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How Social Unrest Started Innovations in Food Supply Chains: Simulation of Opinion Dynamics

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Abstract Transitions leading to sociotechnical innovations in food supply chains have been described in dramaturgical analyses on the basis of newspaper articles and parliamentary records. The time scale of such transitions driven by aroused public opinion is typically a decade. Actors are primary producers (farmers), other supply chain parties, authorities, NGOs voicing particular opinions, political parties, and consumers. Their interactions and reactions to external events are modelled in an agent-based simulation. The purposes of the simulation are (1) to validate that hypothetical relations derived from the dramaturgical analysis indeed lead to the emergence of the observed transitions, and (2) to study how the system could have developed under different behaviours or a different course of external events. Simulation results and a sensitivity analysis are discussed. The simulation shows particularly sensitive for the participation of both moderate and activist NGOs.

1 Introduction

This work is inspired by analyses of public debates on social responsibility aspects of food production. Debates in The Netherlands addressed pesticide residues on fruits and vegetables [3, 4], and animal welfare in the livestock industry [2, 6]. The debates studied in that work entailed long-lasting controversies between the involved actors. Eventually the debates resulted in innovations in the food supply chain, with new products from new production systems being taken to the market. In that sense, the debates can be understood as constructive processes.

The discourse analyses were based on publicly available documents: articles in national newspapers and professional journals and questions in Parliament. Babbie [1] defines content analysis as "*the study of recorded human communications,*

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such as books, websites, paintings and laws". Lasswell [14] formulated the core questions of content analysis as: "*Who says what, to whom, why, to what extent and with what effect?*" These questions represent the aim of the analyses of the public debates. It requires a systematic approach to analyse hundreds of documents. Hajer [11] introduced dramaturgical analysis as a systematic framework to analyse such processes. Dramaturgical analysis considers the public debate as a theatre performance with scripting (story lines and actors), setting (locations and discourses), staging (parties involved) and plots (crucial moments). The dramaturgical analysis was used to identify events, conditions and actors having a critical role in turning points in the debates. In addition to the dramaturgical analyses, content-based media analyses were conducted by tagging newspaper articles with discrete speech acts of specified actors groups at specific moments to identify trends in the topics of the discourse.

The understanding of transitions toward increased social responsibility in food production and consumption currently tends to be limited to a macro level identification and characterization of a handful of phases or stages in food innovation processes (see, e.g., [10]). A deeper understanding of the dynamics behind these transitions, and in particular of the movement from one stage to the next, requires a micro level analysis of who voices what, when and how in the public debate. The dramaturgical analyses provide a basis for such understanding. The data resulting from the analyses can be input to agent-based simulations. The hypothesis of our present paper is that agent-based simulations can be applied to partially validate the conclusions of the dramaturgical analyses, by reconstructing the assumed relations between actors' behaviours, showing that they indeed cause the observed patterns of transition, and that these patterns do not emerge if the assumptions are changed. Further, the simulations can be used to gain deeper understanding of the processes by answering questions like "What if actor A would have ...?" and "What if event E would not have occurred?".

The following sections of this paper will successively summarize the results of the dramaturgical analyses, propose a first version of an agent-based simulation, analyse the simulation's sensitivity to parameter variations, and compare simulation outputs with the observed patterns from a dramaturgical analysis.

2 Results of dramaturgical analyses

The analysed public debates show a pattern of non-governmental organizations (NGOs) staging discussions and starting campaigns, which after some years result in new arrangements, codes of conduct, and practices [5, 6]. This pattern is shown in Fig. 1. The process starts with societal criticism on product qualities or production practices. The flow of criticism puts pressure on the central cell (NGOs and the government, represented by the ministry of agriculture). They assign knowledge parties to objectify the societal criticism. Subsequently, societal criticism is translated to improved production systems, new legislation, or societal pressure on primary pro-

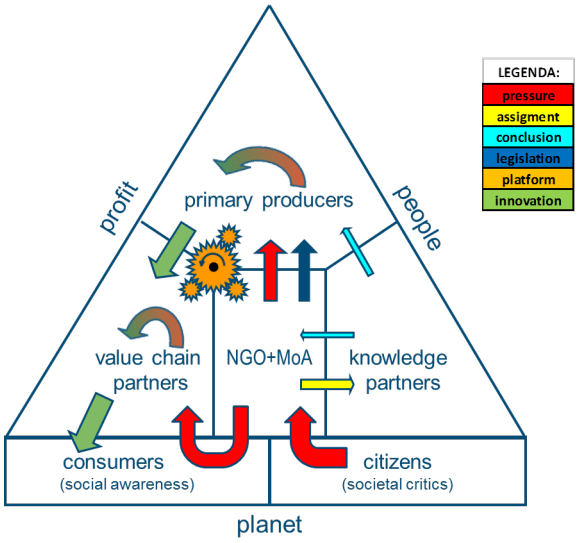

Fig. 1 The dynamics of societal pressure leading to sociotechnical innovations

ducers. Another part of the pressure goes via consumers to value chain partners, e.g., retailers. The increased pressure in central, top and left-hand cells frequently results in organising a platform, where actors align efforts for product or production innovation. As a result the flow of societal criticism is transformed to social awareness among consumers and a flow of improved products to consumer markets.

Pesticide residues

In the years 1998-2005 a public debate on compliance with maximum residue levels (MRLs) of pesticides was staged by NGOs in the Netherlands. In 1998-1999 they called upon the government to immediately ban several pesticides because of the possibility of hormone disruption. The government rejected the requests for lack of scientific evidence. In 2000-2004 the NGOs took samples of vegetables and fruits in supermarkets, had them analysed on residues by a well-known laboratory, found unauthorized pesticides and violations of MRLs, and took two retail companies to court. The two retailers reached an agreement with the NGOs on MRL compliance. They took over the inspection on MRLs from the government and forced traders and growers to implement GlobalGAP. [3, 4]

Animal welfare

Since 2001 public debates on animal welfare in livestock production were staged by the Animal Protection Society. In 2001-2002 they called upon the government to support the marketing of organic meat and to introduce regulations for animal welfare. In 2002-2004 they started consumer campaigns in newspapers, supermarkets and fast-food restaurants. More activist NGOs entered the stage and increased

the pressure. In 2005-2007 the Animal Protection Society started an initiative for an intermediate segment between the conventional and organic segments in the meat market. They introduced the 'Better Life' label for animal-friendly meat and eggs. This initiative got support of specific feed suppliers, farmer groups, slaughterhouses and retailers. [2, 6]

Case study

The agent-based model proposed in this paper was informed by a case study regarding the public debate on animal welfare in pork production in The Netherlands in the period 2005-2012 [6]. The objective of this case study was to improve the understanding of the roles of activist and moderate NGOs, in interaction with government, research, primary producers, processing industry and retailers, in improving animal welfare in pork production in The Netherlands.

In the case study two sets of newspaper articles were analysed:

1. 146 articles mentioning Animal Protection Society (moderate NGO);
2. 116 articles mentioning Pigs in Distress (activist NGO).

The analysis revealed striking differences in the main issues raised by the two NGOs. The Animal Protection Agency strongly focused at the development of an animal friendly housing systems (Comfort Class stable) and at market segmentation for animal friendly meat (Better Life label). Furthermore, they rejected routine castration of piglets and the industrial production of pork in mega-farms. The activist NGO "Pigs in Distress" strongly focused at influencing the buying behaviour of consumers through introduction of the so-called meat marker and campaigning against animal suffering and record low meat prices. The other part of their strategy was campaigning against abuses in the value chain. They denounced anaesthesia in slaughterhouses, long-lasting transportation of livestock, and the very stress- and painful castration of male piglets.

The activist NGO thus created the urgency for change and a potential market for animal-friendly meat. In turn the moderate NGO exploited this urgency and potential market to strike deals with primary producers, slaughterhouses and retail companies.

3 Agent-based simulation of the transitions

Multi-agent systems offer a natural paradigm to simulate social processes with diverse, interacting, agents [15]. A well-established application is the simulation of opinion dynamics. Deffuant et al. [8] proposed an agent-based simulation in which opinions are represented by a continuous variable x on the interval [0, 1]. Agents meet at random and then exchange opinions if their difference in opinion is less than some threshold d. When an agent having opinion x_{t-1} meets an agent having opinion x'_{t-1} at (discrete) time t, x is updated as:

$$x_t = \begin{cases} x_{t-1} + \mu(x'_{t-1} - x_{t-1}) & \text{if } |x'_{t-1} - x_{t-1}| < d \\ x_{t-1} & \text{if } |x'_{t-1} - x_{t-1}| \geq d \end{cases} \quad (1)$$

where μ is a convergence parameter, $0 \leq \mu \leq 0.5$. One can think of d as the agent's openness to others' opinions or uncertainty about its own opinion, and of μ as the agent's flexibility or urge to compromise in a discussion. We build on these concepts to simulate the transitions described in the previous section.

Four classes of actors are discerned in the simulation:

- Consumers,
- Supply chain parties (in the simulation represented by retail companies),
- Primary producers (farmers),
- NGOs (producers and animal welfare organizations).

All agents have a position on the scale x ranging from 0 (preference for cost minimization) to 1 (preference for social responsibility, e.g., animal welfare maximization).

The first three classes are segmented into subclasses discerned by [13, 17, 7], respectively. Typical values of μ and d for each of the subclasses have been assumed by expert judgement. Supply chain actors have a small value of μ, because they act very frequently with consumers. All of these agents have an initial position $x_0 = 0$.

The fourth class is represented by agents voicing particular positions on x. The producers organizations are initially positioned at $x_0 = 0$ and have a small value of $\mu > 0$. The activist NGOs are positioned at $x_0 = 1$ with $\mu = 0$. The moderate NGOs also start at $x_0 = 1$, but have a small value of $\mu > 0$, which allows them to compromise. However, they tend to move back if possible. For that purpose, we use the concept of asymmetric confidence as described by Hegselmann and Krause [12]:

$$x_t = \begin{cases} x_{t-1} + \mu(x'_{t-1} - x_{t-1}) & \text{if } -d_l < x'_{t-1} - x_{t-1} < d_r \\ x_{t-1} & \text{if } x'_{t-1} - x_{t-1} \leq -d_l \vee x'_{t-1} - x_{t-1} \geq d_r \end{cases} \quad (2)$$

The moderate animal welfare NGO will be more susceptible to opinions with high values of x, which is represented by assigning a higher value to d_r than to d_l. On the other hand, the producers organization is assumed to be more open to opinions with a lower value of x and is assigned a higher value of d_l.

The concept of asymmetric confidence is also applied to model the effect of media events that arouse uncertainty among consumers. In the beginning of the simulation, d_l and d_r are assigned symmetric values for consumers, retailers, and producers. For consumers these values may be influenced by events reported in the media. For instance, images of animals in bad conditions may make consumers more susceptible to opinions with higher values of x, while news about fraud with organic food may have an adverse effect. This is modelled in the simulation by randomly generated rare events which for one week increase all consumers' values of either d_l or d_r with a factor $\alpha > 1$. The factor α quantifies the arousal of uncertainty by media events. The frequency of the events is typically set to a probability of twice per year for events increasing d_r and once per year for events increasing d_l.

Table1 presents the actor types, the number of agents in the simulation and the default parameter settings. The relative positions of high, medium, and low values are based on the descriptions in the source publications and expert judgement.

Table 1 Number of agents in the simulation and default parameter settings for each actor type[a]

Agent type	frequency	x_0	μ	d_l	d_r
Consumer types, according to [13]					
- Conservatives	16	0	medium	low	low
- Caring	15	0	high	medium	medium
- Balanced	21	0	medium	medium	medium
- Committed	11	0	high	high	high
- Open-minded	7	0	medium	high	high
- Professionals	8	0	low	medium	medium
- Materialists	11	0	low	low	low
- Hedonists	11	0	low	low	low
Producer types, according to [7]					
- Traditional	22	0	low	low	low
- Economical	14	0	low	low	low
- Balanced	21	0	medium	medium	medium
- Open-minded	18	0	high	high	high
- Professional	25	0	low	high	high
Retail types, according to [17]					
- Inactive	1	0	0	0	0
- Reactive	1	0	0.0001	0.30	0.30
- Active	1	0	0.0001	0.70	0.60
- Proactive	1	0	0.0001	1.00	1.00
NGO types, according to [6]					
- Producers organization	1	0	0.00001	1.00	0.60
- Animal welfare (activist)	1	1	0	0	0
- Animal welfare (moderate)	1	1	0.0001	0.70	1.00

[a] x_0 denotes the initial opinion; *mu*, d_l, and d_r are the opinion dynamics parameters; 'high' denotes a uniformly distributed random value on the interval [0.10, 0.15]; 'medium' on [0.05, 0.10]; 'low' on [0, 0.05]; the random values are generated for each agent during the simulation's initialization

For retailers and NGOs the values of μ are relatively small, because these agents interact more frequently with other agents than consumers and producers do. The producers organization in particular has a low value of μ, to represent a stable policy and keep the organization connected with the majority of the producers.

Interactions occur between consumers and NGOs, among consumers, between consumers and supply chain actors, between supply chain actors and producers, among producers, and in the public debate, as displayed in Fig. 2. When the NGOs' positions are far away from groups in the public, they are voices calling in the wilderness. This may be changed by events with emotional impact that get media attention, e.g. outbreak of a livestock disease or news about pesticide residues in food. Such events may temporarily increase the susceptibility of citizens/consumers to other opinions (i.e. increase the value of either d_l or d_r), with a typical value of $\alpha = 10$.

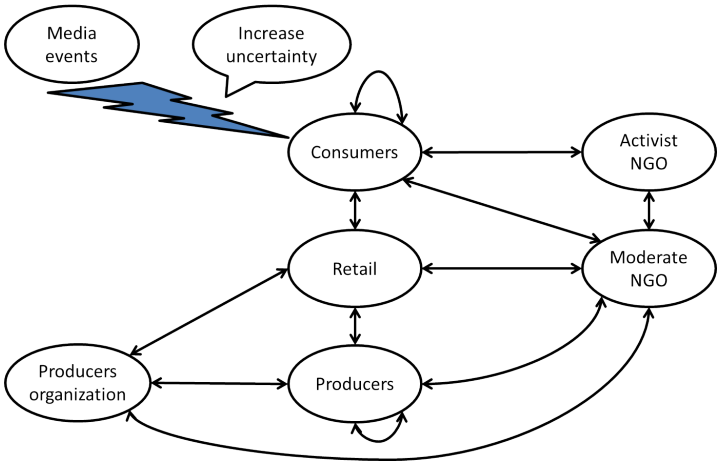

Fig. 2 Interactions among agents modeled in the simulation

The simulation is implemented in NetLogo [18], with agents as described in Table 1. Five daily interactions per week according to Fig. 2 are implemented as follows, in NetLogo code:

```
to apply-opinion-dynamics
  repeat 5
  [ ask consumers
    [ interact-with one-of ngos
      interact-with one-of other-consumers
      interact-with one-of retailers ]
    ask producers
    [ interact-with one-of ngos
      interact-with one-of other-producers
      interact-with one-of retailers ]
    repeat 100
    [ ask ngos
      [ interact-with one-of other-ngos
        interact-with one-of retailers] ] ]
end
to interact-with [other-agent]
  consider [opinion] of other-agent
  ask other-agent [consider [opinion] of myself]
end
to consider [other-agent-s-opinion]
  let difference other-agent-s-opinion - opinion
  if difference > (- d_l) and difference < d_r
  [ set opinion opinion + mu * difference ]
end
```

4 Results of agent-based simulations

The simulation's user interface presents the results as displayed in the figure at the end of the paper[1]. The view shows positions of agents on the opinion scale from $x = 0$ (price oriented) to $x = 1$ (animal welfare oriented). Consumer agents are positioned in the top part of the view; producer agents in the bottom part. Agents representing NGO's and retailers are depicted in the middle layer of the view. In this setting experiments are performed to explore the patterns that can emerge from the simulation and the conditions under which they actually do emerge. The simulation runs span 10 years with time steps of 1 week.

The simulation runs start with the two animal welfare NGOs positioned at $x = 1$ and all other agents at $x = 0$. Three typical patterns can be observed when running the simulation. The first pattern emerges when there is insufficient arousal. If $\alpha < 7$ or media event frequency on the animal welfare side is very low, all agents stay on or near their initial positions. With higher values of α and event frequencies of one or several events annually, two other scenarios can evolve, one of which is the scenario found in the dramaturgical analysis reported in Section 2.

Arousal of the consumer agents by media events causes the proactive retailer agent to shift to higher values of x. When sufficient consumers are moving their positions toward the right-hand side, the moderate NGO is attracted and shifts to the left. The extent to which this occurs mainly depends on the positions taken by the consumer agents, which in turn depend on the randomly generated events.

For the scenario reported in Section 2 to emerge, the moderate NGO agent overcome a turning point, from where it can move further to the left and exchange opinions with the other agents. If the turning point is reached, the NGO agent first moves toward the other agents and then pulls them to the right, including the producers organization. Some consumers, some producers, and the inactive retailer remain at the price oriented end, but most of the producers follow the other retailers and the farmers organization and shift to the right relatively rapidly.

The presence of the activist NGO agent is a sine qua non for the latter scenario to evolve. This agent continuously attracts aroused consumer agents and pulls the moderate NGO to the right. If there is no NGO agent permanently voicing opinions at $x = 1$, all other agents end up at $x = 0$. Furthermore, this scenario can only emerge if the proactive retailer agent is open to the animal welfare opinions (it must have $d_r \geq 0.9$) and if the moderate NGO agent is sufficiently susceptible to other opinions ($d_l > 0.5$).

We assume that broad uptake of sociotechnical innovations can occur as a result of this scenario if the moderate NGO has indeed pulled retailers and producers to the right (i.e. more animal friendly production systems can be introduced and more animal friendly produced meat can be delivered to the consumer market).

The third pattern that can occur is one in which the consumer agents are aroused but the moderate NGO agent does not cross the turning point. In that case the retailers and producers move only slowly and there is no ground for innovations.

[1] The NetLogo code is available from http://www.verwaart.nl/SocialUnrest/

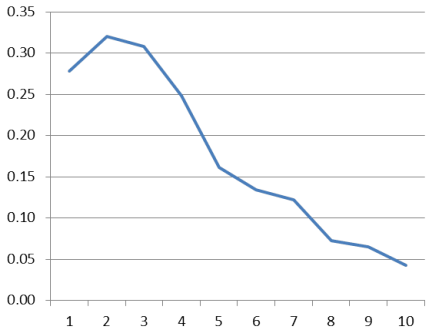

Fig. 3 Final average opinion of producers by year where the turning point was reached (vertical axis: average opinion after 10 years; horizontal axis: year of the turning point)

Based on the outcomes of the first set of experiments, a second set was specified and performed to test the simulation's sensitivity to parameter variations. Thirty replications were run for each combination of the following values:

- α: $\{8, 10, 12\}$,
- the frequency of both left-hand and right-hand media events: $\{0.02, 0.05\}$,
- d_l of the moderate NGO: $\{0.6, 0.8\}$,
- d_r of the proactive retailer: $\{0.9, 1.0\}$.

The main observables from the simulations are:

- whether a turning point occured or not,
- if a turning point occurred, the number of weeks in which it was reached,
- the average producer's opinion as an indicator of the potential innovation uptake.

In the 1440 simulations, the turning point where sociotechnical innovations could occur was overcome 659 times. In the cases where this point was overcome, the average opinion of producers was 0.22 with standard deviation 0.16 after 10 years. In the cases where no turning point was reached, the average opinion of producers was 0.022 with standard deviation 0.014. The final average opinion of the producers depended on the year in which the turning point was reached, as diplayed in Fig.3.

The results are sensitive to the parameter settings. Tables 2, 3, 4, and 5 present the fraction of simulation runs in which turning points occurred, and the resulting average opinion of producers for several parameter settings.

Table 2 Fraction of simulations where a turning point occurred, by d_r of proactive retailer and d_l of moderate NGO

	d_l of moderate NGO		
d_r of proactive retailer	0.6	0.8	average
0.9	0.22	0.55	0.39
1.0	0.24	0.89	0.56
average	0.23	0.72	

Table 3 Average opinion of producers by d_r of proactive retailer and d_l of moderate NGO

	d_l of moderate NGO		
d_r of proactive retailer	0.6	0.8	average
0.9	0.03	0.15	0.09
1.0	0.03	0.26	0.15
average	0.03	0.21	

Table 4 Fraction of simulations where a turning point occurred, by arousal frequency and strength

	arousal strength (α)			
right-hand versus left-hand frequency[a]	8	10	12	average
0.02 versus 0.05	0.06	0.26	0.48	0.27
0.02 versus 0.02	0.14	0.43	0.67	0.41
0.05 versus 0.05	0.25	0.60	0.86	0.57
0.05 versus 0.02	0.32	0.70	0.93	0.65
average	0.19	0.50	0.74	

[a] frequency of randomly generated events that temporarily increase either d_r or d_l of consumers

Table 5 Average opinion of producers by arousal frequency and strength

	arousal strength (α)			
right-hand versus left-hand frequency	8	10	12	average
0.02 versus 0.05	0.02	0.08	0.15	0.08
0.02 versus 0.02	0.05	0.12	0.17	0.11
0.05 versus 0.05	0.09	0.18	0.21	0.16
0.05 versus 0.02	0.10	0.13	0.13	0.12
average	0.06	0.13	0.17	

5 Conclusion

This paper summarizes previous work on dramaturgical analyses of sociotechnical innovation processes in food supply chains. Informed by that work, the paper proposes an agent-based simulation, building on the concept of opinion dynamics. When the simulation is run for a period of 10 years with a time step representing 1 week, patterns emerge which are comparable with those observed in the dramaturgical analysis.

The outcomes are most sensitive to the frequency and impact of events and the distribution of the NGOs' and retailers' parameters of susceptibility to others' opinions. The shift toward opinions that enable uptake of sociotechnical innovations only emerges if a turning point is reached where a proactive retailer and a moderate NGO can share their opinions and pull the producers and other retailers toward innovation. Such a shift only occurs in the simulation if activist and moderate NGOs are both participating in the discourse and at least one retailer is open to animal welfare oriented opinions before actual consumer demand evolves. In this respect, the sim-

ulation can realistically simulate the actors opinions that may lead to innovations in food supply chains.

The present simulation provides a basis to include cognitive modelling of the NGOs and supply chain agents. Those parties take positions and communicate deliberately to influence opinions. Their decision making could, for instance, be modelled through the doubt management mechanisms according to Karl E. Weick, as decribed by Selnes and Termeer [16]. We expect such cognitive modelling to increase the simulation's value for policy support.

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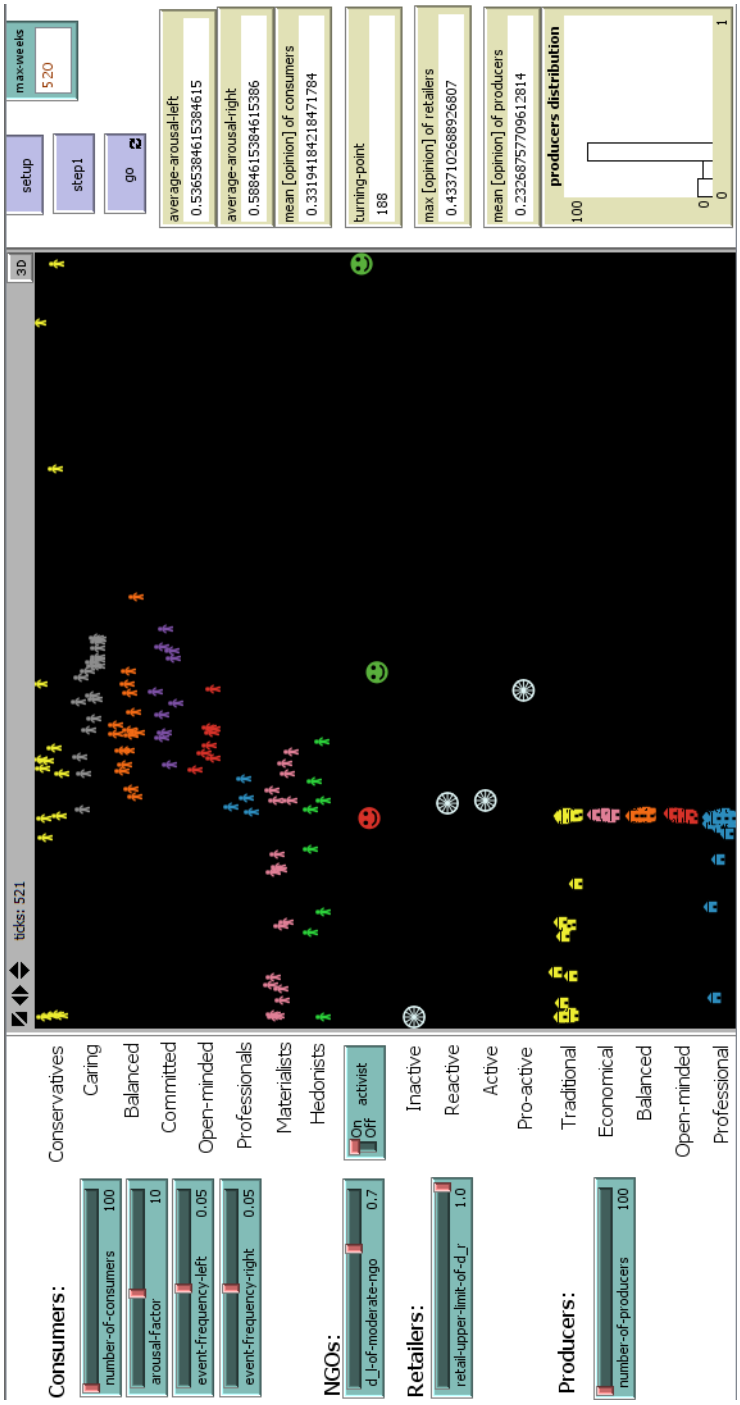

Fig. 4 The simulation's user interface