role of farmers' demographics, such as age (Kemp et al., 2014; Oude Lansink et al., 2003; Tuytens et al., 2008) and education (Aubert et al., 2012); farmers' personality, such as their innovativeness (Aubert et al., 2012; Rogers, 2003; Tepic et al., 2012) and their openness to experience (Austin et al., 2001); and on behavioural characteristics, such as beliefs (Palis et al., 2006; Sok et al., 2015), attitudes (de Lauwere et al., 2012; Hyland et al., 2018; Kemp et al., 2014; Willock et al., 1999), and motivations (Mills et al., 2018; van Duinen et al., 2015; Wilson and Hart, 2000). These studies were done at one point in time and did not consider dynamic interactions between farmers and between farmers and markets.

### 1.2. Social interaction

Previous research indicates that social influence plays a role in farmer decision-making in general (Bartkowski and Bartke, 2018; Edwards-Jones, 2006; D. C. Rose et al., 2018a), and in organic conversion in particular (Alexopoulos et al., 2010; Ambrosius et al., 2015; Lamine and Bellon, 2009). More specifically, social influence is related to specific reference groups (Ambrosius et al., 2015; Burton, 2004), i.e. a real or perceived group whose opinion and behaviour matters to one's choices (Brown, 2000; Kemper, 2011). Important reference groups among farmers can be identified via farming styles (Commandeur, 2006; de Rooij et al., 2010; van der Ploeg, 1994). Whereas a "farming strategy" pertains to an individual farmer's decisions, a "farming style" is a culturally shared repertoire of 'good' farming practices that distinguishes one group of farmers from another according to structuring principles, such as technology and market integration (van der Ploeg, 1994), technology and business (Commandeur, 2006), or animal welfare (de Rooij et al., 2010). Farmers with the same farming style act as reference groups to other farmers, setting implicit norms for practice.

<sup>1</sup> Four farming strategies are distinguished by policy makers (Provincie Noord-Brabant, 2017). The first is to enlarge and modernise the farm to stay competitive in the conventional international market. The second strategy is to convert to an intermediate market, which has slightly higher animal welfare and/or environmental requirements than set by law. The best known is the '1-star better life' concept established by the Dutch Society for the Protection of Animals, which requires farmers, e.g., to give fattening pigs 1.0 m<sup>2</sup> of living space instead of 0.8 m<sup>2</sup>, more distraction material, and males are not allowed to be castrated (Dierenbescherming, 2018a). The third is to convert to a niche market segment, which has higher animal welfare and/or environmental requirements than the intermediate market segment. The best known example of a niche market is the organic market, which corresponds to three stars from the Dutch Society for the Protection of Animals (Dierenbescherming, 2018b). The fourth and last farming strategy proposed by policy-makers is to quit farming. In the remainder of the article, when we mention alternative farming strategies, we refer to strategies 2 and 3. We leave out the fourth strategy, i.e. to quit farming all together.

### 1.3. Market price dynamics

Apart from social influence, the size of the market of an alternative farming strategy limits adoption (Ambrosius et al., 2015, 2019). Markets of alternative farming strategies like organic are small as opposed to international conventional markets where prices are internationally determined. In these small markets any marginal change in supply or demand could potentially affect the farm gate price and therewith farm income (Ambrosius et al., 2019). Both aspects - social influence and market price dynamics - thus need to be considered when studying the diffusion of alternative farming strategies.

### 1.4. Aim of research

The aim of this research is to gain insight in factors that contribute to the diffusion of alternative farming strategies. We explicitly consider social interaction mechanisms, market price dynamics, and farming style heterogeneity. More specifically we look at: (1) “What factors influence the size of the alternative market?”, and (2) “What factors influence the diversity of farming styles in the alternative market?” Conversion to organic farming in the Dutch pork sector is taken as a case study for the diffusion of alternative farming strategies. In this article the research questions are answered by means of an agent-based model on organic market conversion. Sensitivity analysis and expert validation are performed on model results.

The paper is structured as follows. First, the conceptual framework of pig farmer decision-making and social influence is explained. Next, agent-based modelling is introduced as a method for research and a short literature review is given on agent-based models of organic market conversion. Then the methods are outlined, including a description of the case study, the model, sensitivity analysis, and expert validation. This is followed by results, discussion and conclusion.

## 2. Conceptual framework

### 2.1. Pig farmer decision-making behaviour

Pig farmer decision-making is related to many factors, which can roughly be grouped into personal, contextual, and social factors (Ambrosius et al., 2015). Personal factors that are associated with a higher chance to invest in stables in general (e.g. new, more sustainable, renovation) are younger age and having a successor (Kemp et al., 2014; Oude Lansink et al., 2003; Tuytens et al., 2008). Personal factors that are associated with investments in higher animal welfare or more sustainable stables are a positive attitude towards the alternative (de Lauwere et al., 2012; Kemp et al., 2014), higher innovativeness (Tepic et al., 2012), and an idealistic farming style (Commandeur, 2006; de Rooij et al., 2010). Some of these factors are relatively static, i.e. a pig farmer's innovativeness (Ambrosius et al., 2015) and a farmer's farming style (Burton et al., 2008), while other factors are dynamic, i.e. age and attitudes (Helitzer et al., 2014).

Contextual factors that influence pig farmers' decision-making are the farmers' investment rhythm and farm size. Farmers' investment rhythm is determined by the useful life of an asset, such as the time that it takes for a stable to be depreciated, and the farmer's opportunity rhythm to make a long-term change on his farm determined partly by the availability of a successor (Oude Lansink et al., 2003). Farmers take into account their farm size as follows: the larger the size the more additional supply from the farm would affect the elastic organic market price; and therefore farmers with a large farm do not see organic as a viable alternative (Ambrosius et al., 2015).

Finally, social factors that influence investment decisions are norms, i.e. the behaviour and opinions of peers that can influence behaviour, and the status of farmers within reference groups. In a game environment, social interactions have shown to influence farmers' strategic investments through opinion leadership (Ambrosius et al., 2019). Also,

in a study on the adoption of an alternative housing systems for sows, i.e. group housing instead of individual crates, those farmers who did not yet convert felt less peer pressure (de Lauwere et al., 2012).

### 2.2. The social identity approach

The Social Identity Approach relates social interaction to behaviour change, through the social dimension of a person's self-concept. The main idea behind the Social Identity Approach is that humans have a universal drive to evaluate their opinions and attitudes to increase their self-esteem and/or confidence and status as a group member (Brown, 2000; Hogg et al., 1995; Turner and Oakes, 1986). Individuals within a group are motivated to act according to the norms associated with being a member of the group (Brown, 2000), and disagreement in opinion or attitude between in-group members can result in attempts to reduce the disagreement through social influence (Bagozzi and Lee, 2002; Brown, 2000; Turner and Oakes, 1986). The Social Identity Approach states that the level of influence is based on (1) similarity between self and other(s), i.e. whether they are in-group or out-group members; (2) the similarity of the situational context between self and other(s); (3) the status of oneself and the other(s) within the group, i.e. the direction of influence; and (4) the level of identification with the in-group (Brown, 2000; Terry and Hogg, 1996; Turner and Oakes, 1986). To understand and model influence between farmers, it is, therefore, important to know about similarity in person, situational context, and what gives status within a certain reference group.

### 2.3. Reference groups in the context of organic market conversion

To identify Dutch pig farmers' reference groups in the context of organic market conversion, we looked at previous findings and distinguish four reference groups. As shown above, pig farmers take into account their farm size when considering conversion to an added-value market (Ambrosius et al., 2015). Therefore, the first reference group consists of farmers who are similar in farm size. Second, organic and conventional farmers opposed each other's' practices in the past (de Rooij et al., 2010). Therefore, the second reference group consists of farmers producing for the same market. Third, previous research identified three farming styles that have been relatively stable over time in the Dutch pig farmer population: idealists, craftsmen and entrepreneurs (Commandeur, 2006; de Rooij et al., 2010). They differ in their definition of 'being a good farmer' and in status symbols, those factors that give farmers a high status within their farming style reference group (see Table 1). Idealists see pig farming as a way to earn a living instead of a way to maximise profits, and they like to keep investments low (Commandeur, 2006). In addition, they value farming methods that incorporate the intrinsic needs of animals into farm design and management. They oppose conventional farming methods that are harmful to animal welfare and think that behaviour of conventional farmers contributes to current societal criticism regarding the Dutch pig sector (de Rooij et al., 2010). Both craftsmen and entrepreneurs opt for maximising profits instead of maintaining a livelihood (Commandeur, 2006). Craftsmen

**Table 1**

Farming styles in the Dutch pig farmer population, their status symbols according to literature and the status symbols in the model.

Farming style	Status symbols literature	Status symbol(s) in model
Idealists	The level of intrinsic needs of animal on the farm; low investments; farming as a lifestyle	Producing for the organic market (which represents performance on animal's intrinsic needs)
Craftsmen	Profit/income through high productivity	Productivity performance
Entrepreneurs	Profit/income through optimising farm management; farm size; market integration	Income performance Farm size performance

gain profits through high productivity, e.g. intensification through increasing litter size and/or daily growth, while entrepreneurs optimise farm management, farm scale and market integration (Commandeur, 2006; de Rooij et al., 2010). The latter two oppose the idealistic worldview. Therefore, the third reference group consists of farmers with a similar farming style. Finally, innovative farmers, as opposed to conservative farmers, are more open to new ideas and alternative investments (Tepic et al., 2012) as described above. We, therefore, assume in the remainder of this article that farmers who are more innovative have a different reference group than their conservative colleagues: conservative farmers' reference groups are similar farmers (in farm size, market and farming style), while innovative farmers' reference group are farmers who are higher in status (instead of similar colleagues). Therefore, the fourth reference group consists of farmers who are higher in status according to one's own farming style. For example, the reference group of innovative farmers with an entrepreneurial farming style are all farmers who earn a higher income than themselves regardless of farming style, farm size or market. This will be further outlined under 'interaction mechanism' below.

### 3. Agent-based modelling

Agent-based models can capture heterogeneous individuals, i.e. agents, and interaction between these individuals, so that it can generate and explore macro-level or group-level outcomes (Flache et al., 2017; Gilbert, 2008; Squazzoni et al., 2014). These include innovation diffusion patterns (Berger, 2001; Deffuant et al., 2002; Kaufmann et al., 2009), segregation (Schelling, 1971), and opinion dynamics (Gargiulo and Gandica, 2017; Hegselmann and Krause, 2002). The method is, therefore, a good choice for studying factors that contribute to organic farming diffusion while considering pig farmer heterogeneity, social influence mechanisms, and market price dynamics. Since agent-based models are dynamic, they require understanding of the underlying mechanisms. In this case this means understanding of cognitive mechanisms of behaviour change, e.g. how social influence affects farmer decision-making behaviour, as opposed to snap-shot studies on farmer decision-making behaviour. The emergent outcomes of the system, here the diffusion of farming strategies, can in turn be compared with empirics or with expert knowledge.

Previous studies that used agent-based modelling for studying the diffusion of organic farming also included social interaction mechanisms (Deffuant et al., 2002; Kaufmann et al., 2009; Olabisi et al., 2015; Rozman et al., 2017; Xu et al., 2018). Some studies modelled the effect of social interaction with a social imitation mechanism (Olabisi et al., 2015; Rozman et al., 2017), e.g. if at least half of the neighbours of a conventional farmer converted to organic farming, the conventional farmer would do so as well. Other studies modelled social interaction with an opinion mechanism: e.g. if opinions are not too different, farmers influence each other (Deffuant et al., 2002; Kaufmann et al., 2009). Both types of organic conversion models do not take into account the social dimension of interaction, namely the farmers' farming style reference groups that dictates what makes a good farmer, while this has proven to play a role (Alexopoulos et al., 2010; Ambrosius et al., 2015; Home et al., 2018). There is one notable exception to these conversion models, which is the model developed by Xu et al. (2018) on understanding why farmers do *not* convert to organic. They acknowledge that farmers differ in their view on what makes a good farmer, e.g., environmental or productivity performance (Xu et al., 2018). The social influence mechanism in the model presented in this article differs from the one in Xu et al. (2018) in two ways. Firstly, the farmers' reference groups in this article go beyond the farmers' current practice: conventional farmers can value environmental performance more than productivity performance or organic farmers can value productivity performance more. This is done, because literature shows that a farmer's idea of good farming practices is based on the current practice *and* on their ambition (Commandeur, 2006; van der Ploeg, 1994). In other

words, organic farmers can have the ambition to increase productivity performance (instead of environmental performance) and conventional farmers can have the ambition to increase environmental performance (instead of productivity performance). Secondly, another farmer's credibility depends on similarity in farm context (e.g., farm size) in addition to similarity in farming style. In the model by Xu et al. (2018) similarity is based on environmental and economic performance comparison, what we refer to as status. In this model we take into account additional reference groups based on similarity, i.e., farming style, farm size, and market, next to differences in status.

Furthermore, in this model price dynamics in the conventional market and the organic market are modelled. To our knowledge, no previous agent-based model on organic market conversion assumed that additional organic supply would affect organic market prices. This is not realistic in the context of existing evidence that the farm gate price for organic meat is sensitive to new entrants (Ambrosius et al., 2019; Biologica, 2003). Previous models assumed that the organic market price is either fixed (Deffuant et al., 2002), similar to conventional (Olabisi et al., 2015), not taken into account (Xu et al., 2018), or indirectly modelled as a control belief of conversion, where an increase in control belief represents a subsidy or an increase in demand and/or farm gate price (Kaufmann et al., 2009). In this model we include a more sophisticated mechanism to capture market price dynamics.

### 4. Methods

#### 4.1. Case study description

The province of Noord-Brabant is the densest pig production region in the Netherlands. The majority of these pig farmers have intensive pig husbandry systems that are characterised by an increasing average farm size (from 903 animals per farm in 2000 to 3360 animals per farm in 2020, van der Meulen, 2021), high capital intensity, and indoor production systems (Geels, 2009; Hendrickson and Miele, 2009). Their income is under pressure – 12 of the past 20 years, 2000–2020, the average income per annual work unit on a pig farm fell below the Dutch poverty line (van der Meulen, 2021), and fluctuates due to volatile feed and meat prices (Bondt et al., 2002; Hoste et al., 2004), while pig production methods are criticised by citizens and consumers (Backus and Dijkhuizen, 2002; de Rooij et al., 2010; Greef and Casabianca, 2009). To increase sustainability in the pork sector, organic farming is proposed as one of the investment strategies for pig farmers (see footnote 2 for the other strategies, Provincie Noord-Brabant, 2017). Conversion to the organic market requires a change in building and inventory, e.g., a higher percentage in solid floors compared to slatted floors, more space per animal, and outdoor access, and a higher cost price partly influenced by the price for organic feed. Conversion to organic is, therefore, considered a strategic long-term and irreversible investment and can only be done on average once every 25 years when the farmer's current stable is depreciated (Gocsik et al., 2015b).

Dutch pig farmers, including those in Noord-Brabant, interact through study groups and farmer organisations (Tepic et al., 2012). Study groups are geographically formed, and vary in size from 5 to 35 farmers. Study groups partly define the farmers' network. Note that farmers in study groups are not automatically a reference group, although they could be, dependent on the factors described above. Organic and conventional pig farmers generally have their own study groups to maximise learning. Study groups merge over the years with decreasing numbers of pig farmers. Some pig farmers, who are particularly active in study groups or farmer organisations, are well-known to many pig farmers whom themselves do not know all these farmers in return. Pig sector news, such as price information, latest innovations or knowledge, and farmers' experience, is spread via farmer magazines and websites. These magazines have nine to eleven editions per year and run around 3000 copies per edition, reaching about 70% of the Dutch pig farmer population (Pigbusiness, 2018; van der Meulen, 2021; Varkens.



nl, 2020).

## 4.2. Model description

### 4.2.1. From conceptual model to agent decision-making

Based on the literature background, the decision to convert in the model, from conventional to organic or the other way around, is influenced by farmers' personal, social and contextual factors. The personal factors that are included in the model are age, innovativeness, farming style and attitude. Age does not influence the decision to convert, it only determines retirement age, while the other factors do affect the decision. A farmers' innovativeness and farming style, both being static throughout the model run, influence the social interaction mechanism, which is further explained below. The social interaction mechanism, in turn, influences the farmers' attitudes; the attitude towards organic or the attitude towards conventional. We assume that farmers first need to have a more positive attitude towards the alternative investment (e.g., the organic attitude needs to prevail the conventional attitude if the farmer is conventional, and be higher than a threshold), before farmers make a rational calculation of whether the expected income for the next five years is better than the average of the past five years. Therefore, rationality comes after farmers' interest in the alternative market, which is influenced by social interaction. If the expected income is higher, the farmer converts from his current market to the alternative market.

The social interaction mechanism in the model separates four reference groups, and makes a distinction between the reference groups of conservative and innovative farmers. Conservative farmers have similar farmers as reference groups (i.e. farmers who are similar in farming style, farm size and market), while innovative farmers have farmers with a higher status as reference group. The attitudes of the farmers who are part of the farmers' reference group are regarded as the norm of the reference group. Farmers who are high in status according to one's own farming style reference group can be regarded as opinion leaders. Following the Social Identity Approach, we furthermore, assume that there can be both positive and negative social influence: farmers do not want to be identified with their outgroup, so they change their attitude in the opposite direction after interaction with an outgroup farmer.

Finally, the rational calculation of the expected income depends on three factors: (1) the information the farmer gathered on other farmers' technical results in the alternative market; (2) the investment rhythm through the depreciation period of the stable (we assume that when a farmer converts, the stable needs to be replaced); and (3) the farm size. If the farmer wants to convert before his previous investment is depreciated (i.e., 25 years), the remaining value is considered as a cost that is deducted from the expected income in the next year. Farm size expressed in number of pigs affects the expected income in organic farming through additional organic supply in the market and resulting market price for organic meat (subsection "Income calculation" provides further details on assumed price and demand functions). If average expected income over the next five years of the alternative market is higher than the average income over the past five years, the farmer converts immediately, without considering a conversion period. This is done for simplicity reasons.

### 4.2.2. The model

The agent-based model was built in Netlogo version 6.0.2. The model distinguishes two types of agents: farmers and markets. Farmers differ from each other in e.g. innovativeness, market, farm size (i.e. the number of pigs), farming style, and the status within the farming style reference group (see Appendix 1 for an overview of all state variables). All farm sizes are modelled, i.e. from 'farms' with one pig to farms with 5000+ pigs, because small farms contributed to the image of organic as idealistic and non-professional. We assumed that a successor can on average financially own the farm at the age of 37 years, so successors start at age 37. Farmers retire at the age of 67 years in the Netherlands.

Two market agents are distinguished: an organic and a conventional market agent. Markets differ from each other in average costs per pig, indoor and outdoor space required per pig, and meat price (see Appendix 2 for more information). The primary time-step is one month, which reflects the meeting frequency of study groups. Some mechanisms play a role once per year, so they are executed every twelve steps (see 'process overview and scheduling' in ODD+D, in Appendix G, for the specific mechanisms).

### 4.2.3. Network description

Farmers are connected in a spatial, directed network. Note that the network of farmers differs from the four reference groups, because it includes farmer neighbours (representing members of the study group), which are not necessarily reference groups. The network is imported into the Netlogo model, and is, therefore, the same at the start of each model run. The imported network is formed according to the following principles. First, farmers are spatially distributed according to existing data and farmers are given with a market, a farming style, and a status for each farming style reference group (see Table 1 for the status symbols of each farming style, Appendix 1 for the distribution of markets and farming styles at initialisation, and ODD+D in Appendix G, for all the details). Second, farmers make, on average, ten directed links. The directed links of farmers in the model are for 95% neighbourhood contacts (i.e. a neighbourhood link is made with one out of the 25 closest farmers whom he does not have a directed link to), for 90% farmers with the same market, for 80% farmers who are already linked to the farmer, and for 50% farmers who have a higher status according to one's farming style reference group (see ODD+D, in Appendix G, for details). The directed network formed under these rules represent a situation in which some farmers with a high status are known by many other farmers, while they do not know all these farmers in return (see ODD+D, in Appendix G).

Note that at initialisation there are six organic farmers (out of 1964 farmers), all of which are idealists, and 19 conventional idealist farmers (see Appendix 1 for all initialisation values). Given that the network is based for 90% on homophily in market and for 50% on high status individuals, organic idealists are more likely to be connected with each other through their market, and conventional idealists are more likely to be connected with organic idealists through the high status of organic idealists. This is not the case for craftsmen and entrepreneurs: they are mostly connected with each other, since they produce for the same market, but they can be connected to organic idealists through the 10% random contacts.

The network can change at two points in the model run. The first is when farmers switch to other markets: farmers change their network according to the parameters described above. The second is when a successor takes over the farm. In the latter case, homophily is determined by farming style instead of market. Finally, the network serves as an interaction network through which social influence is exerted.

### 4.2.4. The farmers' decision procedure

The farmers' decision procedure to convert goes as follows. Farmers update their attitude towards the two markets in three ways: farmer-to-farmer interaction (every time-step), news interaction (every time-step), and through changes in own income (every 12 time-steps). If the highest value for attitude is not for the market the farmer already produces for, and the attitude exceeds a threshold, the farmer wants to convert. The ultimate decision is made when the expected income for the next five years in the new market is similar or higher than the average income of the past five years in the current market (see 'income calculation' below). To get informed about the expected income in the new market, the farmer has the chance to collect the technical- and management efficiency factors of one farmer whom already produces for that market every time-step.

In the model this looks as follows: every month, (1) all farmers interact with one random farmer in their network (the details described

below), (2) all farmers check whether they want to convert from conventional to organic, or from organic to conventional (details are described below), (3) if farmers want to convert, they collect information from one random farmer producing for the desired market (see ODD+D, in Appendix G for details) and (4) during a news interaction, one farmer influences 75% of conventional farmers and one farmer influences 75% of organic farmers. These farmers are determined independently and there is a (small) chance that they are in fact the same farmer. A model parameter (default value 25%) defines the probability that the selected farmer belongs to the other market than the influenced farmers. Each of these selected farmers for 'news interaction' are randomly picked from the applicable farmer population. Farmers in the news interaction update their attitude according to the interaction mechanism described below. Note that this interaction is one-time only, and does not imply a new permanent link. Every year, at the end of the year, the age of the farmers is updated. Then farmers check whether they retire and whether they have a successor. They update their income and their statuses (see ODD+D, in Appendix G for details). If they want to switch to another market, they check whether it is profitable to convert at this moment and if so, they convert and update their variables accordingly. Model outputs were derived after 180 months, i.e. time steps, corresponding to 15 years, which represent the time from January 2000 to December 2015. The remainder of this section outlines the interaction mechanism used for both network interaction and news interaction, the retirement and succession mechanism, income calculation, and market price dynamics (for more details see ODD+D, in Appendix G).

#### 4.2.5. Interaction mechanism

The topic (organic or conventional) for interaction is randomly chosen per interaction. When farmer A interacts with farmer B, the effect of the interaction on farmer A depends on the credibility of farmer B to farmer A. The perceived credibility of farmer B depends on a number of factors: the innovativeness of farmer A, the farming styles of farmer A and farmer B, the status farmer A assigns to farmer B according to farmer A's farming style (see Table 2 for more details on statuses), the farm sizes of farmer A and farmer B, and the markets of farmer A and farmer B. Following the Social Identity Approach, the status of farmer B, as well as the similarity in farming style farm size and market between the two farmers, matter for the perceived credibility of farmer B. The basic idea is that an innovative (or less conformist) farmer A considers the status of

farmer B more than the similarity between them, while a conservative (or more conformist) farmer A considers the similarity between them more than the status of farmer B. This results in the formula given in Eq. (1) below. For the calculation of the status value and the similarity value see Eqs. (2) and (3) respectively.

Each farmer has three statuses: idealist-status, craftsmen-status, and entrepreneur-status (see Table 2). The idealist status is based on the market the farmer produces for and changes when the farmer converts. The craftsman status is based on productivity performance and changes with farm succession through re-initialisation of productivity performance. The entrepreneurial status is the average of the normalised income and normalised farm size (see Table 2). Income performance changes with market conversion through changes in farm size and market price, and with farm succession through re-initialisation of productivity and management performance value. Farm size changes with conversion: fewer pigs can be kept on the same m<sup>2</sup> in organic farming. The total area of the building is static throughout the model run.

In interaction, farmer A compares the status relevant for his own farming style with the status of farmer B relevant for A's farming style. The higher the status of farmer B compared to the status of farmer A, the higher farmer B's credibility in the eyes of farmer A (see Figure 1 for an example of this calculation). The similarity value is comprised of personal and farm similarities: similarity in farming style (personal), similarity in market (farm), and similarity farm size (farm). The more similar farmers are, the higher the perceived credibility of farmer B (and even more so when farmer A is conservative); see Eq. (1).

$$C = I_A * St + (1 - I_A) * G \quad (1)$$

$C$  = Credibility of farmer B (in the eyes of farmer A).

$I_A$  = Innovativeness of farmer A.

$St$  = The relative status of farmer B perceived by farmer A; see Eq. (2).

$G$  = The similarity value; see Eq. (3).

The credibility of farmer B has to exceed a negative/positive 'credibility threshold' for influence on farmer A to be negative/positive. Otherwise, there will be no influence. If there is influence, the influence is either negative or positive. A positive influence means that the attitude of farmer A will go in the direction of the attitude of farmer B, while a negative influence means that the attitude of farmer A will move away from the attitude of farmer B. The more credible a farmer is perceived, the stronger the influence; see Eq. (4). Any change in attitude values will be restricted to a minimum of 0 and a maximum of 1.

The status value is calculated according to the following formula:

$$St = -1 * (S_A - S_B) * 0.5 \quad (2)$$

$St$  = Status value of farmer B perceived by farmer A.

$S_A$  = Status of farmer A for his farming style.

$S_B$  = Status of farmer B for farming style of farmer A.

The similarity value is calculated as follows:

$$G = Wr * R + Wm * M + Wf * F \quad (3)$$

$G$  = The similarity value of farmer B perceived by farmer A.

$Wr$ ,  $Wm$ , and  $Wf$  = the relative weights for similarity in farming style ( $Wr$ ), market ( $Wm$ ) and farm size ( $Wf$ ) ( $Wr + Wm + Wf = 1$ ).

$R$  = farming style similarity (same farming style: 1; entrepreneurs vs. craftsman: 0; otherwise: -1).

$M$  = market segment similarity: same market: 1; different markets: -1.

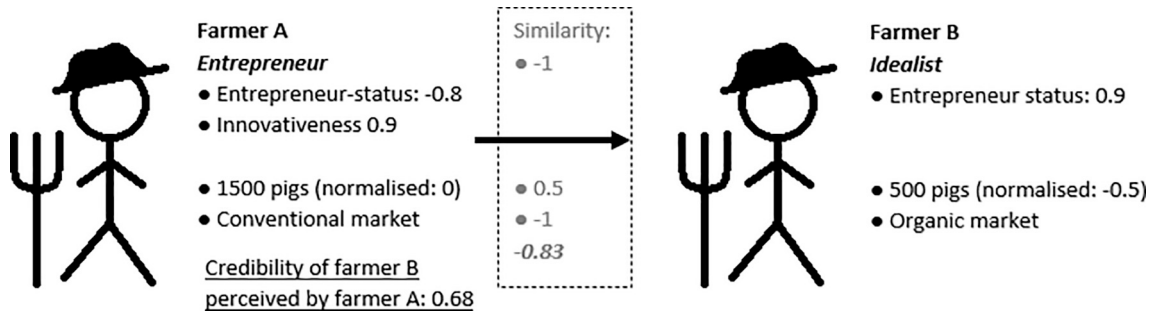
$F$  = farm size similarity (i.e.  $1 - |F_A - F_B|$ , where  $F_A$  and  $F_B$  are adjusted to a value between -1 and 1 (i.e. -1 represents the smallest farm in the model, 1 the largest farm size in the model).

The likelihood of influence is determined by the positive and negative credibility thresholds ( $x_1$  and  $x_2$  in Eq. (4)) when the thresholds are closer to zero, the likelihood of influence increases. If the attitude

**Table 2**

Farmers' farming style status in the model, their status symbols, operationalisation in the model, and the moments in the model when their value changes.

Farmers' farming style status	Status symbol (s) in model	Operationalisation in model	Dynamics
Idealist-status	Market	Organic = random-normal 0.8 0.1, Conventional = random-normal -0.8 0.1	Changes with market conversion
Craftsmen-status	Productivity performance	Normalised productivity performance 1 = lowest value for productivity performance -1 = highest value for productivity performance	Re-computed for all farmers when any farmers have retired
Entrepreneur-status	Income performance	Average of (1) Normalised income 1 = highest income among farmers -1 = lowest income among farmers	Re-computed every single year
	Farm size (i.e. number of pigs) performance	(2) Normalised Farm size -1 = smallest farm in model 1 = largest farm the model	



**Fig. 1.** Example of an interaction between farmer A and farmer B, including the factors that are important, their value, and the resulting perceived credibility of farmer B perceived by farmer A resulting from Eq. (1). Note that  $-0.83$  represents the similarity value, and that the idealist farmer B is still perceived to be relatively credible by entrepreneurial farmer A due to his own innovativeness and farmer A's entrepreneurial status.

exceeds one of the credibility thresholds, the 'magnitude of influence' parameter ( $M_i$ ) determines the percentage with which the difference in attitudes between two farmers can be overcome (see Eq. (4)):

$$\begin{aligned} \text{if } C < x_1 : Li &= M_i * C_n * (1 - \Delta A) \\ \text{if } C > x_2 : Li &= M_i * C_n * \Delta A \\ \text{if } x_1 \leq C \leq x_2 : Li &= 0 \end{aligned} \quad (4)$$

$x_1$  = credibility threshold for negative attitude influence.

$x_2$  = credibility threshold for positive attitude influence.

$Li$  = The level of influence.

$M_i$  = a constant that defines the magnitude of influence: the percentage with which the difference in attitudes between the two farmers can be overcome.

$C_n$  = The normalised credibility ( $C$ ), i.e. the credibility is adjusted to a number between 0 and 1 (from a number between  $-1$  and  $1$ ).

$\Delta A$  = the absolute difference in attitude between farmer A and farmer B.

Note that the mechanism used for one-to-one interactions applies for the interpretation of 'news' as well. After interaction, farmers check whether they want to convert. First the farmer checks which attitude — organic or conventional — prevails, then the farmer checks whether that attitude exceeds the threshold, i.e. the minimum value for attitude. If it exceeds the threshold, the farmer wants to convert if the prevailing attitude is not towards the market the farmer already produces for.

#### 4.2.6. Retirement and succession

Succession is the only procedure through which 'new' farmers enter the model and through which change in farming style is possible. Each farmer annually checks whether s/he has the age to retire (67). If s/he retires, there might be a successor. This depends on a random factor for 50%, and on the farmer's average income over the past five years for the remaining 50%. The lower the average income compared to the modal income of all farmers, the smaller the chance to have a successor (see Eq. (5)). This formula indicates that if the income is modal, the chance is 50%, while if the income is higher or lower the chance decreases relatively steep. If there is a successor, the model sets his/her age, innovativeness, management and productivity performance, and network according to the corresponding initialisation parameters (for more details see ODD+D, in Ambrosius and Kramer, in preparation). The farming style of the successor is determined by a predefined chance (parameter 'probability successor has the same farming style as the predecessor') that the successor has the same farming style as his predecessor. If it is not the same, the farming style is randomly selected. At last, the market attitudes are re-initialised. This is for 90% derived from the attitude of his best friend and for 10% randomly. The best friend is a connected farmer who is most similar to him in terms of farming style and age, and only influences the successor at his/her initialisation.

$$F_x = \frac{1}{1 + \exp^{-x/a}} \quad (5)$$

$F_x$  = Probability successor wants to take over the farm based on the average income of the farm over the past 5 years.

$x$  = The difference between the average income of the farmer over the past five years and the modal income.

$a$  = a parameter to adjust the income in the model to a representative value for the successor to evaluate the income of the farm.

#### 4.2.7. Income calculation

The main principle behind income calculation of farmers is that (1) differences in income between farmers is dependent on technical efficiency (Gocsik et al., 2015a), referred to as productivity performance in the model, and management efficiency (Commandeur, 2006; de Rooij et al., 2010), referred to as management performance in the model, and (2) that there is a representative difference in average cost and meat price between conventional and organic markets. For this, the model contains parameters for initial meat prices, average costs per pig, and rotation speed in conventional and organic markets as specified in the model by Gocsik et al. (2015a) (see Appendix 2). Farm income is derived based on the following formula:

$$I_t = (W * P_{m,t} - C_m * x) * (N_t * r_m) \quad (6)$$

$I_t$  = Annual farm income (in euro).

$W$  = Average carcass weight per pig in kg.

$P_{m,t}$  = Farm gate price (in euro) per kg meat in year  $t$  of market segment ( $m = org$  if organic;  $m = conv$  if conventional).

$C_m$  = Average cost price per pig of market segment (in euro).

$N_t$  = The number of pigs of the farmer agent at time  $t$ .

$r_m$  = Rotation speed (number of rounds of fattening pigs per year) of market segment.

$x$  = Efficiency factor of the farmer agent (for range see farmer initialisation variables in Appendix 1).

The two markets have different price mechanisms. Meat price on the conventional market is volatile and assumed to follow a stochastic process adopted from Gocsik et al. (2015a), hence being independent on the supply and demand on the market (Eq. (7)).

$$\overline{P_{conv,t+1}} = \overline{P_{conv,t}} + e^{\sigma \varepsilon + (\mu - 0.5\sigma^2)} \quad (7)$$

$\overline{P_{conv,t+1}}$  = Market price for conventional meat in year  $t$  (in € per kg).

$\sigma$  = constant.

$\varepsilon$  = an independent and identically distributed standard normal random variable.

$\mu$  = constant.

The market price for organic meat, in contrast, is assumed to be defined via organic market equilibrium. More specifically, we assume a constant elasticity demand function for organic meat combined with a constant trend in demand for organic meat (Eq. (8)), which is derived

based on statistical data and literature (see Appendix 3 for greater details).

$$\overline{P_{org,t}} = a * \frac{Q_{org,t}^{1-E}}{T^t} \quad (8)$$

$\overline{P_{org,t}}$  = Market price for organic meat in year  $t$  (in € per kg).

$Q_{org}$  = Amount of organic meat produced in North Brabant (kg).<sup>2</sup>

$T$  = A constant that represents the annual increase in demand.

$E$  = Price elasticity<sup>3</sup> of organic meat.

$a$  = constant.

#### 4.3. Exploratory analysis

Two categories of outputs were selected to analyse the effect of parameter changes on model outputs: the size of the organic market, i.e. the number of organic farmers and organic pigs; and the shares of farming styles in the organic market, i.e. the number of idealists, craftsmen and entrepreneurs in the organic market. First, an exploratory analysis on the effects of the social influence parameters on model outputs was done, because their initialization values are uncertain. The social influence parameters were: (1) the credibility thresholds: the level of credibility another farmer needs to have before it leads to social influence; (2) the weights of the factors that determine similarity: the weight of farm size, market and farming style were each set to zero in turn; and (3) the magnitude of influence once the credibility of the farmer exceeds the threshold (see Table 3).

#### 4.4. Sensitivity analysis

After the exploratory analysis, a full local sensitivity analysis was performed for three selected scenarios: a low threshold scenario ( $L$  = Threshold 0.25), the baseline scenario ( $B$  = Base = Threshold 0.5), and a high threshold scenario ( $H$  = Threshold 0.75). The full sensitivity analysis covered all model parameters as specified in Table 4. For each combination of parameter  $p$  and output variable  $v$ , the relative sensitivity of output  $v$  to parameter  $p$  was computed as:

$$\frac{v_2 - v_1}{p_2 - p_1} \bigg/ \frac{|v_s| + (|v_1| + |v_2|)/2}{|p_s| + (|p_1| + |p_2|)/2} \quad (9)$$

where:

$p_s$  is the scenario value of parameter  $p$ .

$p_1$  is the low value for SA of parameter  $p$ .

$p_2$  is the high value for SA of parameter  $p$ .

$v_s$  is the average output value of  $v$  for replicated runs with all parameters set to their scenario values.

$v_1$  is the average output value of  $v$  for replicated runs with (only) parameter  $p$  changed to value  $p_1$ .

$v_2$  is the average output value of  $v$  for replicated runs with (only) parameter  $p$  changed to value  $p_2$ .

For each parameter setting, for the exploratory analysis as well as the sensitivity analysis, the runs were replicated 1000 times with different random seeds. Initially, the baseline scenario was replicated 20,000 times. By comparing increasingly large subsets of these runs, following the guidelines by Troitzsch (2014), we found that variances of outputs

stabilise between 600 and 900 replications. Therefore, a replication factor of 1000 was used for all runs.

We ranked the most influential parameter per output, and then we summed up the ranks for each parameter over the (threshold) scenarios L, B, and H per category of output. This gives an overall rank for the most influential parameters per category of output. Two categories of outputs are distinguished: size of the organic market (i.e., number of organic pigs and number of organic farmers), and the diversity of farming styles in the organic market (i.e., number of organic idealists, organic craftsmen and organic entrepreneurs). We use the term ‘diversity’ for this measurement, because at initialisation there are only organic idealists: organic craftsmen and organic entrepreneurs increase the diversity of farming styles in the organic market. In the results section we discuss the influential parameters per category of output.

#### 4.5. Discussion model results with experts

Finally, three selected experts were asked to reflect on what they thought were the most important factors that influence the size of the organic market for output validation (Gilbert, 2019). The three experts were a pig sector economist, an organic slaughterhouse farm manager and an organic feed advisor. They were selected based on their experience in the organic pig sector over the past 20 years.

### 5. Model results

#### 5.1. Results of exploratory analysis

We explored the effect of three categories of social influence parameters on all selected outputs: two credibility threshold parameters (‘threshold lack of credibility’ and ‘threshold credibility’); three similarity parameters (‘weight farm size’, ‘weight market’ and ‘weight farming style’); and four different values for the ‘magnitude of influence’ parameter when influence takes place (see Table 5). The two credibility threshold parameters have most influence on the size of the organic market, then comes the similarity parameter ‘weight farming style’ and ‘weight farm size’. The credibility threshold parameters also affect the diversity of farming styles in the organic market: the number of organic farmers with a craftsmen and entrepreneurial farming style increases when the credibility thresholds are closer to zero (i.e. when interaction leads more often to influence). The ‘weight farming style’ also affects the diversity of farming styles in the organic market: when similarity in farming style does not affect whether or not influence takes place (i.e. ‘weight farming style’ is set to zero), diversity of organic farmers’ farming styles also increases. The magnitude of influence (referred to as ‘magnitude of influence’ parameter) and ‘weight market’ have hardly any effect on model outputs (see Appendix 4 and 5).

#### 5.2. Results of sensitivity analysis

Below the trends in sensitivity analysis are outlined for all parameters that are in the top five most influential parameters in one of the scenarios. This is done for the most influential parameters on the size of the organic market (eight parameters in total) and on the diversity of farming styles in the organic market (ten parameters in total).

##### 5.2.1. Size of organic market

Overall, the results show that the five most influential parameters on the number of organic farmers and pigs are (see Table 6): (1) trend in demand, which affects the organic meat price in our model (i.e. parameter ‘trend in demand’); (2) the social influence parameter, which determines the magnitude of influence that follows from interaction (i.e. ‘magnitude of influence’ parameter); (3) the parameter that determines the minimum value a farmers’ attitude needs to have for a farmer to start calculating the economic benefits of conversion (i.e., ‘threshold attitude for market conversion’); (4) the parameter that determines the farming

<sup>2</sup> When farmers calculate their expected income in organic farming we included a parameter to account for total additional supply of all other farmers that want to convert. We performed a sensitivity analysis on this parameter. It turned out that this hardly influences the outcomes, because the number of farmers that want to convert to the organic market at one point in time is so small that this hardly affects the outcomes of the model.

<sup>3</sup> A high price elasticity means that a small change in price results in a large change in demand, whereas a low price elasticity (i.e. inelastic demand) means that a small change in price results in a small change in demand.



**Table 3**

Three groups of scenarios of the social influence parameter settings for an exploratory analysis of its effects on model outcomes. The baseline scenario can be seen as belonging to all groups as “Threshold 0.5”, “Similarity Base”, and “Magnitude of influence 1.0”, respectively.

	Scenarios for social influence parameter settings										
		Threshold			Similarity			Magnitude of influence			
Name parameter	Base	0.75	0.25	0	xS*	xM*	xF*	0.8	0.6	0.4	0.2
Thr. lack of credibility (−1–0)	−0.5	−0.75	−0.25	0	−0.5	−0.5	−0.5	−0.5	−0.5	−0.5	−0.5
Thr. credibility (0–1)	0.5	0.75	0.25	0	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Weight farm size (0–100)	50	50	50	50	0	50	50	50	50	50	50
Weight market (0–100)	50	50	50	50	50	0	50	50	50	50	50
Weight farming style (0–100)	50	50	50	50	50	50	0	50	50	50	50
Magnitude of influence (0–1)	1	1	1	1	1	1	1	0.8	0.6	0.4	0.2

\* xS = scenario where weight farm size is set to zero, xM = scenario where weight market is set to zero; xF = scenario where weight farming style is set to zero.

**Table 4**

Parameter settings for the full local sensitivity analysis (SA) of the three selected scenarios that differ in the likelihood of influence.

Name parameter in model		Range	Likelihood of influence scenario's		
			Scenario value: $p_s$	Low value for SA: $p_1$	High value for SA: $p_2$
Thr. lack of credibility ( $x_1$ in Eq. (4))	[L: Low threshold scenario]	–1 - 0	–0.25	–0.3	–0.2
Thr. credibility ( $x_2$ in Eq. (4))		0–1	0.25	0.2	0.3
Thr. lack of credibility ( $x_1$ in Eq. (4))	[B: Baseline scenario]	–1 - 0	–0.5	–0.55	–0.45
Thr. credibility ( $x_2$ in Eq. (4))		0–1	0.5	0.45	0.55
Thr. lack of credibility ( $x_1$ in Eq. (4))	[H: High threshold scenario]	–1 - 0	–0.75	–0.8	–0.7
Thr. credibility ( $x_2$ in Eq. (4))		0–1	0.75	0.7	0.8
Weight farm size ( $W_f$ in Eq. (3))		0–100	50	45	55
Weight market ( $W_m$ in Eq. (3))		0–100	50	45	55
Weight farming style ( $W_r$ in Eq. (3))		0–100	50	45	55
Magnitude of influence ( $M_i$ in Eq. (4))		0–1	1	0.9	0.95
Probability a farmer collects information on desired market		0–1	0.5	0.55	0.55
Elasticity of demand for organic meat price ( $E$ in Eq. (8))		No range	–1.13	–1.14	–1.12
Trend in demand ( $T$ in Eq. (8))		No range	5	4	6
Probability successor has the same farming style as the predecessor		0–100	50	45	55
Number of peers on which successor bases his attitude		1–10	1	0	2
Threshold attitude for market conversion		0–1	0.8	0.75	0.85
Max attitude based on income		0–0.5	0.2	0.15	0.25
% of farmers that receive news		0–100	70	65	75
Chance other market is in the news		0–50	25	20	30
Chance that information seeking behaviour is the same for all farmers or based on a farmer's innovativeness		0–1	0.5	0.45	0.55
% successor's attitude based on peers		0–1	0.9	0.85	0.95
Income scaling factor ( $a$ in Eq. (5))		No range	30,000	28,000	32,000

**Table 5**

Effects of different social influence assumptions on the size of the organic market (i.e. number of organic farmers and pigs), and the distribution of farming styles in the organic market (each line average of 1000 runs).

Scenario	# organic farmers	# organic pigs	Organic craftsmen	Organic idealists	Organic entrepreneurs
Base	44	9348	1	43	1
Thr 0.75	23	6741	0	22	0
Thr 0.25	52	10,812	8	42	2
Thr 0	121	27,648	59	37	25
xS	37	8458	1	36	0
xM	45	9391	1	43	1
xF	51	11,015	16	29	6
M 0.8	44	9150	1	42	1
M 0.6	43	9171	1	42	1
M 0.4	41	8733	1	40	1
M 0.2	39	8578	0	38	1

style of the successor (‘probability successor has same farming style as predecessor’); and (5) ‘the elasticity of demand for organic meat’, which also influences the price of organic meat.

In addition, the results show that four out of eight parameters have a consistent influence on the size of the organic market over all three scenarios listed from highest to lowest influence (see Table 6): (1) an increase in demand (i.e. ‘trend in demand’) increases the number of organic farmers and organic pigs; (2) an increase in the threshold for a farmers’ attitude to start calculating the economic benefits of conversion decreases the number of organic farmers and organic pigs; (3) an increase in the likelihood of influence between farmers (i.e. ‘threshold credibility’) leads to more organic farmers and organic pigs (the results of the exploratory analysis revealed the same trend); and (4) an increase in the probability that the successor has the same farming style as his/her predecessor leads to a decrease in the number of organic farmers and organic pigs (i.e. ‘probability successor has same farming style as predecessor’).

The remaining parameters differ in their effects on the size of the organic market across the scenarios. In the scenario with a higher likelihood of influence (i.e. the low threshold scenario), a decrease in the magnitude of influence that follows from interaction (i.e. ‘magnitude of influence’) leads to *more* organic farmers and organic pigs, while in the scenario with a lower likelihood of influence (i.e. the baseline scenario and high threshold scenario) that same decrease leads to *less* organic farmers and organic pigs. This seems to indicate that when interaction less frequently leads to influence, the influence that takes place is more often positive. The same trend is the case for the negative social influence parameter (i.e. ‘threshold lack of credibility’): in the scenario with a higher likelihood of influence (i.e. low threshold scenario), a decrease in the likelihood of negative social influence leads to *more* organic farmers and organic pigs, while in the scenario with a lower likelihood of influence, that same decrease leads to *less* organic farmers and organic pigs. This seems to indicate that when interaction less frequently leads to

**Table 6**

Overview of parameters that are in the top five most influential parameters on either the number of organic farmers or on the number of organic pigs.

	Sensitivity of output on parameter <sup>a</sup>												Sum of ranks	Overall rank
	# Organic farmers						# Organic pigs							
Parameter name	L <sup>b</sup>	R <sup>c</sup>	B <sup>b</sup>	R	H <sup>b</sup>	R	L	R	B	R	H	R		
Trend in demand	0.47	2	0.51	4	0.57	5	0.69	2	0.71	1	0.69	6	20	1
Magnitude of influence	−0.70	1	0.76	1	0.39	7	−0.84	1	0.52	4	0.37	7	21	2
Threshold attitude for market conversion	−0.20	5	−0.62	2	−0.81	4	−0.22	5	−0.65	2	−1.00	4	22	3
Fraction successor's attitude based on peers	0.09	10	−0.35	5	1.33	3	0.17	6	−0.23	6	1.18	2	32	4
Elasticity of demand for organic meat price	−0.18	6	−0.28	6	−0.51	6	0.14	8	−0.43	5	−1.05	3	34	5
Threshold credibility	−0.31	4	−0.04	13	−3.12	1	−0.23	4	0.00	17	−1.72	1	40	6
Threshold lack of credibility	−0.02	15	0.54	3	1.52	2	−0.05	14	0.62	3	0.85	5	42	7
Prob successor same farming style as predecessor	−0.41	3	−0.17	8	−0.25	9	−0.25	3	−0.06	15	−0.25	8	46	8

<sup>a</sup> Sensitivity of the output to a small change in parameter.<sup>b</sup> Scenario names: L = Low threshold scenario; B = Baseline scenario; H = High threshold scenario (see Table 4).<sup>c</sup> R = Rank of the influence of the parameter on the output (where 1 = most influential).

influence, negative social influence stimulates conversion. In the baseline scenario stronger influence from successors' peers leads to *less* organic farmers and organic pigs, while in the high and low threshold scenarios this leads to *more* organic farmers and organic pigs. The same effect can be found on the number of organic idealists (see Appendix 7), meaning that this effect can be attributed to idealists, who have a more positive attitude towards organic when there is either a higher likelihood of influence in interaction (i.e. high threshold scenario) or a lower likelihood of influence in interaction (i.e. low threshold scenario). Finally, an increase in the price elasticity of demand for organic meat (the price elasticity is closer to one) leads to *more* organic pigs in the low threshold scenario, produced by *fewer* organic farmers. In the other scenarios, a lower price elasticity leads to fewer organic farmers *and* organic pigs. This effect suggests that a lower price elasticity favours farmers with a large farm size in the low threshold scenario (when there is a higher likelihood for influence). This scenario also results in more organic craftsmen (see Appendix 7).

### 5.2.2. Distribution of organic farmers' farming styles

Overall, the results show that the five most influential parameters on the organic farmers' farming styles are (see Table 7): (1) the price elasticity of demand for organic meat, which affects the number of organic craftsmen and organic entrepreneurs most; (2) the magnitude of influence when influence takes place; (3) the threshold for a farmers' attitude to start calculating the economic benefits of conversion (i.e., 'threshold attitude for market conversion'); (4) the probability the successor has the same farming style as his predecessor; and (5) the parameter that determines the fraction on which the successor's attitude is based on peers instead of a random value for attitude.

There is only one parameter that has a consistent effect on all three outputs (i.e. number of organic idealists, organic craftsmen and organic entrepreneurs) over all three scenarios. This is the trend in demand: a higher trend in demand (more demand) leads to more organic idealists, organic craftsmen and organic entrepreneurs. For the number of organic idealists there are five consistent parameters: (1) a lower price elasticity of demand for organic meat results in more organic idealists, irrelevant of the likelihood of influence; (2) a higher threshold for attitude leads to less organic idealists; (3) a higher probability that the successor has the same farming style as his predecessor leads to less organic idealists; (4) an increase in the percentage of farmers who receive news (i.e., '% of farmers that receive news') leads to more organic idealists; and (5) when similarity in farming style is more important for the credibility of another farmer (i.e. 'weight farming style'), the number of idealists increase. Two parameters are consistent in their effect on the number of organic craftsmen and organic entrepreneurs: (1) an increase in the fraction on which the successor bases his attitude on peers leads to less organic craftsmen and entrepreneurs; and (2) an increase in the threshold of credibility also leads to less organic craftsmen and organic entrepreneurs. Two parameters have a different effect on the number of

organic idealists, organic craftsmen and organic entrepreneurs across scenarios: (1) an increase in the magnitude of influence when influence takes place leads to less organic idealists in the low threshold scenario and baseline scenario, while it leads to an increase in organic craftsmen and organic entrepreneurs in these scenarios. For the high threshold scenario this is exactly the opposite. This indicates that when there is a higher likelihood of influence, craftsmen and entrepreneurs become more positive towards organic, while idealists less. (2) A lower likelihood of negative social influence (i.e. a decrease in the 'threshold lack of credibility') leads to more organic idealists in the low threshold scenario, and it leads to more organic craftsmen and organic entrepreneurs in the high threshold scenario. In the baseline scenario, a higher likelihood of negative social influence leads to more organic idealists, organic craftsmen and organic entrepreneurs. This indicates that disassociation actually stimulates organic farming diffusion.

### 5.3. Expert discussion on results

The experts reflected on what they thought were the three most important factors included in the model that influenced the size of the organic market over the past 20 years. Additionally, the experts were asked to reflect on the diversity of farming styles in general, and in the organic market over the past 20 years.

#### 5.3.1. Three most important factors for the size of the organic market

All experts thought market factors to be the most important factor for the size of the organic market. Their explanations were different: one argued that farm gate price stability in the organic market is the most important factor (price stability is regulated partly by a waiting list of the slaughterhouse for conventional farmers who want to convert), and two thought demand by consumers would be most important (see Table 8). Experts differed on the second most important factor. One expert thought that this was social influence among farmers, another expert thought social influence among consumers (not included in the model), and the third expert thought that shocks or events in the conventional market was the second most important factor. The third most important factor, according to all experts, was farm succession. According to these experts, most recently converted organic farmers are young farmers who think differently than their predecessors.

#### 5.3.2. Farming style diversity in the organic market

All experts are familiar with the farming styles used in the model. All argue that at the start of the organic market (from roughly 1980s till 2000) organic farmers were idealists, while in the course of time, idealistic reputation of organic farming disappeared. As a result, organic farmers now consist of craftsmen and a couple of entrepreneurs next to idealists. Experts gave two explanations for the increase in craftsmen in the organic market: either more craftsmen entered the organic market, or most organic idealists changed from a dominant idealist rationale to a

**Table 7**  
Overview of parameters that are in the top five most influential parameters on the number of organic idealists, organic craftsmen and/or organic entrepreneurs.

Parameter name	Sensitivity of output on parameter <sup>a</sup>															Sum of rank	Overall rank			
	# organic idealists					# organic craftsmen					# organic entrepreneurs									
	L <sup>b</sup>	R <sup>c</sup>	B <sup>b</sup>	R	H <sup>b</sup>	L	R	B	R	H	L	R	B	R	H					
Price elasticity demand for organic meat	-0.25	5	-0.30	4	-0.55	6	6.17	1	1.61	4	-3.20	1	-1.73	2	-6.27	1	5.07	1	25	1
Magnitude of influence	-0.74	1	-0.21	6	0.42	7	0.60	5	5.90	1	-0.94	4	0.62	7	4.87	2	-0.45	10	43	2
Threshold attitude for market conversion	-0.22	6	-0.41	2	-0.83	4	0.40	10	-1.61	3	0.36	9	1.13	4	-1.43	5	-1.07	2	45	3
Prob successor same farming style as predecessor	-0.40	3	-0.38	3	-0.23	9	-0.62	4	0.74	10	-1.17	2	-1.43	3	0.78	8	-1.04	3	45	3
% successor's attitude based on peers	0.14	8	-0.23	5	1.39	3	-1.29	2	-0.78	8	-1.15	3	-1.97	1	-1.27	6	-0.49	9	45	3
Threshold credibility	-0.30	4	0.11	9	-3.20	1	-0.51	8	-0.77	9	-0.05	15	-0.64	5	-0.40	13	-0.89	4	68	6
% of farmers that receive news	0.07	11	0.18	7	0.09	11	-0.89	3	-0.82	7	0.62	6	0.35	11	-0.90	7	0.75	5	68	6
Threshold lack of credibility	-0.03	14	0.02	17	1.59	2	0.53	6	3.00	2	-0.58	7	0.42	10	1.62	4	-0.68	7	69	8
Trend in demand	0.49	2	0.49	1	0.58	5	0.04	16	0.56	11	0.39	8	0.04	16	0.64	9	0.20	13	81	9
Weight farming style	0.05	12	0.10	10	0.17	10	0.53	7	-1.41	5	-0.14	13	-0.31	12	-1.71	3	-0.09	17	89	10

<sup>a</sup> Sensitivity of the output to a small change in parameter.

<sup>b</sup> Scenario names: L = Low threshold scenario; B = Baseline scenario; H = High threshold scenario (see Table 4).

<sup>c</sup> R = Rank of the influence of the parameter on the output (where 1 = most influential).

**Table 8**

Top three most important factors that influence the size of the organic market according to model results and experts.

	Model results	Expert 1	Expert 2	Expert 3
1	Trend in demand	Farm gate price stability	Consumer demand	Consumer demand
2	Magnitude of influence in interaction	Social influence among farmers	Social influence among consumers	Events in the conventional market
3	Threshold attitude for market conversion	Successors think differently than their predecessors	Successors think differently than their predecessors	Successors think differently than their predecessors

dominant craftsmen rationale to professionalise organic farming, Still, according to the experts, most organic farmers have some idealism in them.

## 6. Discussion

This research aimed to gain insight in what factors influence the size of organic pig farming (i.e., number of organic farmers and number of organic pigs) and the diversity of farming styles among organic pig farmers, by considering social influence mechanisms, market price dynamics and farmer heterogeneity. The exploratory analysis showed that when there is a higher likelihood of influence in interaction (i.e. credibility thresholds closer to zero), the numbers of organic farmers and organic pigs increase, as well as the diversity of organic farmers' farming styles. The latter also happens when similarity in farmers' farming style does not affect the credibility of another farmer. The sensitivity analysis showed that the most influential factor on the size of the organic market is the trend in demand. The most influential factors on the distribution of farming styles in the organic market were similar to the factors that affect the size of the organic market, except for the successors' farming style which was important for the diversity of farming styles, while trend in the demand was not. In addition, the importance and effect of parameters on outputs differed between number of organic idealists versus number of organic craftsmen and organic entrepreneurs. Experts categorised and confirmed that demand is the most important factor stimulating diffusion. They furthermore pointed to the importance of successors in the diffusion of organic farming, a trend also found in the model.

### 6.1. Market factors

One of the innovations in this model, compared to previous agent-based models on organic farming diffusion (Deffuant et al., 2002; Olabisi et al., 2015; Xu et al., 2018) is inclusion of market factors in the farmer decision-making process in addition to their personal and social factors. The importance of including demand is in line with previous research by Smith and Marsden (2004) and Rose et al. (2018b) who argued that the wider agricultural system should be taken into account (Rose et al., 2018), including consumer demand (Smith and Marsden, 2004), to understand diffusion processes of alternative farming strategies in general (Rose et al., 2018b), or organic farming in particular (Smith and Marsden, 2004). They both argued that considering other actors and components in the system, diminishes, though does not kill, the importance of individual farmer behaviour. Both our model results and experts judgement confirm that an increase in the trend in demand is the most important factor to stimulate organic market diffusion. In addition, increase in demand is related to an increase in the diversity of organic farmers' farming styles according to model results and expert discussion.

Another component of demand is the price elasticity of demand for organic meat, which we used to account for volatility in organic meat

price as a consequence of imbalances in supply and demand. Interviewed experts, however, argued that gains or losses caused by imbalances in supply and demand are currently taken by supply-chain actors instead of consumers, which basically hints towards a low price elasticity. To this end, further research focusing on dynamic price mechanism in an agent-based modelling framework might either be to model stakeholders, such as the role of slaughterhouses in the formation of prices as outlined by experts, or confirm the current level of price elasticity of demand for organic meat through empirical studies. Additionally, it would be interesting to identify and quantify factors that affect price elasticity of demand for organic meat. In particular, the growing supply of substitutes might affect both demand for organic meat and its price elasticity (Bielik and Sajbinorová, 2009; Delpont et al., 2017). Due to more available environment-friendly alternatives, e.g., plant-based meat, it can be hypothesized that the current level of price elasticity of demand for organic meat is higher than the one we adopted from Bunte et al. (2010), meaning that an increase in price of organic meat would force more consumers to switch to substitutes. Another point which affects the organic meat price is when organic farmers do not have a successor: the organic meat price will go up as these organic pigs disappear from the model. In reality, they might have been taken over by another farmer, which could be an interesting addition to the model.

Although one of the experts believed risk preferences related to meat price volatility to be an important factor for organic market conversion, we did not consider it in the model. In line with the observation of the expert, an hypothesis could be that risk-averse farmers in a less volatile organic market context, would have more incentives to convert to organic farming. Yet, quantification of the effect usually requires quite strong assumptions on the level of risk aversion, which is rather difficult to estimate. Furthermore, even in the farm-level context, research on dynamic decisions under uncertainty and risk preferences is limited (see, e.g., Spiegel et al., 2020). Hence, including risk preferences in agent-based modelling requires, first of all, further methodological research. The same applies to learning mechanism linked to organic farming, which has proven to be an important factor in conversion (Lamine and Bellon, 2009; Sutherland and Darnhofer, 2012). Instead, we assumed that intrinsic motivation shaped by the Social Identity Approach in interactions is the most important prerequisite to consider conversion to organic farming, discussed further below.

## 6.2. Social dynamics

The social identity approach was the theoretical backbone of the social interaction mechanism between farmers in the model. Four reference groups were distinguished which differed in importance between innovative and conservative farmers: farmers who have a high status compared to one's own status were more credible for innovative farmers, while similar farmers (in farm size, market and farming style) were more credible for conservative farmers. In addition, following the social identity approach, farmers who were respectively low in status or dissimilar were considered outgroups and disassociation followed through negative social influence. Model parameters were operationalised to determine how much credibility (or lack of credibility) was necessary before influence takes place (also referred to as the likelihood of influence), the magnitude of influence when influence takes place, and a threshold for the value of attitude before a farmer continues to calculate the expectation income in the alternative market. Model results showed that the likelihood of influence in interaction affected organic market diffusion, and that similarity in farming styles obstructs diffusion of organic farming and diversity of organic farmers' farming styles.

### 6.2.1. Likelihood of influence

A higher likelihood of influence increases the number of organic farmers and organic pigs. It also leads to fewer organic idealists, and more organic craftsmen and organic entrepreneurs in the organic

market. This indicates that when different types of farmers influence each other more easily, i.e. are more open to each others' ideas, it favours the attitude towards organic of craftsmen and entrepreneurs, but disfavours the attitude of conventional idealists. Taking expert observations into account, a more positive attitude of entrepreneurs and craftsmen regarding organic is indeed the case. But, probably more importantly, the effect of threshold values on output supports the argument made by Flache et al. (2017) that in agent-based models attention should be paid to the technical implementation of interaction between agents and the sensitivity of the outcome on the parameterisation of the interaction mechanism. In other words, model operationalisation of a conceptual model on influence affects model outcomes.

### 6.2.2. Negative social influence

An important model assumption, following from the social identity approach, was negative social influence to avoid association with outgroups. In this research, the effect of disassociation between farmers on number of organic farmers and organic pigs depend on the likelihood of influence: when there was a higher likelihood of influence (in the low threshold scenario and baseline scenario), negative social influence was actually a motivation for craftsmen and entrepreneurs to convert, while when there was a smaller likelihood of influence (in the baseline scenario and high threshold scenario), negative social influence was a motivation for conventional idealists to convert to organic farming. This means that disassociation (negative social influence) was an incentive for craftsmen and entrepreneurs to stay conventional in the scenario with a smaller likelihood for influence (high threshold scenario), which is in line with empirical research that showed that craftsmen and entrepreneurs oppose idealistic motivations (de Rooij et al., 2010). It also means that disassociation with outgroups was an incentive for craftsmen and entrepreneurs to convert to organic farming in the scenarios with a higher likelihood for influence. This is in contrast with empirical research, which showed that craftsmen and entrepreneurs oppose idealistic motivations for organic farming (de Rooij et al., 2010).

The question is whether disassociation can be an incentive to consider market conversion in real life. So far, empirical evidence for or against negative social influence is poor (Flache et al., 2017). A way forward on this discussion would be to further explore model results with only positive social influence in accordance with the critique by Flache et al. (2017). Given the results, it is likely that this would lead to fewer organic farmers in the scenarios with less likelihood for influence (i.e., base and high scenario), and it would lead to fewer organic craftsmen and entrepreneurs in the scenarios with more likelihood for influence (i.e., base and low threshold scenarios).

### 6.2.3. Similarity in influence

According to the social identity theory, influence occurs through similarity (Hornsey, 2008). The results of the model showed that the three factors that defined similarity (i.e., market, farm size and farming style) hardly affected the number of organic farmers, whereas similarity in farming style did affect the organic farmers' farming styles: if similarity in farming style did not influence the credibility of another farmer, the number of organic craftsmen and organic entrepreneurs increased, while the number of organic idealists decreased. Similarity in farming style, therefore, obstructs diffusion of organic farming from idealists to craftsmen and entrepreneurs, given that the initial organic farmers were idealists. This social identity mechanism can, therefore, explain the finding by de Rooij et al. (2010) that entrepreneurs and craftsmen oppose organic farming because of idealist organic farmers. According to the experts, this mechanism mainly applies to the older generation farmers, since young farmers seem to have another rationale for converting than existing farming styles. The rationale used by the young farmers, mentioned by experts, fits the constructivist discourse identified by de Rooij et al. (2010): they accept changes in societal norms regarding animal welfare and recognise the need to respond to this.



Young farmers are, therefore, not obstructed by organic farmers' farming styles. In addition, it is likely that similarity in farming styles does not weigh heavily within the decision-making process for some entrepreneurs and craftsmen, since they did enter the organic market according to the experts. Finally, experts also mentioned that most organic idealists changed from a dominant idealist rationale to a dominant craftsmen rationale to professionalise organic farming. This is interesting input for further refinement of the social influence mechanism: e.g., multiple farming style reference groups exist within one farmer (instead of one), and the dominant farming style is flexible to the context.

#### 6.2.4. Status

The effect of status on the number of organic idealists was seen by the relatively high number of organic idealists in the scenarios with a lower likelihood for influence: organic farmers had a high idealist status compared to the idealist status of conventional farmers. This triggered especially idealist farmers in the higher credibility threshold scenarios to convert. The effect of the status mechanism was, furthermore, seen in the relative importance of the price elasticity parameter on the number of organic entrepreneurs whose status is dependent on income: in the scenario with a small likelihood for influence, a decrease in price elasticity increased organic entrepreneurs (a smaller price elasticity prevents the organic meat price to drop relatively fast with any new supply, which is favourable for organic farmers' income and, therefore, their entrepreneurial status); in the scenarios with a larger likelihood for influence, a decrease in price elasticity resulted in fewer organic entrepreneurs (despite a relatively small drop in organic meat price with extra supply, and a relatively small decrease in entrepreneurial status of organic farmers). One explanation could be that the higher likelihood for influence outweighed the effect of status, since relatively lower status farmers could still influence an entrepreneurial attitude towards organic. The status mechanism in the high threshold scenario can, therefore, explain why, e.g., entrepreneurs enter the organic market, and/or why homophily in farming styles in markets develop.

#### 6.3. New entrants

An interesting result of the model, is that new entrants are important for the diffusion of organic farming. The influence of new entrants in this research went via two factors: their farming styles and their peer influence. A higher chance that the successor had the same farming style as his/her predecessor led to fewer organic farmers and organic pigs, irrespective of the parametrisation of the social influence mechanism in the model. This result was confirmed by the experts. Moreover, it is in line with previous research findings that associated organic farmers more often with an urban background (Padel, 2001), assuming that farmers with an urban background have a different farming style through different peers. It is also in line with the social identity theory (Burton and Wilson, 2006), assuming that successors have a higher chance for different farming styles than their predecessors through different reference groups. More research in the farming styles of successors, including the diversity of farming styles and development of new rationales, would be interesting for gaining insight in diffusion of alternative farming practices. It should be noted that this result also means that when farmers have a smaller chance to have a successor, the number of organic farmers would decrease and the diversity of organic farmers' farming styles as well. The importance of successors in conversion to organic is, however, in contrast with studies that found no correlation between age and early or late adopters of organic farming (Parra-Lopez et al., 2007), or between age and farmers with a conservation identity (Burton, 1998). The role of successors in adoption of alternative farming practices might, therefore, be different per context.

#### 6.4. Farmer and network initialisation

Finally, in this research we used a predefined network for farmers, predefined characteristics for farmers and markets, including the distribution of markets and farming styles, and the instantiation of attitudes among farmers with a specific farming style. Different instantiations could have an effect on model results. For example, a distribution of age that better resembles reality (more older farmers), could affect more changes in farming styles in the model and, therefore, more organic farmers, or more quitters. Future empirical research on farmers' characteristics including their network and/or sensitivity analysis on the instantiation of market parameters, attitude distribution, and pig farmer characteristics including their network can give more insight in the effects of different initial situations on diffusion of added-value markets. In addition, it would be interesting to gain more insight in social influence mechanisms among consumers that affect demand of organic meat, given a static price, through e.g. agent-based modelling.

#### 6.5. Methodological implications

Currently it is challenging to find out how empirical and sociological knowledge can be brought to bear upon policy advice. In this research we used the social identity theory to gain better insight in the mechanisms behind social influence. As discussed above, this gives a good starting point for operationalizing social influence and in some parametrization scenarios similarities can be found in model outputs and trends in the pig farmer population. In others, contradictions still exist (such as negative social influence as motivation for conversion). Agent-based modelling serves as a good method to further explore how social identity theory affects decision-making and macro patterns, by identifying reference groups, status symbols per reference groups, and changes in reference groups. Specific model operationalisations should, however, still be explored further, such as the value for thresholds, and the effect of only positive social influence versus positive and negative social influence.

#### 6.6. Policy implications

If policy makers aim to promote alternative farming strategies, they have several policy instruments at their disposition. There are legal instruments for labelling and certification. There are financial instruments, such as payments for conversion and continued organic production, investment grants, and biodiversity offsets to penalise intensive farming practices through taxes. Finally, there are communicative instruments that focus on changing social norms in society (Allen and Hof, 2019; Stolze and Lampkin, 2009; Van Kooten, 2019).

Since supply in reality is largely regulated by an organic slaughterhouse, and consumer prices are kept stable by supermarkets, the level of demand for organic meat cannot be addressed via consumer price, and the price elasticity of demand cannot be exploited. This is a constraint on diffusion of organic farming, since our results suggest that price elasticity of demand is an important mechanism to increase the trend in demand to stimulate diffusion of organic farming. Given the importance of the trend in demand for organic pork meat, two alternative financial policy instruments can be suggested. Both need further research to support the policy instrument that best fits organic farming diffusion. First, structural payments to organic pig farmers can decrease the cost price for organic pigs. A decrease in production costs should lead to a decrease in farm gate price, which in turn might lead to a decrease in consumer price. Given the high price elasticity of demand for organic pork meat (Bunte et al., 2010), a lower consumer price for organic pork should lead to a high increase in demand for organic pork. Increase in demand then leads to increase in supply. A second policy direction would be to stimulate consumers to switch from conventional pork to organic pork. If we assume that conventional pork consumers can be triggered by price changes to start consuming organic pork,

biodiversity offsets to penalise conventional pork can equalize prices between conventional pork and organic pork. This does require more empirical research into cross-price elasticities of organic meat in comparison to conventional meat.

Also, two communicative policy instruments can be interesting given the currently regulated market. First, communicative policy instruments can be developed that target consumer demand by, e.g., explaining the benefits of organic farming to consumers as to try and change social norms among consumers in favour of organic pork instead of conventional pork (e.g., Konuk, 2018; Vega-Zamora et al., 2019). The second direction for policy is to focus on new entrants, as this might contribute to diversity in farming styles in the farmer population and therewith diffusion of alternatives. Communicative policy instruments can focus on improving the image of farming within society for the younger generation. Financial policy instruments can focus on easing the entrance of young farmers into the farmer population. Both are interesting directions to further explore.

## 7. Conclusions

The integrated systems approach adopted in this research, integrating sociological and economic factors that explain farmer decision-making behaviour in an agent-based model, showed that both disciplines contribute to a better understanding of the diffusion of organic farming. First, this research showed that consumer demand is the most important limiting factor for diffusion of organic farming. This implies that it is important for researchers and policy-makers to go beyond

individual farmer decision-making to understand diffusion of organic farming and include market price dynamics in their analysis. Second, this research showed that the social identity approach serves as a helpful framework to capture empirical and sociological knowledge of farmer decision-making and understand the diffusion of organic farming. The social identity approach in this research showed that new entrants contribute to diffusion of organic farming through diversification of farmers' farming styles. Policy-makers and researchers should, therefore, pay attention to facilitating new entrants into the pig farmer population, and to better understanding the development of successors' farming styles.

## Declaration of Competing Interest

None.

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## Appendix A. Appendices

### A.1. State variables of farmers

**Table 9**

State variables of farmers.

State variables	Range	Initialisation	Static or dynamic?
Innovativeness	[0–1]	Normal distribution 0.5 0.2. 0 is conservative, 1 is innovative	Static
Age	{37, ..., 67}	Random	Dynamic
Market-name <sup>a</sup>	{Conventional, organic}	On for each market; read from file (1958 conventional farmers; 6 organic farmers; Biologica, 2003; CBS, 2000)	Dynamic
Number of pigs <sup>a</sup> (i.e. farm size)	{1, ..., 1e4}	Read from file (1,448,220 conventional pigs; 2393 organic pigs; Biologica, 2003; CBS, 2000)	Static
Area indoor	{0, 5000}	Read from file	Static
Year last investment <sup>b</sup>	{1977; ...}	Uniform distribution	Dynamic
Management performance	[0.5, 1.5]	Normal distribution 1 0.005	Static
Productivity performance <sup>b</sup>	[0.5, 1.5]	Normal distribution 1 0.005	Static
Overall efficiency factor	[0.5, 1.5]	Average of management performance and productivity performance	Static
Entrepreneur-status <sup>c</sup>	[–1–1]	Average of the normalised income and normalised farm size	Dynamic
Craftsman-status <sup>c</sup>	[–1–1]	Normalised productivity performance	Static
Idealist-status <sup>c</sup>	[–1–1]	Defined by market-name: - Organic: normal distribution 0.8 0.1 - Conventional: normal distribution –0.8 0.1	Dynamic
Farming style reference group	{Idealist; entrepreneur; or craftsman}	1%, 30%, 69% of farmer population respectively; all organic farmers are idealists	Static
Attitude conventional <sup>c</sup>	[0–1]	Organic farmers: normal distribution 0.1 0.1 Conventional: normal distribution 0.85 0.1	Dynamic
Attitude organic <sup>c</sup>	[0–1]	Organic farmers: normal distribution 0.85 0.1 Conventional craftsmen: normal distribution 0.3 0.1 Conventional entrepreneurs: normal distribution 0.1 0.1	Dynamic

Note that the income at initialisation and throughout the model run is normally distributed, because farmers base their cost price in their market on the 'overall efficiency factor' multiplied by the 'average costs per pig' (see Table 10), see also Eq. (6).

<sup>a</sup> (Biologica, 2003; CBS, 2020a, 2020b).

<sup>b</sup> (Gocsik et al., 2015a, 2015b).

<sup>c</sup> Based on qualitative descriptions of Commandeur (2006) and de Rooij et al. (2010).

## Appendix B. State variables of markets

**Table 10**  
State variables of markets.

State variables	Range	Initialisation	Static or dynamic?
Name market	{Conventional, organic}	1 conventional market; 1 organic market.	Static
Average costs per pig <sup>a</sup>	[100,300]	Conventional: 119.41; Organic: 243.85	Static
Rotation speed <sup>b</sup>	[2.0–4.0]	Conventional: 3.09 Organic: 2.82	Static
Conversion costs per m2 <sup>c</sup>	370	Conventional: 370; Organic: 370	Static
m2 indoor per pig <sup>b</sup>	[0.8–1.3]	Conventional: 0.8; Organic: 1.3	Static
m2 outdoor per pig <sup>b</sup>	[0–1]	Conventional: 0; Organic: 1	Static
Meat price per kg <sup>b</sup>	[0, ∞)	Conventional: 1.27; Organic: 2.54	Dynamic
Meat price per pig	[0, ∞)	Computer from meat price per kg	Dynamic
Meat price history per pig <sup>d</sup>	[0, ∞)	Conventional: 1.66 0.97 1 1.24 1.12 Organic: 2.92 2.11 2.23 2.28 2.54	Dynamic

Note: The standard deviation of the technical and management efficiency factors of the farmers is derived from the standard normal distributions for feed conversion, mortality rate, and daily growth that influence the spread in cost price among pig farmers (Gocsik et al., 2015a).

<sup>a</sup> Own calculation derived from (Gocsik et al., 2015a).

<sup>b</sup> (Gocsik et al., 2015a).

<sup>c</sup> Personal communication with R. Hoste (2017), economist at Wageningen Economic Research.

<sup>d</sup> Derived from a random generator based on the closed-form expression function for meat price used in this model and adopted from Gocsik et al. (2015a).

## Appendix C. Details for conventional and organic meat price equations

### C.1. Conventional meat price equation

$$\overline{P}_{conv,t+1} = \overline{P}_{conv,t} + e^{\sigma\epsilon + (\mu - 0.5\sigma^2)} \quad (10)$$

$\overline{P}_{conv,t+1}$  = Price per kg of conventional meat in year  $t$  (euros per kg).

$\sigma = 0.12$ .

$\epsilon = 0.5$ .

$\mu = 0$ .

### C.2. Organic meat price equation

For the organic market we assumed a constant elasticity function for demand in organic meat:

$$\overline{P}_{org,t+1} = a * \frac{Q_{org}^{1/E}}{T^t} \quad (11)$$

$\overline{P}_{org,t+1}$  = Market price for organic meat (euros per kg).

$a$  = constant.

$Q_{org}$  = Amount of organic meat produced in North Brabant that can be sold for  $P_{org}$ , i.e. demand for organic meat (kg).

$E$  = Elasticity of demand for organic meat to the market price for organic meat.

$T$  = Trend in organic demand per year.

We assume that (1) price elasticity  $\epsilon = -1.13$  following Bunte et al. (2010); (2)  $T$  is 1.05, i.e. a 5% yearly increase in demand in organic meat, following Verhoef (2005); (3) in 2000  $P_{conv}^{2000} = 0.5 * P_{org}^{2000}$  following Gocsik et al. (2015a)' assumption on the relation between conventional and organic meat prices, with  $P_{conv}^{2000} = 1.27$ ; (4) in 2000 16% of organic farmers and 26% of organic pig places in the Netherlands were in the province of North Brabant, i.e. average % over the years 2011–2019 (CBS, 2020a, 2020b); (5) one pig outputs 92.4 kg meat following (Gocsik et al., 2015a); (6) the rotation speed of organic pig places in the Netherlands during the model run is 2.82 following (Gocsik et al., 2015a) (7) in 2000 there were 9302 organic pig places in the Netherlands (own calculation following Hoste, 2005). This means that in 2000 there were  $0.26 * 9302 = 2393$  organic pig places,  $2393 * 2.82 = 6748.26$  organic pigs were slaughtered, and  $6748.26 * 92.4 = 623,539.22$  kg of organic pig meat was produced in North Brabant; and (8) all organic meat produced in North Brabant in 2000 could be sold for organic price. Based on these assumptions, the demand function can be derived by plugging-in the values for 2000<sup>4</sup>:

$$\overline{P}_{org} = a * \frac{Q_{org}^{1/E}}{T_{org}^t} \quad (12)$$

<sup>4</sup> The value for price elasticity of demand was adopted from Bunte et al. (2010), who derived it based on an experiment run in 2006.

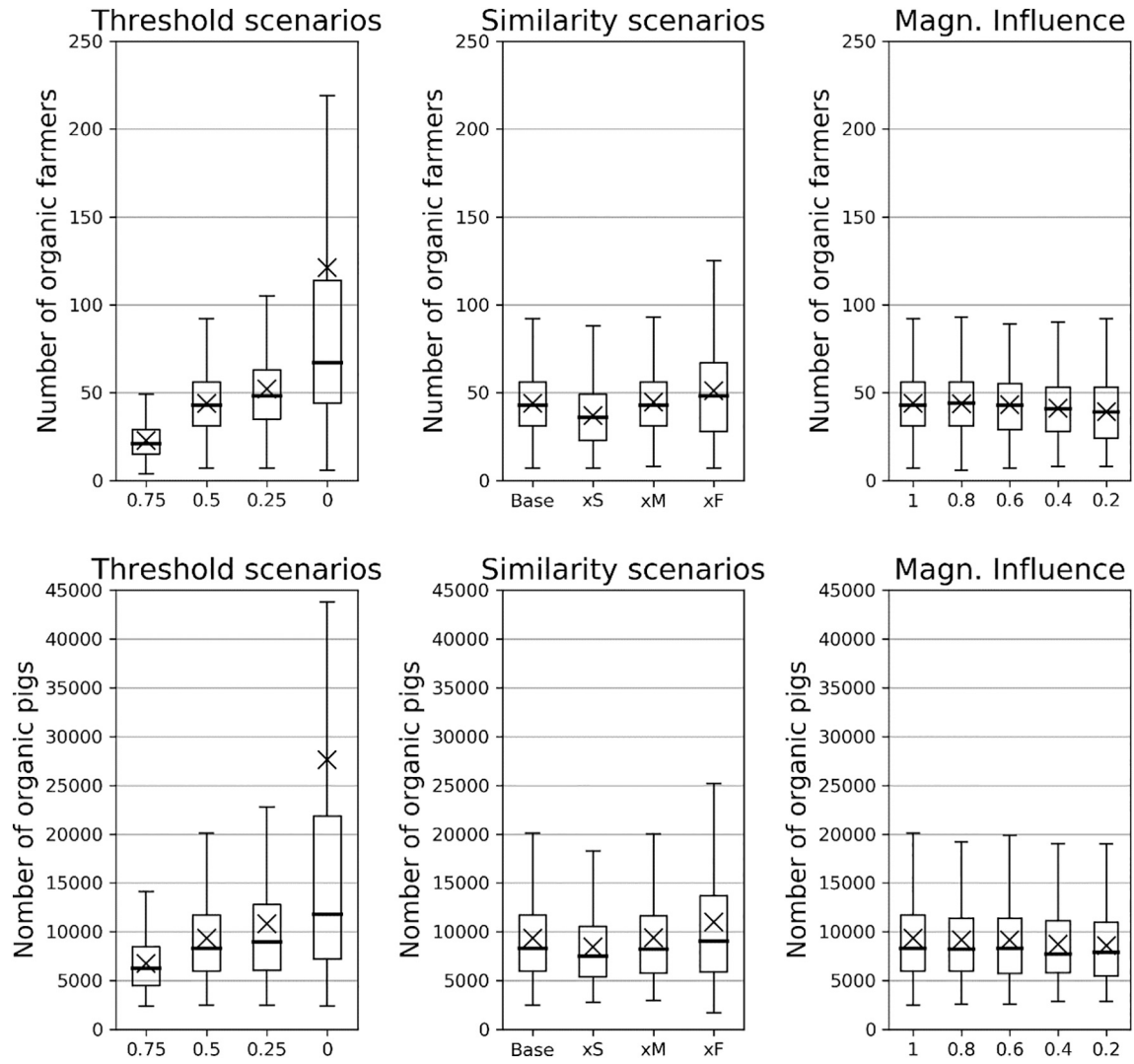
$$2.54 = a^* \frac{623539.22^{1/-1.13}}{1.05^0} \quad (13)$$

$$a = \frac{2.54}{623539.22^{1/-1.13}} = 341217.85 \quad (14)$$

The demand function for organic meat is:

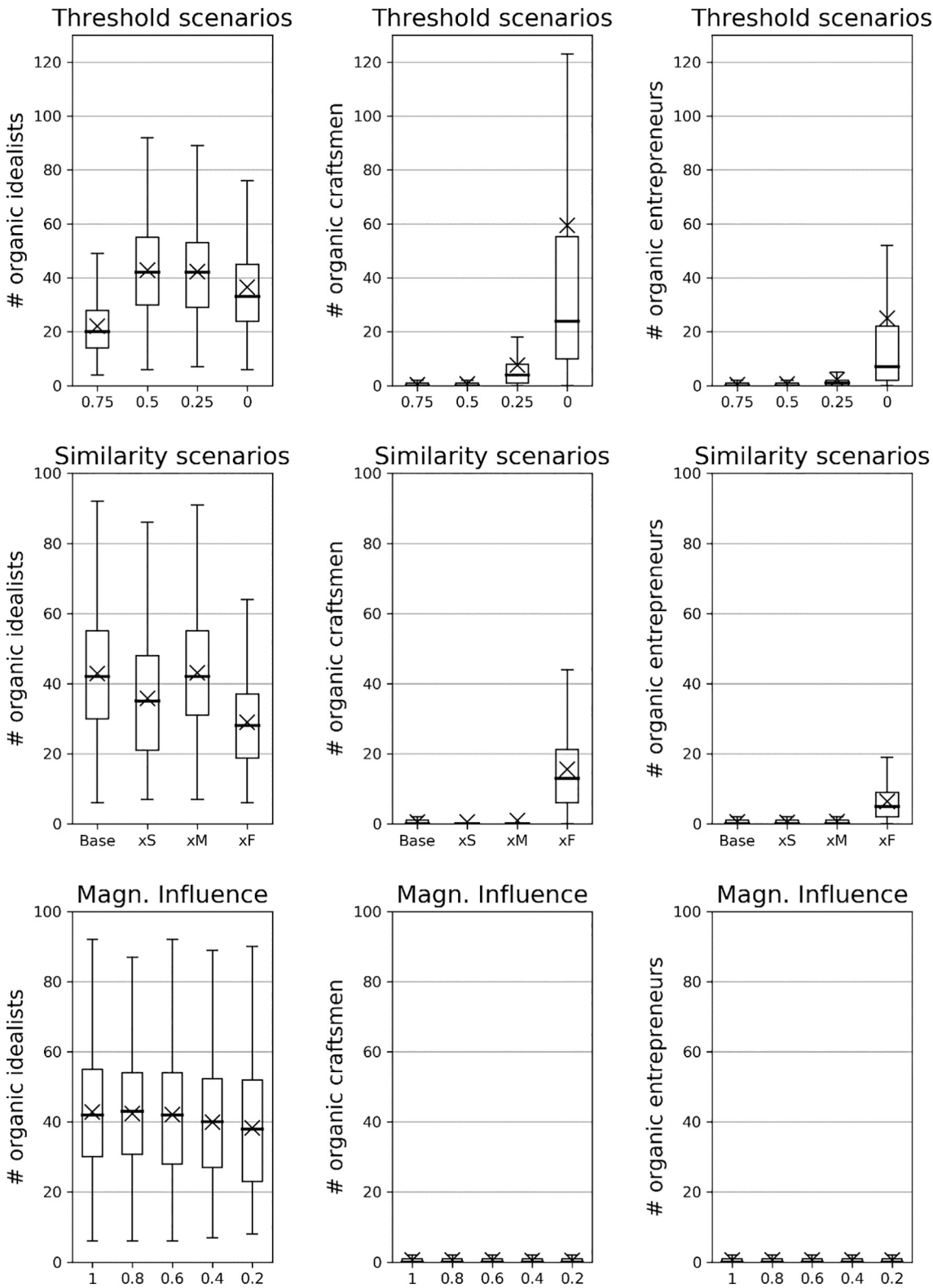
$$\overline{P}_{org} = 341217.85 * \frac{Q_{org}^{1/-1.13}}{1.05^t} \quad (15)$$

#### Appendix D. Results exploratory analysis – effect of social influence parameters on size organic market (excl. outliers)



#### Appendix E. Results exploratory analysis - effect of social influence parameters on diversity of farming styles (excl. outliers)





## Appendix F. Results sensitivity analysis

**Table 11**

Scaled sensitivity of the model outputs to the model parameters and their rankings. Outputs Number organic farmers and Number organic pigs.

	Sensitivity of output on parameter <sup>a</sup>												Sum of ranks	Overall rank
	# Organic farmers						# Organic pigs							
Parameter name	L <sup>b</sup>	R <sup>c</sup>	B <sup>b</sup>	R	H <sup>b</sup>	R	L	R	B	R	H	R		
Trend in demand	0,47	2	0,51	4	0,57	5	0,69	2	0,71	1	0,69	6	20	1
Magnitude of influence	−0,70	1	0,76	1	0,39	7	−0,84	1	0,52	4	0,37	7	21	2
Threshold attitude for market conversion	−0,20	5	−0,62	2	−0,81	4	−0,22	5	−0,65	2	−1,00	4	22	3
Fraction of successor's attitude based on peers	0,09	10	−0,35	5	1,33	3	0,17	6	−0,23	6	1,18	2	32	4
Elasticity of demand for organic meat price	−0,18	6	−0,28	6	−0,51	6	0,14	8	−0,43	5	−1,05	3	34	5
Threshold credibility	−0,31	4	−0,04	13	−3,12	1	−0,23	4	0,00	17	−1,72	1	40	6
Threshold lack of credibility	−0,02	15	0,54	3	1,52	2	−0,05	14	0,62	3	0,85	5	42	7
Prob successor same farming style as predecessor	−0,41	3	−0,17	8	−0,25	9	−0,25	3	−0,06	15	−0,25	8	46	8
Weight farming style	0,05	12	−0,20	7	0,16	10	0,05	13	−0,16	10	0,13	10	62	9
Info seeking homogeneous or heterogeneous	0,13	8	0,10	11	−0,07	14	0,14	9	0,20	7	−0,03	16	65	10
Weight market	−0,11	9	0,01	16	−0,27	8	−0,12	10	−0,08	14	−0,22	9	66	11
Prob info seeking behaviour	0,05	13	−0,10	10	0,08	12	0,09	12	−0,17	9	0,07	13	69	12
Weight farm size	0,16	7	0,05	12	−0,01	17	0,12	11	0,10	13	−0,11	12	72	13
% of farmers that receive news	0,06	11	0,00	18	0,11	11	−0,02	15	0,11	12	0,12	11	78	14
Income scaling factor	0,01	17	0,03	14	0,05	16	0,16	7	0,13	11	0,04	15	80	15
Max attitude update based on income	−0,02	14	0,14	9	−0,07	15	−0,02	16	0,17	8	0,00	18	80	15
Chance other market is in news	0,00	18	0,03	15	0,08	13	−0,01	18	0,01	16	0,05	14	94	17
# peers on which successor bases attitude	−0,01	16	0,00	17	0,00	18	−0,01	17	0,00	18	−0,01	17	103	18

<sup>a</sup> Sensitivity of the output to a small change in parameter.

<sup>b</sup> Scenario names: L = Low threshold scenario; B = Base scenario; H = High threshold scenario (see Table 4).

<sup>c</sup> R = Rank of the influence of the parameter on the output (where 1 = most influential).

**Table 12**

Scaled sensitivity of the model outputs to the model parameters and their rankings. Outputs idealists craftsmen and entrepreneurs in organic.

	Sensitivity of output on parameter <sup>a</sup>																		sum of ranks	overall rank
	# Idealists in organic						# Craftsmen in organic						# Entrepreneurs in organic							
Parameter name	L <sup>b</sup>	R <sup>c</sup>	B <sup>b</sup>	R	H <sup>b</sup>	R	L	R	B	R	H	R	L	R	B	R	H	R		
Elasticity of demand for organic meat price	−0,25	5	−0,30	4	−0,55	6	6,17	1	1,61	4	−3,20	1	−1,73	2	−6,27	1	5,07	1	25	1
Magnitude of influence	−0,74	1	−0,21	6	0,42	7	0,60	5	5,90	1	−0,94	4	0,62	7	4,87	2	−0,45	10	43	2
Threshold attitude for market conversion	−0,22	6	−0,41	2	−0,83	4	0,40	10	−1,61	3	0,36	9	1,13	4	−1,43	5	−1,07	2	45	3
Prob successor same farming style as predecessor	−0,40	3	−0,38	3	−0,23	9	−0,62	4	0,74	10	−1,17	2	−1,43	3	0,78	8	−1,04	3	45	3
Fraction of successor's attitude based on peers	0,14	8	−0,23	5	1,39	3	−1,29	2	−0,78	8	−1,15	3	−1,97	1	−1,27	6	−0,49	9	45	3
Threshold credibility	−0,30	4	0,11	9	−3,20	1	−0,51	8	−0,77	9	−0,05	15	−0,64	5	−0,40	13	−0,89	4	68	6
% of farmers that receive news	0,07	11	0,18	7	0,09	11	−0,89	3	−0,82	7	0,62	6	0,35	11	−0,90	7	0,75	5	68	6
Threshold lack of credibility	−0,03	14	0,02	17	1,59	2	0,53	6	3,00	2	−0,58	7	0,42	10	1,62	4	−0,68	7	69	8
Trend in demand	0,49	2	0,49	1	0,58	5	0,04	16	0,56	11	0,39	8	0,04	16	0,64	9	0,20	13	81	9
Weight farming style	0,05	12	0,10	10	0,17	10	0,53	7	−1,41	5	−0,14	13	−0,31	12	−1,71	3	−0,09	17	89	10
Weight market	−0,11	10	−0,18	8	−0,28	8	−0,18	12	1,01	6	0,00	18	0,00	18	0,45	12	0,23	12	104	11
Info seeking homogeneous or heterogeneous	0,13	9	0,04	13	−0,07	14	0,02	17	0,26	14	−0,29	12	0,58	8	0,59	11	0,55	8	106	12
Income scaling factor	0,02	16	0,04	14	0,07	16	−0,26	11	−0,10	15	−0,87	5	−0,45	9	0,34	15	−0,74	6	107	13
Prob info seeking behaviour	0,04	13	−0,02	15	0,08	12	−0,07	15	−0,42	13	−0,34	10	0,63	6	−0,60	10	0,19	14	108	14
Max attitude update based on income	−0,02	15	0,07	11	−0,08	13	0,17	13	0,53	12	0,12	14	0,08	15	0,35	14	0,39	11	118	15
Weight farm size	0,16	7	0,06	12	−0,01	17	0,48	9	0,02	17	0,04	16	0,23	13	−0,10	16	0,17	15	122	16
Chance other market is in news	0,00	18	0,02	16	0,07	15	−0,15	14	0,07	16	0,33	11	0,12	14	0,08	17	0,13	16	137	17
# peers on which successor bases attitude	−0,01	17	0,00	18	0,00	18	−0,02	18	−0,02	18	0,03	17	−0,01	17	−0,05	18	−0,02	18	159	18

<sup>a</sup> Sensitivity of the output to a small change in parameter.

<sup>b</sup> Scenario names: L = Low threshold scenario; B = Base scenario; H = High threshold scenario (see Table 4).

<sup>c</sup> R = Rank of the influence of the parameter on the output (where 1 = most influential).

## Appendix G. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.agry.2021.103336>.

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