Agent-based simulation of competing sustainability enhancing strategies for the pork supply chain

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Abstract:. The alarming state of the primary pork sector urges policy makers and supply chain actors to design new business models that push competition away from price competition only. The present drive toward more sustainably produced meat offers opportunities. On the other hand, consumer preferences, consumers budgets and social norms must be taken into account. These may be influenced by communication campaigns and occasional interactions between consumers. Only when the complexity and the dynamics of the system are well-understood, successful long-term strategies can be designed. Multi-agent simulation incorporating the characteristics of pork supply chain actors can contribute to that understanding. This paper proposes an agent-based simulation that represents diverse types of producers, consumers and intermediate supply chain actors. It implements four potential interventions. Outcomes are presented in which the four scenarios are implemented simultaneously in different combinations. The conclusion is that the tool can be useful for two purposes: for all stakeholders to understand potential effects of interventions, and for supply chain actors to understand potential effects of their own decisions.

1 Introduction

Despite the alarming state of the primary pork sector, new business models involving more sustainable meat production have so far not managed to capture a large market share. The reasons are diverse. First, the meat supply chain is characterized by short term markets, while investments in sustainability certification only pay off after a longer time interval. Moreover, hardly any new brands are developed at the producer level, pushing competition towards price competition only (de Jonge and Van Trijp 2013). Finally, the dynamic dependencies between consumer buying behaviour, the availability of sustainable meat in the supermarket, and the behavioural norms evolving from these dependencies, pose an additional barrier on the uptake of sustainable meat production.

In this paper we introduce a multi-agent simulation that incorporates the characteristics of pork supply chain actors. The purpose is to support the design of long term strategies towards sustainability by policy makers and supply chain actors. Previous agent-based simulations of artificial markets and supply chains have added to the understanding of realistic features such as local interaction, learning and time dynamics (e.g., Kirman 2008, Lacagnina and Provenzano 2010, Mizgier et al. 2012). Agent-based simulations allow for differentiation of actors' characteristics (heterogeneity) and the diffusion of social norms. This may considerably affect the overall sustainability levels. Fluctuations induced by consumer demand or batch deliveries have been shown to induce pork cycle and bullwhip effects and to propagate through the chain up to producer bankruptcies.

The agents in the simulation represent diverse types of producers, consumers and intermediate supply chain actors. Through brand positioning, societal pressure and opinion dynamics, patterns of sustainable meat production and distribution emerge. The simulation’s setup and scenarios are informed by a research project conducted in 2013, which comprised workshops and interviews with experts, stakeholders, and researchers of the Dutch pork production and retail chain (Reinders et al. 2014). Based on successful transitions towards sustainability in other sectors, plausible business models were developed and presented to the stakeholder parties. In two consecutive rounds, future scenarios were constructed that may lead to an increase in value and sustainability, but require coordination.

The simulation builds upon previous work, in which four strategic options for interventions in the supply chain were simulated (van den Broek and Verwaart, 2014). The "Green Track" option entails the introduction of regulations for a mandatory proportion of organic meat. The "Market Differentiation" scenario introduces brands which offer consumers a choice between traditionally produced, a variety of intermediate levels, and fully organic meat. In addition, a commercial "Market Orientation Platform" may be introduced, which confers supply forecasts for organic meat to the producers. The fourth option is a "Producers Organization" which negotiates exclusive contracts between retail and a group of producers, with a fixed premium for a certain amount of certified meat.

The previous work has shown that, when implemented in isolation, the "Market Orientation Platform" maximizes the level of sustainability while maintaining a reasonable profit for the producers with little bankruptcies. The "Producers Organisation" scenario maximises profits for the producers admitted to the organization, but results in lower levels of sustainability and inhibits competition when implemented exclusively. In the present paper we present outcomes of simulations in which the four scenarios are implemented simultaneously and disruptive effects of particular choices can be shown.

Section 2 introduces the principles of agent-based simulation. Section 3 presents the model of the pork supply chain, the types of agents implemented, and the agents' decision making. Section 4 describes scenario's and simulation results. Section 5 concludes the paper with a discussion of perspectives for policy support using agent-based simulations.

2 Agent-based simulation

Agent-based models simulate social systems by representing the individual actors and their individual interactions (Gilbert 2008, Railsback and Grimm 2012). According to Tesfatsion (2006) an agent in an agent-based computational economics model is an economic, social, biological, or physical entity represented by a software object: a bundle of data and methods. The data and the methods can be understood as an agent's intelligence.

Wooldridge (2012) defines an intelligent agent as a computer system that is situated in some environment, and that is capable of autonomous action in order to meet its delegated objectives. An intelligent agent may be expected to have the following properties (Wooldridge and Jennings 1995):

- *Autonomy*: Operate without direct intervention and have control over actions and internal state;
- *Social ability*: Be aware of other agents and exchange information;
- *Reactivity*: Perceive the environment and respond in a timely fashion to changes in it;
- *Pro-activeness*: Exhibit goal-directed behaviour by taking the initiative.

Testfatsion (2006) concluded that the constructive grounding in the interactions of agents is the defining characteristics of agent-based computational economics models. Agent-based simulations are independent of a-priori assumption about equilibria to prevail in social or economic systems. The simulated system's aggregated dynamics emerge from the agents' autonomous interactions. In terms of generative explanation, agent-based models answer the question "*How could the autonomous local interactions of heterogeneous boundedly rational agents generate the given reality?*" (Epstein 2006).

By representing individual agents and applying individual decision making procedures for each agent, the following features of agent-based simulations can be realized (Epstein 2006):

- *Heterogeneity*: Individuals may differ by wealth, preferences, memory, capabilities, decision rules, location, social networks, culture, etcetera, and may adapt over time.
- *Autonomy*: Although feedbacks between macrostructures and microstructures may exist or emerge, no central controllers such as Walrasian auctioneers are assumed a priori.
- *Explicit space*: Agent can function in a simulated spatial environment or in a social network with explicit connections.
- *Local interactions*: Agents interacted can be limited to neighbours in a simulated physical or virtual space or through their social network connections, without uniform mixing.
- *Bounded rationality*: Agents have no infinite computational capacity. They may use simple rules, based on local information, and may not be forced into Nash equilibria.
- *Non-equilibrium dynamics*: Agent-based simulations study the emergence of macroscopic patterns, such as transitions and tipping points, from decentralised local interaction.

The explicit and realistic modelling of the agents and their behaviours allows for use of actual data of populations, and the environment they operate in, to be represented in the simulations, including the diversity prevailing in the populations. In addition, stakeholders can be involved to formulate the decision rules applied by the agents. The resulting simulations can enhance stakeholders' understanding of the functioning of complex systems and the potential consequences of their decisions. Companion Modelling (Etienne 2014) is an example of such an approach to collective decision making.

Since policy problems tend to be increasingly complex and often require a multidisciplinary approach, there is a growing interest in the perspectives that agent-based simulation offers for policy support and advanced methods are being developed to deploy it (see, e.g., Colander and Kupers 2014, Scherer et al. 2015). Large-scale application is enabled by current computer technology and the availability of agent-based simulation software and big data sets to realistically configure the environment and the agent population.

The agent-based simulation that is proposed in the following sections illustrates how agent-based simulation can support policy decisions in a complex situation where many heterogeneous supply chain actors mutually affect the consequences of others' decisions. It allows for experimentation with different scenario's, taking into account the joint effects of the development of consumer demand, risk attitude and investment decisions by producers, marketing strategy of brands, time lags in the supply chain, and diversity of the producers' and consumers' populations.

3 The model

Different types of agents are represented in the simulation. There is an information agent, representing an NGO that campaigns for sustainability, there are consumer and producer (farmer) agents and there are brand agents representing the supply chain.
The messages conveyed by the information agent are received by consumers and producers with some probability. When the messages are received they affect the sustainability preference of consumers and producers, depending on their openness to new insights (a personal characteristic of each agent). An opinion variable on the interval [0, 1] represents an agent’s sustainability preference: 0 stands for full price-orientation; 1 stands for full sustainability-orientation.

Under the influence of the information agent's messages, the sustainability preference of consumers and producers will gradually increase. This sustainability preference is one factor in the decision making of consumers and producers. Other factors include the consumers' budgets, actual purchasing behaviours they can observe from other consumers (social norms), the offer of sustainable products in the retail sector, and for producers their risk attitude and capital and opportunities to invest in sustainable production.

A collection of brands (brand agents) represent the supply chain. Several brands with different levels of sustainability may operate simultaneously. The brands offer meat according to a certified level of sustainability, which may range from 100% regular to 100% organic. The simulation assumes that consumers are willing to pay a premium for sustainable meat, in response to the NGOs' campaigns and consequently evolving social norms. To the producers the brands can pay a premium for supply of sustainably produced meat. Depending on the simulated scenario, some brands may operate as producers' organizations, dealing with exclusive contracts with producers and lifting the risk from their members by guaranteed take-up of an agreed quantity of sustainably produced meat.

Producers who expect a better revenue from sustainably produced meat may decide to invest in their production system to switch from regular to certified sustainable production, thus increasing their production cost. However, if the supply of sustainable meat from all producers exceeds the demand, the surplus must be sold for the price of regular meat. Producers are assumed to pursue contracts with producers' organizations, but the organizations will only allow new members if their sales are sufficiently increasing.

The simulation typically runs with 100 producer agents, each delivering 100 pigs per week, and 1000 consumer agents, each representing a larger number of real world consumers. Consumers and producers are endowed with personal characteristics that parameterize their decision making. Tables 1 and 2 present the classes of consumers and producers used in the simulation. The segmentations are based on segmentations described in literature (Hessing-Couvret et al. 2002, de Lauwere et al. 2002). The values of the characteristics are based on expert judgement and can be adjusted in the simulation’s user interface. Values were randomly generated within a certain range. In the actual simulations 'high' denotes values set between [0.65, 0.95]; 'medium' between [0.35, 0.65]; and 'low' between [0.05 - 0.35]. Similarly, a high budget is set to 1, a medium budget to a value between [0, 1], and low to [0, 0.5].

The UML class diagram in Figure 1 depicts the agents represented in the simulation with their state variables and capabilities.

Table 1. Typology of consumers applied in the present simulation

Consumer segment	frequency	openness to information	norm sensitivity	budget
Conservative	0.27	low	high	low
Caring	0.15	low	low	low
Balanced	0.21	medium	medium	medium
Engaged	0.18	high	high	high
Openminded	0.19	high	low	high

Table 2. Typology of producers applied in the present simulation

Producer segment	frequency	openness to information	Norm sensitivity	risk aversion	farm size	capital
Traditional	0.22	low	high	high	20	50000
Economical	0.14	low	high	high	20	50000
Balanced	0.21	medium	medium	medium	20	50000
Professional	0.25	high	high	high	20	50000
Openminded	0.18	high	low	low	20	50000

The agent-based simulation is implemented in NetLogo (Wilensky 1999). The simulation, including source code, is available for download[1].

The agent-based simulation models the dynamics of the system for a period of several years, with time steps of one week, under several regimes of market organization and information supply. Regulations may be in place that oblige the brands to offer meat with a minimal average level of sustainability. In every time step the brands are assumed to check the regulations and adjust their products accordingly. Furthermore, in every time step the (NGO) information agent conveys information to the consumers and the producers. Then the agents perform the sequence of actions as specified in Table 4 (at the end of the paper). Van den Broek and Verwaart (2015) present a formal specification of the decision making.

Observable outputs that the simulation produces relate to the uptake of sustainably produced meat by consumer segments, the level of sustainability of meat production, the distribution of wealth among farmers, the number of farms defaulting due to overproduction, and the brands' turnover.

4 Results

We systematically varied combinations of scenarios and compared these in terms of the (speed of) the uptake of sustainable products, the share of producers in financial problems, and their wealth after 312 weeks (6 years) with the parameters equal across all runs as described above. Table 3 summarizes the results. We have indicated the results qualitatively for two reasons. First, the model is not calibrated to actual observations, so the numeric outcomes are uncertain and can only be indicated relatively to the outcomes of other scenarios. Second, more precise outcomes would require an extensive sensitivity analysis, which remains as future work.

[1] For download of the simulation see: http://www.verwaart.nl/Sustainability/

Table 3. Results of simulations with different combinations of supply chain concepts or interventions

PO[a]	PD[b]	MP[c]	GT[d]	sustainability evolution	sustainability after 6 years	producers in fin. problems	total wealth of producers	wealth distribution
off.....	off.....	off.....	off.....	slow....	low.......	many......	base	skew
off.....	off.....	off.....	....2%	slow....	low.......	many......	decreased	skew
off.....	off.....	.....on	off.....	slow....	medium	.........few	decreased	skew
off.....	off.....	.....on	....2%	slow....	medium	many......	base	skew
off.....	.....on	off.....	off.....	...rapid	.....best	many......	base	less skew
off.....	.....on	off.....	....2%	...rapid	.....best	many......	base	less skew
off.....	.....on	.....on	off.....	...rapid	medium	.........few	base	less skew
off.....	.....on	.....on	....2%	...rapid	.....best	.........few	base	less skew
.....on	off.....	off.....	off.....	slow....	low.......	many......	base	very skew
.....on	off.....	off.....	....2%	slow....	low.......	many......	base	very skew
.....on	off.....	.....on	off.....	slow....	low.......	many......	base	very skew
.....on	off.....	.....on	....2%	slow....	low.......	many......	base	very skew
.....on	.....on	off.....	off.....	slow....	medium	many......	increased	very skew
.....on	.....on	off.....	....2%	slow....	medium	many......	increased	very skew
.....on	.....on	.....on	off.....	slow....	medium	many......	increased	very skew
.....on	.....on	.....on	....2%	slow....	medium	many......	increased	very skew

[a] PO: Producers Organization; an agreement between a brand and a group of producers with exclusive contracts, lifting the risk off the suppliers

[b] PD: Product Differentiation; offering meat with an intermediate level of sustainability, e.g. between fully regular and fully organic

[c] MP: Market Platform; an information platform that supplies producers with a forecast of the expected supply of certified meat

[d] GT: Green Track; a regulatory intervention that obliges brands to mix in a minimal percentage of certified sustainably produced meat

As a reference setting we took the baseline scenario from Van den Broek and Verwaart (2015) which represents the market forces in the current Dutch pork sector. Here, unsatisfied demand from consumers causes producers to overinvest and therefore leads to 60% of the producers ending in deep financial trouble.

The Market Platform transpired as a well-performing scenario in isolation, since the information throughput succeeds in reducing the amplitude of the pork cycle. The opportunity for Product Differentiation has been shown to quickly increase the number of consumers willing to pay for sustainable products, but led to lower results for producers. Many had invested in sustainability and were sub sequentially forced to dump the surplus production on the market for regular meat. Therefore the addition of a Market Platform to the Product Differentiation scenario was promising, but in practice it leads to only average levels of sustainably produced meat after 6 years, lower than PD in isolation. However, the combination with the Market Platform reduces the number of farmers facing serious financial problems.

Producers' Organizations are by nature exclusive, which is represented in the resulting skew of the wealth distribution. Although on average, allowing for Producers' Organizations increases the total wealth of producers, the outsiders cannot compete on their own, even when Product Differentiation and Market Platform are allowed. The producers not contracted by the Producer's Organizations are at risk. Sooner or later they end up in financial trouble. As a consequence, only a relatively low level of over-all sustainability is attained when Producers' Organizations are allowed.

The Green Track scenario is qualitatively different from the other three scenarios, since the imposed percentage of the regulated annual increase in sustainable share influences the speed of the sustainability evolution. Due to the increasing prices of the cheapest meat, the total consumption of meat decreases. The Green Track scenario has disruptive effects, e.g. ten percent per year results in a rapid increase of sustainability, but also in a breakdown of the consumption.

In isolation, a Green Track scenario with two percent increase per year results in a slow uptake of sustainability. When combined with Product Differentiation, still many producers have financial problems but the average level of sustainability is increased. In combination with the Market Platform and the Product Differentiation scenario, it increases the sustainability uptake even further at the cost of a small loss of consumption.

Finally, it was observed (not represented in Table 3) that in simulations where the supply chain does not anticipate the Green Track scenario and does not timely start up the production and marketing of more sustainable meat before new regulations apply, chaotic patterns evolve with many producers defaulting.

5 Conclusion

In the case of the pork supply chain, the agent-based simulation has provided the following insights:

- Allowing for Producers' Organizations that operate on the basis of exclusive contracts results in great wealth for their members at the cost of competition opportunities for the majority of the producers. The resulting sustainability enhancement is inferior to the sustainability attained in the other scenarios, even when applied in combinations.
- Financial problems due to over-investments by large numbers of producers were absent only in simulations where a Market Platform provided information on expected supply. However, not in all scenarios could the platform prevent larger groups of producers getting into financial trouble.
- Product Differentiation results in relatively rapid and substantial uptake of sustainability by consumers and in the end promotes investments in sustainability by the producers. When combined with the Market Platform, good results can be obtained for the whole sector.
- The Green Track scenario can further improve the sustainability. However, in this scenario the increasing meat price resulted in a decrease of the total demand. Only when the minimal level of sustainability imposed on the brands is sufficiently small, the Green Track enhances both sustainability and welfare of the pork sector.

In order to quantify the effects described above and to assess the related uncertainties, an extensive sensitivity analysis must be performed. That remains for future work.

This work has shown the potential of agent-based simulation for policy support. Scenarios can be explored for the organisation of - and interventions in - complex social or economic systems with heterogeneous actors. The approach allows for experimenting with different assumptions about the properties of the system and the distribution of properties over the agent populations. The application of decision rules in the agents allows for involvement of stakeholders in model formulation in order to be realistic for policy support. A drawback of the approach is in the data required. Often detailed data on the distribution of properties in the agent population is not available and assumptions must be made by experts or stakeholders.

Experimenting with different scenarios and property distributions offers insights into the functioning of the system and the potential effects of interventions. These effects may be unintended. For instance, in the work presented in this paper, the supply chain scenario with Producers' Organizations proved counterproductive. While the intentions are to improve the welfare of the pork producers in general and to enhance the sustainability of pork production, the general effects are in all cases inferior to the scenarios without Producers' Organizations.

Implementation of the agent-based model in a serious game is recommended. By using such a game in an individual or in a group session, stakeholders and policy makers can experiment with scenarios and assumptions about the decision rules and other properties of the agents. Thus, participants in such a game can enhance their insight into the functioning of the system and into intended and unintended potential effects caused by either policy interventions at system level or decisions taken by individual supply chain actors.

References

Colander D, Kupers R (2014) Complexity and the Art of Public Policy: Solving Society's Problems from the Bottom Up. Princeton University Press

de Jonge J, van Trijp H (2013) Meeting heterogeneity in consumer demand for animal welfare: A reflection on existing knowledge and implications for the meat sector. Journal of Agricultural and Enviromental Ethics 26:629-661

de Lauwere C, Verhaar K, Drost H (2002) Het mysterie van het ondernemerschap. Rapport 2002-2. IMAG, Wageningen (in Dutch)

Epstein JM (2006) Remarks on the foundations of agent-based generative social science. In: Tesfatsion L, Judd KL (eds) Handbook of computational economics volume 2: agent-based computational economics. North-Holland

Etienne M (2014) Companion Modelling: a participatory approach to support sustainable development.

Gilbert N (2008) Agent-based models. SAGE Publications

Hessing-Couvret E, Reuling A (2002) Het WIN-model Waardensegmenten in Nederland. Amsterdam: NIPO (in Dutch)

Kirman A (2008) Artificial Markets: Rationality and Organisation. In: Schredelseker K, Hauser F (eds.) Complexity and Artificial Markets. Springer, Heidelberg

Lacagnina V, Provenzano D (2010) Threshold Rule and Scaling Behavior in a Multi-Agent Supply Chain. In: LiCalzi M, Milone L, Pellizari P (eds.) Progress in Artificial Economics. Springer, Heidelberg

Mizgier KJ, Wagner SM, Holyst JA (2012) Modeling defaults of companies in multi-stage supply chain networks. International Journal of Production Economics 135:14-23

Railsback SF, Grimm V (2012) Agent-based and individual-based modelling: a practical introduction. Princeton University Press.

Reinders M, Poppe K, Immink V, van den Broek E, van Horne P, Hoste R (2014) Waardevolle perspectieven voor vlees. LEI Wageningen UR, Den Haag (in Dutch)

Scherer S, Wimmer M, Lotzmann U, Moss S, Pinotti D (2015) Evidence Based and Conceptual Model Driven Approach for Agent-Based Policy Modelling. Journal of Artificial Societies and Social Simulation 18 (3) 14

Tesfatsion L (2006) Agent-based computational economics. In: Tesfatsion L, Judd KL (eds) Handbook of computational economics volume 2: agent-based computational economics. North-Holland

van den Broek E, Verwaart T (2015) Evaluating scenarios for upgrading sustainabilityof the meat supply chain. In: Ablard F, Miguel FJ, Blanchet A, Gaudou B (eds.) Advances in Artificial Economics, Springer International Publishing Switzerland

Wilenski U (1999) NetLogo. http://ccl.northwestern.edu/netlogo/. Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, IL

Wooldridge M (2012) An introduction to multiagent systems - second edition. John Wiley & Sons

Wooldridge M, Jennings NR (1995) Intelligent agents: theory and practice. The Knowledge Engineering Review 10(2):115-152

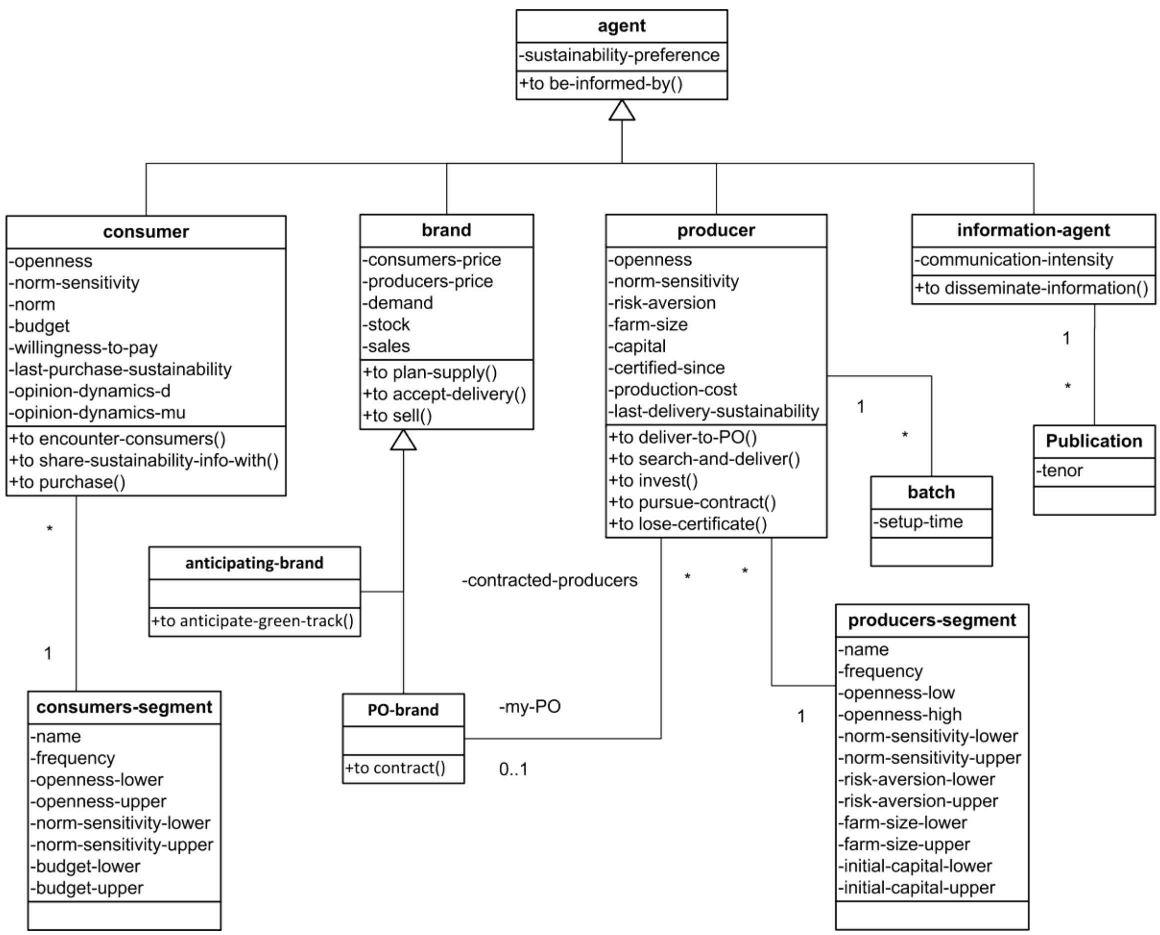

Figure 1. UML class diagram of the agents represented in the simulation

Table 4. Sequence of agent actions and interactions during one time step (1 simulated week) - a time step begins with dissemination of NGO information by the information agent; after that, the simulation proceeds as represented in this table

Consumer agents	**Brand agents**	**Producers' organizations**	**Producer agents**
Update sustainability preference when NGO information is received	If new Green Track regulations apply, then adjust sustainability level	If new Green Track regulations apply, then adjust sustainability level	Update sustainability preference when NGO information is received
	Plan supply, based on stock level and sales in previous period, and publish unsatisfied demand for certified pork	Plan supply, based on stock level and sales in previous period, and publish unsatisfied demand for certified pork	
		Reduce unsatisfied demand for each delivery and increase stock level	If contracted, then deliver according to contract
	Reduce unsatisfied demand for each delivery and increase stock level		If certified pigs are fit for slaughter and not contracted, then search brand with unsatisfied demand and deliver if found
			Deliver uncertified pigs or unsold certified pigs to the regular market
		Reduce unsatisfied demand for each new contract issued	If certified pigs will be fit for slaughter next round and not contracted, then search PO agent with open demand and, if found, apply for a contract
			If certified and broke, then lose certificate
			If not certified, then decide on investment in certification, based on capital, price premium, unsatisfied demand, own risk aversion, and (if available) supply forecast from Market Platform
Select brand with most appropriate level of sustainability; purchase if budget is sufficient	Update stock and sales record for each consumer transaction	Update stock and sales record for each consumer transaction	
Encounter some other consumers, exchange purchase information, and adjust belief about social norm			