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Agent-Based Simulation of the Trust and Tracing Game for Supply Chains and Networks

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Abstract

This paper describes a multi-agent simulation model of the Trust And Tracing game. The Trust And Tracing game is a gaming simulation for human players, developed as a research tool for data collection on human behaviour in food supply chains with asymmetric information about food quality and food safety. Important issues in the game are opportunistic behaviour (deceit), trust and institutional arrangements for enforcing compliance. The goal is to improve the understanding of human decision making with respect to these issues. To this end multi-agent simulation can be applied to simulate the effect of models of individual decision making in partner selection, negotiation, deceit and trust on system behaviour. The combination of human gaming simulation and multi-agent simulation offers a basis for model refinement in a cycle of validation, experimentation, and formulation of new hypotheses. This paper describes a first round of model formulation and validation. The models presented are validated by a series of experiments performed by the implemented simulation system, of which the outcomes are compared on aggregated level to the outcomes of games played by humans. The experiments cover in a systematic way the important variations in parameter settings possible in the game and in the characteristics of the agents. The simulation results show the same tendencies of behaviour as the observed human games.

Keywords:
Trust, Deception, Supply Chain, Multi-Agent System, Simulation

Introduction

1.1

Trust and deceit are key concepts in international trade. In the globalizing production of goods the connections between companies from raw material suppliers to retail outlets are important to optimise the overall efficiency of production. The concept of linked companies producing a good is called supply chain, or supply network in case alternative suppliers and buyers are considered too (Lazzarini et al. 2001). Supply chains and networks are important economic institutional forms (Camps et al. 2004). Connections between companies in a supply chain or network are governed by a mixture of three governance mechanisms, being market, hierarchy and network mechanism (Powell 1993). The market mechanism uses perfect information to bring together supply and demand at an equilibrium price. The hierarchy mechanism uses contracts to determine the production of the supply company for a pre-determined price. Ultimately, the buyer takes over the supplier. The network mechanism uses relations to ensure that agreements are met and situations that are not covered by a previous agreement will be solved equally beneficial to both companies. The relations between companies are operational via relations of employees of a firm. Trust between people from different firms is important.

1.2

New institutional economics (Williamson 1985) is a branch of economics that aims to understand the emergence of economic institutions governing transactions. It analyses the way transactions are made. The concept of Transaction Costs (Williamson 1998) incorporates social interactions around searching, bargaining, monitoring and enforcing of contracts in economic models. Trust between companies can lower transaction costs when trusted trade partners become preferred business partner. Searching and bargaining contracts will go faster and the need for monitoring and enforcing contracts will be low when you trust deliveries.

1.3

If a deception is detected, e.g., at the end of chain, who is the culprit? In case of food supply chains a number of food crises putting consumers at risk received major attention in media and politics over the last decade (Hofstede et al. 2004). The retailer could be the deceiver, but he could also trade in good faith, since he might have obtained the goods from an untruthful middleman or producer. What motivates the agent to cheat, and how does it affect trust? Understanding deceit is vital for detecting deceit, and to design mixes of governance mechanism in trading to discourage deceit, thus safeguarding food for consumers.

1.4

The reality of economic institutional forms is too complex to allow for individual participant based analysis directly: there are too many people involved, the institutions influence each other, and nature plays an unpredictable role as well. An intermediate step between the real world and a model is needed that retains the essential elements of the economic institutional form under consideration. Special gaming simulations are developed that can fulfil the intermediate role (Duke and Geurts 2004; Meijer and Hofstede 2004). By playing these gaming simulations with selected groups of human participants, the exactly same gaming simulation can be played in different settings, with people from different backgrounds, resulting in unique sessions. In this manner useful insight is gained in the way people behave in a certain dilemma (e.g., Zuniga et al. 2006; Druckman 1994; Van Liere et al. 2004; Meijer et al. 2006). However, the number of sessions that can be played with humans is limited as it is expensive and time-consuming to acquire participants (Duke and Geurts 2004). Furthermore, one needs many sessions to control for variances between groups. In short, human gaming simulation is an essential step to overcome the complexity of real economic institutional forms. The number of sessions that needs to be played is a real disadvantage of the gaming simulation method.

1.5

The Trust and Tracing game (Meijer and Hofstede 2003) is a research tool designed to study human behaviour with respect to trust and deceit in commodity supply chains and networks in different institutional and cultural settings. The game played by human participants is used both as a tool for data gathering and as a tool to make participants feed back on their daily experiences. Although the Trust and Tracing game has been played numerous times (Meijer et al 2006), obviously, the problem of the number of sessions that can be and has to be played with humans and the expenses involved and the time-consuming nature of acquiring participants also holds true for this game. Therefore, of necessity, a research method had to be developed to overcome this problem.

1.6

The approach of modelling the Trust and Tracing game differs from other approaches incorporating trust and supply chains in multi-agent systems. It models aspects of a structured socially rich trade environment in a fully automated agent model. TAC-SCM (

http://www.sics.se/tac/) and the ART-testbed (http://www.art-testbed.net) are competitions of agents in a notional market that aim to find the best performing agent models, while the Trust and Tracing model is a research instrument to improve understanding of human behaviour in the game. The Global Supply Chain Game (http://www.gscg.org) uses models of a supply chain in which multiple human agents can play. The emphasis is on chain performance, where the Trust and Tracing game focuses on human relations.

1.7

An empirically validated model of seller behaviour with regard to trust and deceit will be of value to the field of New Institutional Economics. A time-honoured method of checking whether a model is a correct representation of reality is by simulating the model and analyzing the results with respect to reality. However, as mentioned above, the problem of the real world is its complexity. Therefore, it is better to first study the phenomenon in the limited setting of a human gaming simulation, just focussing on the aspects that are well represented in the gaming simulation. The research method to understanding economic reality we introduce in this paper extends the idea of human game playing with agent-based simulation of those games and a rigorous validation method that incorporates both data from the human game playing and insights from conventional economic rationality. In our view agent-based simulation can to some extent overcome the disadvantages of gaming simulation in two ways. It can validate models of behaviour induced from game observations and it can be a tool in the selection of useful configurations for games with humans (test design). Validation of the models is done on the aggregated level using computer simulations. Simulation results are to be compared to a set of hypotheses based on human session observations and conventional economic rationality.

1.8

The theoretical contribution of this paper is in the introduction of an interdisciplinary research approach, bridging the gap between new institutional economics and agent-based economics by using human gaming simulation as intermediary in which individual human transactions can be explicitly monitored and simulated. From the agent-technology perspective, the clear focus of a human gaming simulation presents detailed requirements for the design of the agent-based simulation, whereas the general aims of agent-based economics and new institutional economics set the general requirements of the agent-based simulation. The agent models introduced can be used as a point of departure for the modelling of other trade agents.

1.9

The practical importance of this work is that it provides a tool for research and education. Researchers can use the tool for research into trust and governance mechanisms in supply chains. Business schools and companies acting in supply chains can use the simulation and the game as training tools.

1.10

This paper presents the research method we developed, and illustrates its application for the study of supply chains and networks, using the Trust and Tracing game as gaming simulation. Section 2 describes the fundamental steps of the research method, The Trust & Tracing game, and the results from human sessions. Sections 3 and 4 describe the foundations and elaboration of the agent model. The model has been tested for sensitivity to parameter changes with respect to trust level and honesty of the agents. Section 5 illustrates the validity of the approach by experimental results from multi-agent simulations. It presents the results of the sensitivity tests, together with a first validation against some hypotheses derived from the theory of new institutional economics and game session conclusions. The validation is on the macro level: tendencies expected from theory and game session conclusions correspond with tendencies in model run outcomes. Currently available data do not allow for model validation on the micro level. Section 6 presents the main conclusions of the paper and discusses future directions.

Research approach

2.1

The research subject is the role of trust and deceit in commercial transactions in different cultural and institutional settings. A main problem in the study of the mechanisms involved is that the macro-level system behaviour is not simply a linear combination of micro-level decision functions. There is great interdependence between the behaviour of actors. The main reason to apply gaming simulation as an instrument for experimental data collection is the opportunity it offers to collect data in controlled experiments on the effect of micro-level conditions on macro-level system performance.

2.2

This section provides a brief description of the Trust and Tracing game; an extensive description is available in Meijer and Hofstede (2003) and Meijer et al. (2006). Observations from sessions played are discussed at the end of this section.

2.3

The focus of study is on trust in a business partner when acquiring or selling commodities with invisible quality. There are five roles: traders (producers, middlemen and retailers), consumers and a tracing agency. Typically there are 4 producers, 4 middlemen, 4 retailers and 8 consumers, to reflect the multiple steps and oligopoly character of most supply networks. The real quality of a commodity is known by producers only. Sellers may deceive buyers with respect to quality, to gain profits. Buyers have either to rely on information provided by sellers (Trust) or to request a formal quality assessment at the Tracing Agency (Trace). This costs a tracing fee for the buyer if the product is what the seller stated (honest). The agency will punish untruthful sellers by a fine. Results of tracing are reported to the requestor only or by public disgrace depending on the game configuration. A strategy to be a truthful seller is to ask for a trace before selling the product. Sellers use the tracing report as a quality certificate. Middleman and Retailers have an added value for the network by their ability to trace a product cheaper than a consumer can. Producers cannot trace, to force the environment to use at least one transaction with an unchecked product.

2.4

The game is played in a group of 12 up to 25 persons. Commodities usually but not necessarily flow from producers to middlemen, from middlemen to retailers and from retailers to consumers. Players receive 'monopoly' money upfront. Producers receive sealed envelopes representing commodities lots. Each lot is of a certain commodity type (represented by the colour of the envelope) and of either low or high quality (represented by a ticket covered in the envelope). The envelopes may only be opened by the tracing agency, or at the end of the game to count points collected by the consumers (table 1). The player who has collected most points is the winner in the consumer category. In the other categories the player with maximal profit wins.

Table 1: Consumer satisfaction points by commodity type and quality

Quality	Commodity type		
	Blue	Red	Yellow
Low	1	2	3
High	2	6	12

2.5

Participants in sessions with the Trust and Tracing game can be students for whom participation is a means to learn about transactions and embeddedness in supply chains and networks (Meijer et al. 2006), but also real decision makers from real-world supply chains. In the development of the Trust and Tracing game real decision makers have been used to criticize the design and to indicate parallels with real-world phenomena.

2.6

Sessions played until 2005 provided many insights (Meijer and Hofstede 2003; Meijer et al. 2006). We mention three examples applicable here:

1. Dutch groups (with a highly uncertainty tolerant culture;Hofstede and Hofstede 2005) tend to forget about tracing and bypass the middlemen and retailers as they don't add value. This gives the producers a good chance to be opportunistic. The low tracing frequency encourages deceit.
2. American groups tend to prefer guaranteed products. They quickly find out that the most economic way to do this is by purchasing a traced product and to let the middlemen do the trace, as this is the cheapest step. After initially tracing every lot, when relationships establish the middlemen agree with their customers to take samples.
3. Participants who know and trust each other beforehand tend to start trading faster and trace less. The afterwards indignation about deceits that had not been found out during the game is higher in these groups than it is when participants do not know each other.

Below we explain how gaming simulation and multi-agent simulation are combined to analyze the dynamics of the Trust and Tracing game under different institutional and cultural settings. First, the gaming cycle is introduced. Then the combination of gaming and multi-agent simulation as applied in this research is explained.

2.7

In our approach we started with a ready to use gaming simulation that has been designed and tested in previous projects. It is ready for application in experiments with human subjects, to collect data for testing hypotheses. The data and conclusions from the experiments can be used to refine theory and formulate new hypotheses. The process of test design includes the variable settings for the experiments. Figure 1 presents this gaming cycle.

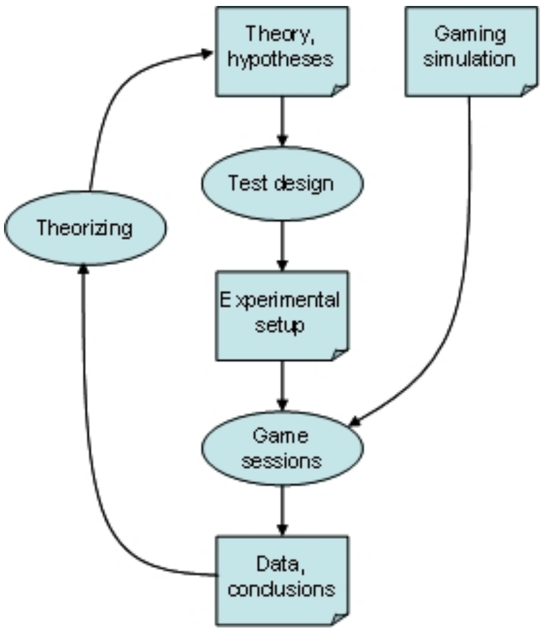

Figure 1. The gaming cycle

2.8

The introduction of this paper referred to some shortcomings of the gaming simulation approach. The first reason for applying multi-agent simulation is that game sessions are time-consuming and require many new participants for each experiment. This research aims to provide a tool that in the long run can be used to select the most interesting game configurations to play. A second reason is the possible use of validated models to predict agent behaviour and test institutional settings and combinations of agents for their impact on supply chain performance.

2.9

Figure 2 shows how multi-agent simulation fits in the research cycle from Figure 1. By analysis of the design of the gaming simulation, a task model for the agents is constructed.

The decision functions implemented in these tasks are formulated on the basis of existing theory. Outcomes of model runs can be compared with gaming results in order to validate the MAS model. This can lead to adaptation of the task model or the decision functions, or to the configuration of the model, or to the tuning of model parameter settings in order to better fit the gaming results.

2.10

In the combined research cycle, the process of test design results in an experimental setup that includes the variable settings for both game sessions and model runs. Conclusions from model runs can in combination with game session conclusions lead to refinements or falsification of theory, for instance improved or rejected models of decision functions.

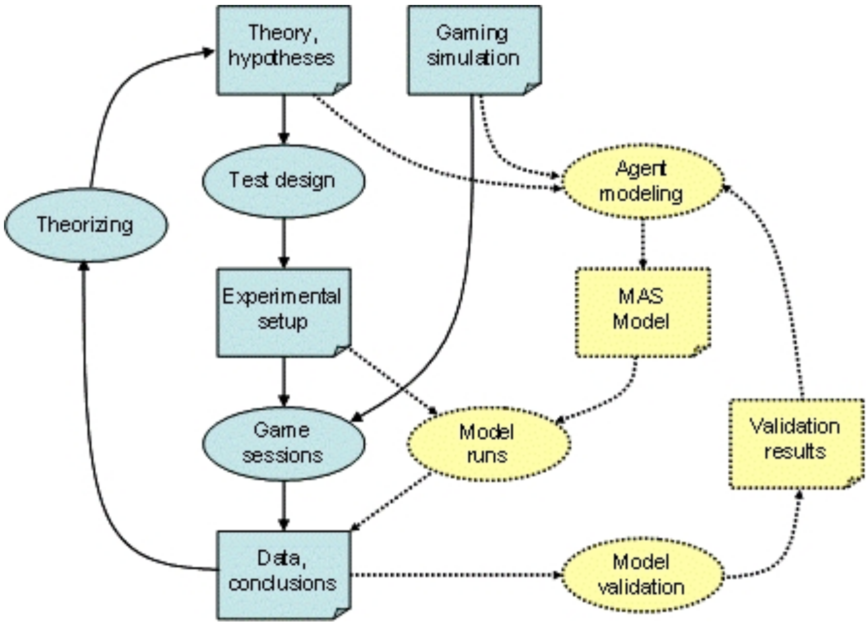

Figure 2. The research cycle combining gaming simulation with multi-agent simulation

2.11

From the general theory of new institutional economics underlying the gaming simulation as explained in Meijer and Hofstede (2003) and Meijer et al. (2006), and from the results of the first set of human gaming simulations, we constructed five hypotheses for a preliminary validation of the multi-agent model, following the right-hand cycle in figure 2. The validation results are described in section 6.

2.12

Some hypotheses refer to the *opportunistic*, *quality-minded*, and *thrifty* strategies defined in 4.13. *Opportunistic* traders aim to trade high quality for attractive prices, and are not particularly serious about the truthfulness of quality statements. *Quality-minded* traders do take these statements serious: like the opportunists they prefer high quality, but their priority is certainty, not attractive price. *Thrifty* traders prefer a good price and avoid risk, and have no particular preference for high quality.

Hypothesis 1: When the initial willingness to trust is high the percentage of high quality products sold is higher than when the initial willingness to trust is low.

Hypothesis 2: In a homogeneous environment with all opportunistic agents there are more cheats than with other profiles.

Hypothesis 3: In a homogeneous environment in which all agents are thrifty, i.e., who want to be certain about value for money, there are more traces than with other profiles.

Hypothesis 4: Thrifty agents buy less high quality products than opportunistic and quality-minded agents.

Hypothesis 5: In a mixed setting with opportunistic and thrifty agents, the opportunistic agents cheat less than in a mixed setting with opportunistic and quality-minded agents.

Literature Overview

3.1

The classical approach explains economic systems at the micro-economic (individual) level and at the macro-economic (system) level independently, using equilibrium-based models (McConnel and Brue 2001). This approach is criticized for being unable to model various real-life economic and social systems such as financial markets and markets for fast-moving consumer goods (Moss and Edmonds 2005). The new field of Artificial Economics (Batten 2000) aims on building a bridge between micro- and macro levels through agent simulations that demonstrate how complex system properties emerge from the interaction of individuals.

3.2

Individual level models in the Trust and Tracing simulation model reproduce agents' decisions and behaviour in the following aspects:

- Trust
- Deception
- Trade

3.3

In the literature a variety of definitions of trust phenomena can be found. The common factor in these definitions is that trust is a complex issue relating belief in honesty, trustfulness, competence, reliability of the trusted system actors (e.g.,Grandison 2000; Ramchurn et al. 2004; Castelfranchi and Falcone 2001; Jøsang and Presti 2004). Furthermore, the definitions indicate that trust depends on the context in which interaction occurs or on the observer's point of view.

3.4

According to Ramchurn et al. (2004) trust can be conceptualized into two directions when designing agents and multi-agent systems:

- Individual-level trust — agent's beliefs about honesty of his interaction partner(s);
- System-level trust — system regulation protocols and mechanisms that enforce agents to be trustworthy in interactions.

In this paper we address problems and models for individual-level trust as our simulation environment already has system-level trust mechanisms such as the tracing agency that encourage trading agents to be trustworthy.

3.5

Defining trust as a probability allows relating it to risk. Jøsang and Presti (2004) analyse the relation between trust and risk and define reliability trust as "trusting party's probability estimate of success of the transaction". This allows for considering economic aspects; agents may decide to trade with low-trust partners if loss in case of deceit is low.

3.6

With respect to deceit, our approach differs from that of Castelfranchi, Falcone and de Rosis (2001) and de Rosis et al. (2003) that treat deception strictly rational as an instrument to win the game. In the social simulation aimed in our research we had to tune the agents to model actual human behaviour including their moral thresholds for deceit. Furthermore, our model does not simulate the purely rational decision as for instance the model of de Rosis et al. (2003) does.

3.7

Ward and Hexmoor (2003) describe an approach similar to ours, but their model does not explicitly recognize honesty as a moral threshold for deceit; it simply enables reinforcement learning from successful versus revealed deceit.

3.8

Our work acknowledges the work of Williamson (1998) stating that transaction cost economics possesses properties of bounded rationality, more precisely, that additional contractual complications can be attributed to an agent's opportunism rather than frailty of its motive. The importance of opportunistic behaviour is further supported by Diederen and Jonkers (2001) that mentions production quality and quality assurance as issues of chain and networks research to keep fast-switching consumers as a client.

3.9

In the real world, chains avoiding opportunistic (free rider) behaviour is an issue (Powell 1993). Following the economic literature (Williamson 1998; Diederen and Jonkers 2001), the simulation has three economic incentives not to cheat:

1. Need to refund money (Contract specific rules)
2. Fee from tracing agency (Governance rules)
3. Damaged reputation / lowering of trust (Social system rules)

3.10

The Trust and Tracing game has possibilities to experiment with relative importance and size of the three cost types. The contract-specific costs are easy to determine and therefore a calculated risk. The governance rules come with more uncertainty, because the fee depends on possible cheating of the agent you bought from. The damaged reputation depends on the socio-cultural system the agents come from, which formed their opinions on importance of trust and honesty and the reaction on being deceived.

Agent Models

4.1

We apply a compositional design approach to the Trust and Tracing simulation. The components represent decision making models for aspects of the agent's behaviour. The models of decision functions were partially published in Jonker et al. (2005a, 2005b). In this section we present the general architecture of the agent and explain details of the individual models. Additional information about the algorithms can be found at http://mmi.tudelft.nl/~dmytro/trustandtracing/.

Agent Architecture

4.2

Types of agents acting in the simulated game are trading agents (producers, middlemen, retailers, and consumers) and the tracing agent. The architecture of the tracing agent is straightforward: it reports the real quality of a product lot to the requestor, informs the sellers that a trace has been requested and penalizes untruthful sellers. In this paper we focus on the trading agents. The agent architecture for simulation of trading agents in the Trust and Tracing game was originally described in Meijer and Verwaart (2005). For the research reported in this paper we apply the modified architecture represented in Figure 3. All trading agents are built according to this architecture except the fact that producers do not have the *buying* process because they stand in the beginning of the supply chain and receive products from the game leader and consumers do not have the *selling* process because they stand in the end of the supply chain.

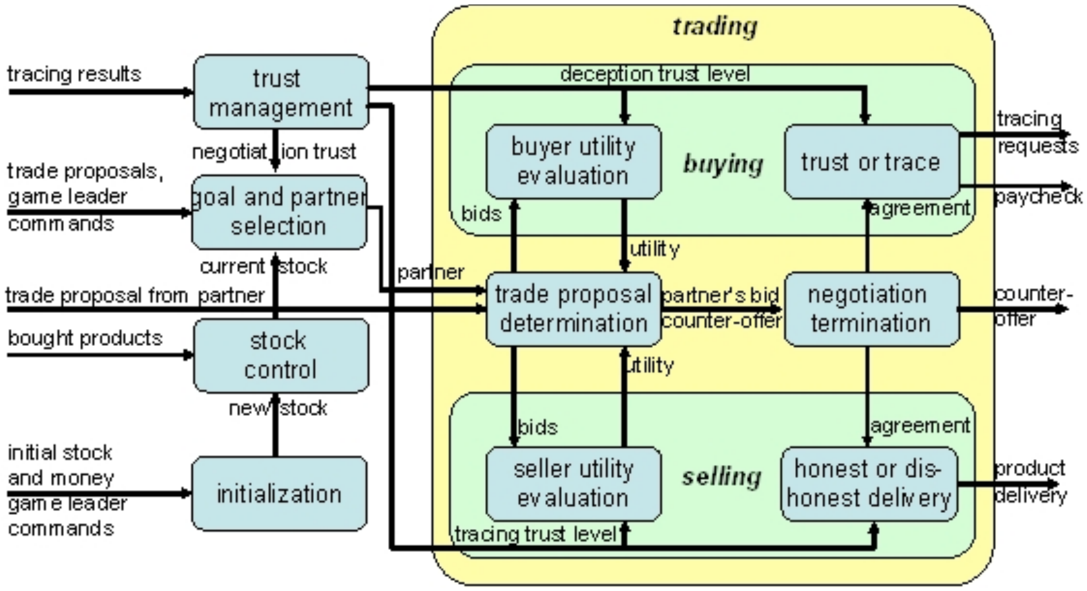

Figure 3. Trading agent architecture

4.3

Trading agents start up with the initialization process that handles communication with the game leader that informs them about initial stock and money. When the game leader broadcasts the "start game" message to the agents the initialization process transfers the control to the goal and partner selection process. The goal and partner selection process decides to buy or to sell, depending on the agent role and stock position, and selects a partner at random, weighted by success or failure of previous negotiations with particular partners. Then the control is transferred to the trading process.

4.4

Because of it's similarity to human bargaining behaviour, as evidenced in Bosse and Jonker (2005), we based the trading process on the algorithm presented in Jonker and Treur (2001). This approach to multi-issue simultaneous negotiations is based on utility theory. Negotiation partners send complete bids (a set of negotiation issues with assigned values) to each other. Once an agent has received a bid from the partner it can accept, or respond with a counter-offer, or cancel the negotiation that is decided in the negotiation termination process. Agents evaluate their own and partner's bids using the buyer (seller) utility evaluation process that uses a generalized utility function that is a weighted linear combination of particular issue evaluation functions (see 4.12 and 4.28).

4.5

If agreement is reached the seller selects the product to be delivered to the buyer in the honest or dishonest delivery process (see 4.36 *et seq.*). On the other side the buyer decides whether he wants to trace the product in the trust or trace process (see 4.20 *et seq.*).

4.6

The utility functions involve individual experience-based trust as an argument to estimate risk. Modelling of trust for this purpose and experience-based updating of trust - as part of the trust management process - is the subject of next subsection. In subsequent subsections we explain the utility functions and the way it can be used to represent agent's preferences or market strategies, and the decision making models for tracing, delivery and goal determination.

Trust Model

4.7

An important sub-process of the agent's trust management process is the update of trust values based on tracing results. Following Castelfranchi and Falcone (2001) we model trust as a joint subjective probability representing the opponent's willingness, capability, and opportunity to behave in a particular way. In the Trust and Tracing simulation we consider three different behaviours that we maintain a subjective probability about:

- successful negotiation (an agreement will be achieved);
- truthful product delivery (buyer: the opponent will deliver the agreed quality);
- not tracing the delivered products (seller: the opponent will trust after delivery).

4.8

Because all interaction that happens in the Trust and Tracing simulation involves two agents we model the trust as an individual-level agent's characteristic. This means that agent A can have low trust in agent B due to a series of bad experiences with him but have high trust in agent C, whose behaviour was honest and reliable.

4.9

In the Trust and Tracing simulation we assume that the experience gained by agents during the game is the only source of information about other agents. Thus, trust evaluation is built as a function of experience evaluation. Formula (1) formalizes trust updating as a function of the agent's experience of trading with its opponent. Instead of Bayesian updating, in order to represent short memory and an endowment effect, we chose an asymmetric trust update function, with either completely positive or completely negative experience according to the classification of Jonker and Treur (1999).

$$\begin{cases} trust_{t+1} = (1-d)trust_t + d^+, \text{ if experience is positive} \\ trust_{t+1} = (1-d^-)trust_t, \quad \text{ if experience is negative} \end{cases} \quad (1)$$

where $trust_t$ represents trust after the t transactions. The value of $trust$=1 represents complete trust, $trust$=0 represents complete distrust, and $trust$=0.5 represents complete uncertainty. The model represents that the most recent experience has the strongest impact (short memory) and that negative experience may have stronger impact than a positive experience. The latter is similar to the endowment effect (Hanemann 1991). Losing trust that one thought to be endowed with has more impact than finding a partner's trustworthiness confirmed. The factors d^+ and d^- are impact factors of positive and negative experiences respectively. They are related by an endowment coefficient e.

$$d^+ = e \cdot d^-, \quad 0 < e \leq 1 \quad (2)$$

Buyer Model

4.10

Trade is an essential type of interaction between agents in the Trust and Tracing game. In the Trust and Tracing game trade is an agreement between buyer and seller achieved through negotiation. The negotiation issues are:

- kind of the product;
- quality of the product;
- price;
- additional conditions: guarantee or certificate or none of these.

4.11

A buyer's motivation to accept or refuse a bid, depends on the price and other attributes of the bid, and on the player's trust in the seller. The buyer will compare the price with value of the product and decide. However, the value will depend on personal preferences of the buyer. Some buyers have a special preference for valuable high quality products, motivated by some form of self-esteem; others prefer low quality to avoid the risk of being deceived. So the trade-off between value and price is not a rational decision in economic sense. A similar reasoning applies to uncertainty. Some players are prepared to evaluate the risk of being deceived based on their trust in sellers; others are afraid to be deceived and avoid risky tranactions even if a rational economic evaluation would suggest to accept the risk.

Depending on the trust in the seller (belief about the opponent) and risk-attitude (personal trait of buyer), the buyer can try to reduce risk. Risk can be eliminated by trading low quality or demanding a quality certificate, or it can be reduced by a money-back guarantee. The attributes of a transaction are product type, stated quality, price, and certificate or money-back guarantee.

4.12

The negotiation model applied in this simulation, requires that bids can be valuated and compared in terms of utility. Real people will not actually calculate a utility. However, a utility function may approximate the player's preference in a simulation. For that purpose the utility is modelled as the sum of three terms, each having a weight factor. The three terms represent the price, the quality, and the risk associated with the bid. The weight factors may be used to model "irrational" preferences for quality and certainty. The buyer's utility function is a weighted sum of normalized functions of price, satisfaction difference between high and low quality (for consumers) or expected turnover (for others), and risk (estimate based on trust in seller, guarantee and prices):

$$u_{buyer}(bid) = w_1 \cdot f_{price}\left(price_{effective}(bid)\right) + \\ + w_2 f_{expected\_turnover}\left(expected\_turnover(bid)\right) + w_3 f_{risk}\left(risk_{seller}(bid)\right) \quad (3)$$

4.13

The weight factors implement buyer's preference for a particular market strategy. For *quality-minded* buyers that are willing to pay to ensure high quality, both w_2 and w_3 are high relative to w_1, for instance <0.2, 0.4, 0.4>. The *opportunistic* buyer prefers a high quality for a low price but is prepared to accept uncertainty, for instance <0.4, 0.4, 0.2>. The *thrifty* buyer also prefers low price, but avoids risk, represented for instance by <0.4,0.2,0.4>.

4.14

The function of price f_{price} normalizes the price of the bid according to the agent's beliefs about maximum and minimum market prices of the product of the given type and quality. The expected turnover normalization function $f_{expected\_turnover}$ normalizes the expected turnover with respect to the maximal and minimal possible number of satisfaction points (see table 1). The risk of the buyer is normalized using the f_{risk} normalization function that is based on the estimation of maximal risk over all possible bids. Such risk value corresponds to the bid with a "yellow" product of high quality and the price equal to the agent's belief of the maximum price. This bid would lead to the maximal money loss in case of deception because the probability of deception attached to the seller does not change during the negotiation.

4.15

Effective price is the total cost of the purchase:

$$price_{effective}(bid) = price_{purchase} + cost_{transaction} \quad (4)$$

where $cost_{transaction}$ represents some extra cost for the buyer that depends on the type of partner. In the current simulations the value is set to zero for purchases of consumers from retailers, of retailers from middlemen, and of middlemen from producers. It is set to infinity for all other combinations, to enforce the agents to follow their role in the supply chain. In future simulations it may be varied to allow for bypassing some links. The expected turnover is the average of the agent's beliefs about the minimal and maximal future selling price of the commodity to be bought. For consumers the expected turnover is set to the satisfaction level.

4.16

The buyer's risk represents is calculated as the product of the probability of deceit and the cost in case of deceit.

$$risk_{buyer}(bid) = p_{deceit} \cdot cost_{deceit} \quad (5)$$

The probability of deceit is greater than zero only if the quality of the commodity quality is high and it is not certified. If these conditions are satisfied than the probability of deceit is estimated as the complement of buyer's trust in the seller.

$$p_{deceit}(bid) = q(bid) \cdot c(bid) \cdot (1 - trust(seller)) \quad (6)$$

where q=1 if the bid suggests high quality, 0 for low quality and c=0 if the bid suggests a certified transaction, 1 without certificate.

4.17

The costs in case of deceit are estimated for middlemen and retailers as the sum of the fine for untruthfully reselling a product and, only if no guarantee is provided, the loss of value that is assumed to be proportional to the loss of consumer satisfaction value taken from table 1. The formula for middlemen and retailers is:

$$cost_{deceit}(bid) = fine_{reselling} + loss_{reselling}(bid) \quad (7)$$

where

$$loss_{reselling}(bid) = g(bid) \cdot price_{effective} \cdot \left(1 - ratio_{low/high}(bid)\right) \quad (8)$$

and *g* represents the guarantee function (5): *g*(*bid*)=1 if the bid involves a guarantee; *g*(*bid*)=0 otherwise.

4.18

For consumers the cost in case of deceit is also assumed to be proportional with the loss of satisfaction value, but they do not risk a fine, so for consumers:

$$cost_{deceit}(bid) = g(bid) \cdot price_{effective} \cdot \left(1 - ratio_{low/high}(bid)\right) \quad (9)$$

4.19

This subsection presented the buyer's model. Before introducing the seller's model in subsection 4.5, we present the model for the tracing decision entailed by a purchase.

Tracing Decision

4.20

Tracing reveals the real quality of a commodity. The tracing agent executes the tracing and punishes cheaters as well as traders reselling bad commodities in good faith. The tracing agent only operates on request and requires some tracing fee. Agents may request a trace for two different reasons. First, they may want to assess the real quality of a commodity they bought. Second, they may provide the tracing result as a quality certificate when reselling the commodity. The decision to request a trace for the second reason originates from the negotiation process. This subsection focuses on the tracing decision for the first reason.

4.21

In human interaction the decision to trust or to trace depends on factors that cannot be modelled in a multi-agent system. Hearing a person speaking and visual contact significantly influences the estimate of the partner's truthfulness (Burgoon et al. 2003). To not completely disregard the variance introduced by these intractable factors the trust-or-trace decision is modelled as a probability instead of as a deterministic process. The distribution involves experience-based trust in the seller and the buyer's confidence factor.

4.22

Several factors influence the tracing decision to be made after buying a commodity. First of all the tracing decision is based on the buyer's *trust* in the seller. Secondly, buyers may differ with respect to their *confidence*, an internal characteristic that determines the preference to trust rather than trace. It can be represented as a value on the interval [0,1]. We expect players with low trust to trace more frequently than players with high trust and we expect players with low confidence to trace more frequently than players with high confidence. Many other factors may influence the decision, like the amount of the tracing fee relative to the effective price, and the value ratio of low and high quality (satisfaction ratio). However, we have insufficient information to realistically model these unexplained influences. Therefore we modelled the decision to trust as a Bernoulli random variable with

$$p(\text{trust rather than trace}) = trust(seller(bid)) \cdot confidence \quad (10)$$

4.23

If an agent has decided to trace the product, it sends a tracing request message to the tracing agent. Once the tracing result has been received the agent updates its trust belief about the seller and adds the product to the stock.

Seller model

4.24

The utility-based multi-attribute negotiation algorithm presented in Jonker and Treur (2001) is used to model the bargaining process. The seller's model mirrors the buyer's model. It accepts and produces bids with the same attributes:

- kind of the product;
- quality of the product;
- price;
- additional conditions: guarantee or certificate or none of these.

4.25

To reduce the buyer's risk, a seller can give a 'money back'-guarantee if the product delivered turns out not to have the promised quality. A buyer can trace a product only when he has paid for it and received it. However, to completely eliminate a buyer's risk, a seller can request a 'trace' for the product which results in a certificate ensuring the real quality. The guarantee itself costs no money, but a certificate involves the tracing agency at the cost of a fee that depends on the position of the seller in the chain. Tracing early on in the chain is cheaper, as fewer steps have to be checked. Consumers pay the highest fee for tracing. Following section 3, producers cannot trace, to force the environment to use at least one transaction with an unchecked product.

4.26

As explained in 3.9, we follow Williamson (1998) and Diederen (2001), in giving a seller three economic incentives not to cheat, which are included in the risk component of the sellers' utility function:

1. Need to refund money. (Contract specific rules)
2. Punishment by the tracing agency. (Governance rules)
3. Damaged reputation / lowering of trust. (Social system rules)

4.27

The opportunity of deceit is not included in the utility function during negotiations. Firstly, for believable deceit sellers would have to act as if they were honest. Secondly, negotiation and delivery are separate processes and actual deceit takes place in the delivery phase. This resembles the real-world situation of firms having departments responsible for different functions in a firm. The model of the decision to deceive is discussed in the next subsection.

4.28

The seller's utility function is the weighted sum (linear combination) of normalized functions of effective price and seller's risk:

$$u_{seller}(bid) = w_1 f_{price}(price_{effective}) + w_2 f_{risk}(risk_{seller}) \quad (11)$$

4.29

The functions f_{price} and f_{risk} present the normalized effective price and seller's risk in the interval [0; 1]. The normalization function of the price f_{price} is similar to the one of the seller. The risk is normalized over the maximum possible risk for the seller. This risk value corresponds to the bid of high quality "yellow" product with a money back guarantee and the price equal to the agent's belief of the maximum price for the product on the market. The weight factors add up to one and represent the seller's strategy with respect to the risk he is willing to take in reselling commodities of uncertain quality. In order to model a risk-neutral seller that acts rationally in economic sense, $w_1=w_2=0.5$. For a risk-avoiding agent $w_1 < w_2$. We use w_1=0.2 and w_2=0.8 for the producers, middlemen and retailers following the quality-minded or thrifty strategies and $w_1=w_2=0.5$ for opportunistic agents.

4.30

The effective price represents the seller's benefit:

$$price_{effective}(bid) = price_{purchase}(bid) - price_{sell,\min} - cost_{transaction} - cost_{certification} \quad (12)$$

where $price_{purchase}(bid)$ represents the proposed price of the anticipated transaction , $price_{sell,min}$ represents seller's belief about the minimal price he may receive receive from alternative buyers (opportunity cost); $cost_{transaction}$ represents cost of making a transaction with the given partner, in the current simulations the value is set to zero for sales of retailers to consumer, middlemen to retailers, and of producers to middlemen (for more details, see the definition of the transaction costs in the "Buyer Model" section); $cost_{certification}$ represents the fee a player has to pay the tracing agency for tracing the commodity and providing a certificate, if needed.

4.31

A seller's risk represents the risk to lose money in case of reselling a high quality commodity untruthfully delivered to the seller:

$$risk_{seller} = p_{neg\,trace} \cdot cost_{neg\,trace} \quad (13)$$

4.32

The probability of a negative trace is zero when the product is stated to be of low quality, or when the seller has bought the product with a certificate, or when seller would provide a certificate in the current transaction. Otherwise the seller has to estimate the probability that a trace would be requested (taking into account the trust he has in the buyer not to trace), and the probability that the product was untruthfully delivered by the supplier of the seller (based on the trust in the honesty of that supplier):

$$p_{neg.trace} = \left[1 - \prod_{seller_i \in S} trust_{honest}(seller_i)\right] \cdot \left[1 - trust_{tracing}(buyer)\right] \cdot q(bid) \cdot \left[1 - c(bid)\right] \quad (14)$$

where S is the set of agents upstream in the supply chain of this particular lot; $trust_{honest}(seller_i)$ represents the experience-based trust the seller has in an upstream seller to deliver according to promise; $trust_{tracing}(buyer)$ represents the experience-based trust the seller has in its negotiation partner to accept a delivery without tracing it; $q(bid)$=1 if the quality is high, 0 if the quality is low; $c(bid)$=1 if a certificate is present or will be provided, 0 otherwise. Both $trust_{honest}(seller_i)$ and $trust_{tracing}(buyer)$ will be updated according to equation (1).

4.33

'Money-back', governance fees and reputation damage are the components of cost in case of a negative trace. Whenever the player bought a high quality product without a certificate and he again sells that product as a high quality product without a guarantee, he runs the risk of a fee for untruthful selling, and a risk of reputation damage. If the seller provides a guarantee, there is the risk of having to pay money back and his reputation would be more severely damaged.

$$cost_{neg.trace}(bid) = fine_{good\,faith} + rep.damage + \\ + g(bid) \cdot [rep.damage.garantee + money\_back(bid)] \quad (15)$$

where $g(bid)=1$ if the bids entail a guarantee, 0 otherwise.

4.34

From the seller's point of view the 'money back' guarantee can be interpreted in terms of costs as an obligation to buy a low-quality product for a high-quality price: if seller is caught on deception he has to pay buyer full price of the transaction but he receives low-quality product back. In a formal way 'money back' can be considered as the following expression:

$$money\_back(bid) = price_{purchase}(bid) \cdot [1 - satisfaction\_ratio(bid)] \quad (16)$$

where the satisfaction ratio is taken from table 1.

4.35

Reputation damage is difficult to estimate, because of the complexity of the phenomenon. It is currently represented in the simulation by a fixed amount of money, set by the game leader at a global level (reflecting societal values). However, further development of models is required. The Trust and Tracing game simulation offers a good environment for developing and testing the models.

Honest or Dishonest Product Delivery

4.36

The seller has to deliver a product after agreement on transaction conditions has been achieved. If low quality has been agreed, the seller will simply deliver a low quality product. If high quality has been agreed, the seller may consider delivering low quality to gain profit. The decision to deceive is not merely a rational one with respect to financial advantages and risks. In real world business social-cultural influences change the decision (Hofstede et al. 2004). As said before, we incorporate reputation and trust in our agents.

4.37

The opportunity of deceit occurs when the agent has sold a high quality product without a certificate and has a low quality product of the same type in stock. The motivation to deceive is in the extra profit that can be gained. In our model we assume that the motivation depends on the difference in consumer satisfaction between high and low quality. Three types of costs (money-back, fine and reputation / trust damage) provide a counterforce to the opportunistic behaviour, of which the third one comes from socio-cultural backgrounds.

4.38

In the agent model for delivery the trust level is only used to estimate the risk of being unmasked, so credulous buyers have an increased risk of being deceived. Thus, trust is not modelled as an incentive not to deceive friends, but only as an asset that enhances market position (Duke and Geurts 2004).

4.39

In reality other factors may influence the decision and not all of them can be taken into account. A random term represents the aggregated effect of unknown influences in the simulation. Furthermore the random effect may cause some unexpected events that may prevent the simulation from getting into a deadlock. The game leader can adjust the weight of the random term. Model calibration on human gaming data is necessary to find realistic values of this parameter.

4.40

All factors are normalized on [0, 1]. The following expresses the deceit decision.

$$\begin{array}{ll} \text{IF} & q(bid)\cdot[1-c(bid)]\cdot s[type(bid),low]\cdot \\ & \{(1-rtw)\cdot[1-satisfaction\_ratio(bid)]\cdot trust_{tracing}(buyer)+rtw\cdot rnd\} \\ & > honesty \\ \text{THEN} & \text{deceive} \end{array} \quad (17)$$

where *rtw* is the weight of the random term, set in the interval [0, 1]; *rnd* represents a uniformly distributed random real number from interval [0, 1]; function s[type(bid),low] returns 1 if the selling agent has low quality products in stock (opportunity to deceive), 0 otherwise. The temptation to deceive depends on the value ratio of low and high quality. Each agent has an honesty parameter that represents the agent's threshold for deceit.

4.41

Four parameters are used to model the dynamics of honesty. The first parameter is the initial level of honesty. The second parameter d^+ defines the honesty decay. Honesty is modelled to decay autonomously over time until some minimum level, which is the third parameter with respect to honesty. The fourth parameter is the tracing effect d^-. The awareness of being traced is assumed to improve honesty to an extent depending on d^-. The following equations model the honesty dynamics analogue to the trust dynamics in equation (1).

$$\begin{cases} honesty_{t+1} = (1-d^+)honesty_t + d^+ minimal\_honesty, & \text{if not traced} \\ honesty_{t+1} = (1-d^-)honesty_t + d^-, & \text{if traced} \end{cases} \quad (18)$$

Goal determination

4.42

In the game consumers will buy as much as they can. Producers will try to sell all products they have in stock. However, for middlemen and retailers some stock management is needed in order to negotiate efficiently. For example, imagine a situation in which a retailer tries to sell a product having in stock only a low quality product with low satisfaction level. This would lead to a negotiation in which the consumer makes concessions in favour of the retailer, whereas the retailer proposes the same product in each bid. Such retailer's behaviour can break consumer's patience, leading him to cancel the negotiation and to update the negotiation trust accordingly. In such a situation it would not be reasonable for a retailer to start or enter negotiations as a seller.

4.43

Middlemen and retailers must decide to operate on the market as a seller or as a buyer. The decision to search a partner for selling or buying is taken at random with

$$p(\text{sell}) = \frac{\sum_{i=\{\text{Blue,Red,Yellow}\}} \sum_{j=\{\text{Low,High}\}} S_{ij}}{\sum_{i=\{\text{Blue,Red,Yellow}\}} \sum_{j=\{\text{Low,High}\}} T_{ij}} \quad (19a)$$

$$p(\text{buy}) = 1 - p(\text{sell}) \quad (19b)$$

where S_{ij} stands for actual stock level of product *i* and quality *j*, and T_{ij} stands for the corresponding target level.

4.44

In reaction to a proposal from a seller, a middleman or retailer will refuse if the stock of the proposed product is at target level, and enter negotiations otherwise. Expected turnover is set to zero in the buyer's utility of middlemen and retailers if the stock of the product/quality offered is at target level. Sellers will refuse negotiations if the requested product is completely out of stock.

Simulation results

5.1

This section presents the results of the first set of simulation runs, following the right-hand cycle in figure 2. 5.3 through 5.19 presents the results of verification runs, aiming to test the model construction and the sensitivity for parameter settings (does it work as intended when designing the model?; do parameter changes adequately influence the results?). 5.20 *et seq.* presents the results of the simulation runs aiming the preliminary validation of multi-agent model against the human gaming simulation based hypotheses that were postulated at the end of section 3. All of the verifications and validations reported in this section concern aggregated game statistics; they do not concern the behaviour of individual agents. The results confirm that emergent behaviour observed in human simulation games can also be observed in the multi-agent simulations.

5.2

The agent parameters to represent individual characteristics of the agents are the trust parameters (initial trust and positive and negative trust update) and honesty parameters (initial and minimal honesty, honesty decay and punishment effect). Only these parameters and the trading strategies were varied in the results discussed in this section. Other parameters, such as game configuration, target stock levels, and fine and damage amounts, were equal for all simulations.

Verifying the multi-agent model

5.3

To test the multi-agent model we performed sensitivity analyses for the parameters that represent individual characteristics (trust and honesty). As a last verification we checked for the occurrence of the so-called endowment effect. During the design of the multi-agent model the asymmetric speed of gaining trust and loosing trust has been a recurring issue. To test for correct implementation we assume that the endowment effect shall occur if trust is implemented correctly. Furthermore the results of this subsection give insight in the magnitude of effects when changing parameters.

Sensitivity of trust update parameters

5.4

The first series of simulation results demonstrate the effect of trust learning in an environment of perfectly honest traders. With an increasing value of the trust update parameters we expect the agents to learn more rapidly that they deal with perfectly honest traders. As a consequence we expect the proportion of high quality transactions to increase, the proportion of certificates and guarantees to decrease, and the tracing frequency to decrease.

5.5

To test the actual sensitivity of the simulation model for trust learning, games were simulated with both positive and negative trust update parameters set to an equal value for all agents (three games with trust update set to 0.1, three with 0.5, and three with 0.9). The games were terminated after 500 transactions or as soon as one of the producers ran out of stock.

5.6

All agents were configured with a neutral negotiation strategy, assigning equal weights to transaction value and transaction risk, the latter being the product of estimated damage and estimated probability that the damage will occur. The weight tuples associated with this strategy are <0.33, 0.33, 0.33> for buyers and <0.5, 0.5> for sellers (see explanation of equation (3) and (11)). Each agent's initial trust in all other agents was set to 0.5, representing total uncertainty about the opponents trustworthiness. All agents were configured to be perfectly honest (initial honesty and minimal honesty = 1.0). The confidence parameter was set to 0.95, so on average the agents will even request a trace in 5% of cases if they completely trust their opponents.

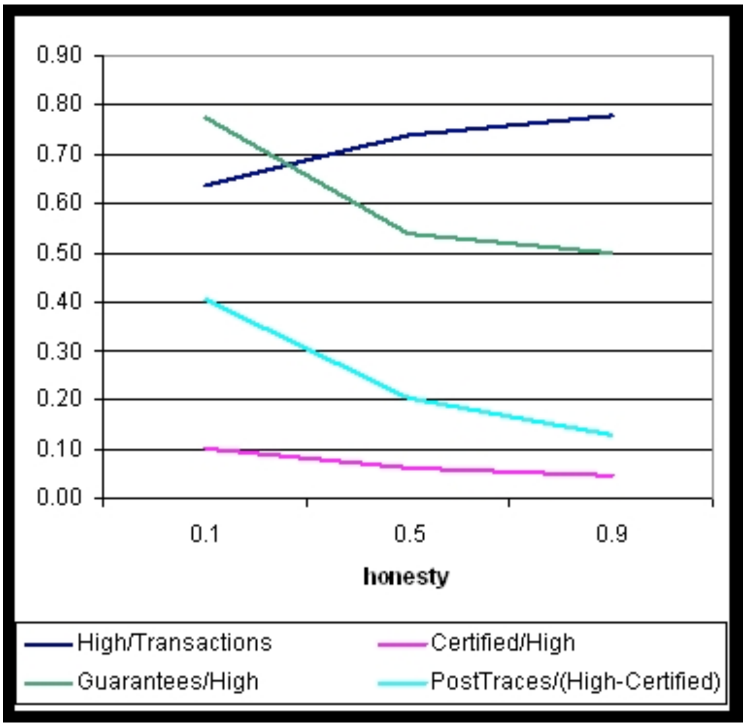

Figure 4. Sensitivity of trust update parameters

5.7

Figure 4 presents the statistics of the simulated games (see Table A1 for details). The effects of increasing trust update factors on statistics in games with perfectly honest agents are:

- increasing proportion of high quality transactions (H/N=0.64, 0.74, 0.78),
- decreasing proportions of certified or guaranteed transactions (C/H=0.10, 0.06, 0.05; G/H=0.77, 0.54, 0.50),
- decreasing tracing ratio (P/(H−C)=0.40, 0.20, 0.13), so game statistics are sensitive to the trust update factor as expected.

Sensitivity of initial trust

5.8

Table A2 shows statistics of simulated games with different strategies that are defined in the explanation of equations (3) and (11), different values of initial trust, and different values of honesty. All games were simulated with a homogeneous agent population: in a particular game all agents had exactly equal parameter settings. Trust update was set to 0.3 for positive and 1.0 for negative experience, honesty decay to 0.3, and punishment effect to 1.0. The confidence parameter was set to 0.95. The games were terminated after 200 transactions, or as soon as one of the producers ran out of stock.

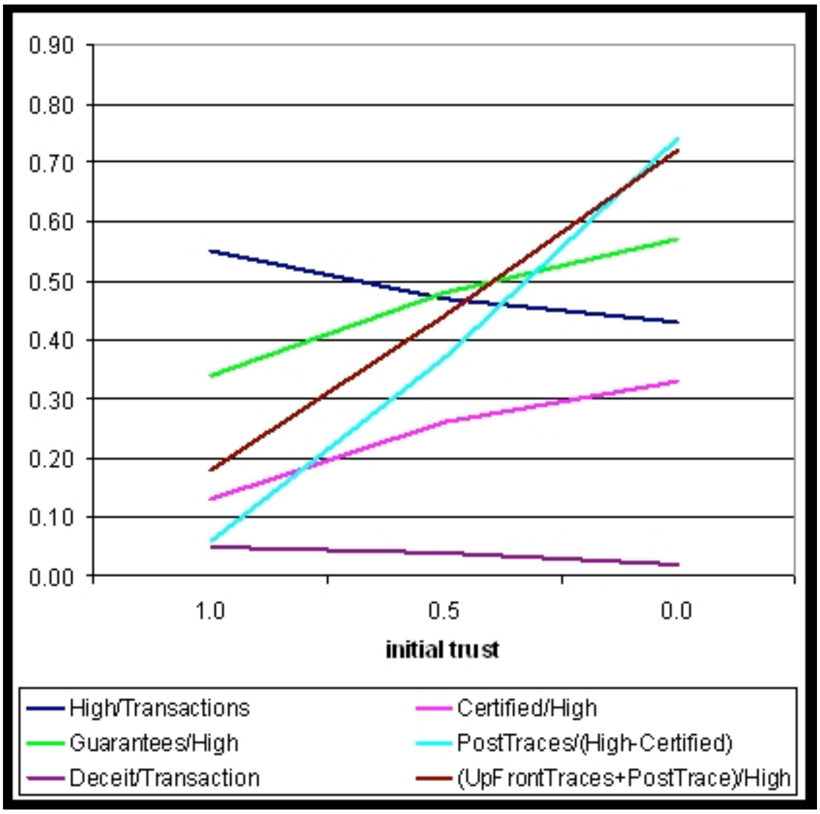

Figure 5. Sensitivity of initial trust

5.9

In short games, decreasing initial trust is expected to decrease the proportion of high quality transactions, to increase the number of certificates and guarantees, and to increase the tracing frequency. Indirectly, decreasing average trust is expected to decrease the deceit frequency in games with agents that are not perfectly honest, because a decreased proportion of high quality and increased certification decrease the opportunity to deceive and more intensive tracing will increase honesty through punishment.

5.10

Figure 5 shows that the sensitivity for initial trust is as expected (see Table A3). The aggregated statistics of games with initial trust set to 1.0, 0.5, and 0 show a decreasing trend for the proportion of high quality transactions (H/N=0.55, 0.47, and 0.43, respectively). The proportions of certificates (C/H) and guarantees (G/H) both show an increasing tendency. Tracing is increased (P/(H−C)=0.06, 0.37, 0.74) and deceit is decreased (D/N=0.05, 0.04, 0.02).

Sensitivity of honesty

5.11

The deceit frequency is expected to be strongly correlated with honesty of the agents. The average level of honesty is also expected to have some indirect effects on game statistics. The average value of trust will decrease when tracing reveals the deceit. As a consequence, the proportion of high quality products is expected to decrease as well, and the frequencies of certificates, guarantees, and tracing are expected to increase.

5.12

Figure 6a presents aggregated game statistics (see Table A4) for games with different values of honesty, taken from Table A2. Initial honesty and minimal honesty are set to equal values in these games. As expected, Figure 6b shows that honesty has a strong effect on the deceit frequency. No deceit occurs in simulated games with initial and minimal honesty both set to 1.0. Setting of the honesty parameters has no effect in games with thrifty agents, because they offer little opportunity for deceit. The strongest effect of the settings of the honesty parameters is found in games with opportunistic agents. These games are the most sensitive for honesty, because opportunistic agents accept the risk of deceit for transactions with a good quality/price ratio. The tracing frequency depends on honesty as expected (P/(H-C)=0.31, 0.33, 0.37 respectively).

5.13

Figure 6 presents the effect of different values of honesty. Of course, simulated games with completely honest agents have the highest proportion of high quality transactions, and only a small proportion of certified transactions. However, the frequency of high quality transactions is higher than one would expect for the completely dishonest agents. This is to be explained as follows. In the beginning of the game, any tracing request will reveal deceit. Average trust is decreased and the average tracing frequency is increased, thus strongly reinforcing honesty. Some agents trace in the beginning of the game, some don't, for instance because the commodity was low quality or certified. The cause of the relatively high frequency of untraced high quality transactions is the rapid decrease of trust in the first links of the chain. A tracing request will always reveal deceit, reduce the remaining trust, and increase the tracing frequency in subsequent transactions. On the other hand, the punishment effect of tracing increases average honesty more rapidly than trust decays: deceit reduces trust of a single buyer, but all buyers benefit from the honesty that is reinforced by tracing. "Knowing" that they will not dare to deceive, sellers offer guarantees for a very attractive price. Thus the delicate equilibrium between trust, tracing frequency and honesty is reached sooner in games that start from complete dishonesty than in "half-honest" games.

5.14

The frequency of certificates (C/H) is much greater in games with dishonest agents. There is a shift from guarantees (G/H) towards certificates (C/H) if honesty decreases. The reason for this is that even after having given a guarantee, sellers may deliver untruthfully. The rapid decrease of trust in games where much is revealed, also decreases trust in guarantees. The total frequency of certificates and guarantees increases with decreasing honesty, as expected (C/H+G/H= 0.61, 0.71, 0.74, respectively).

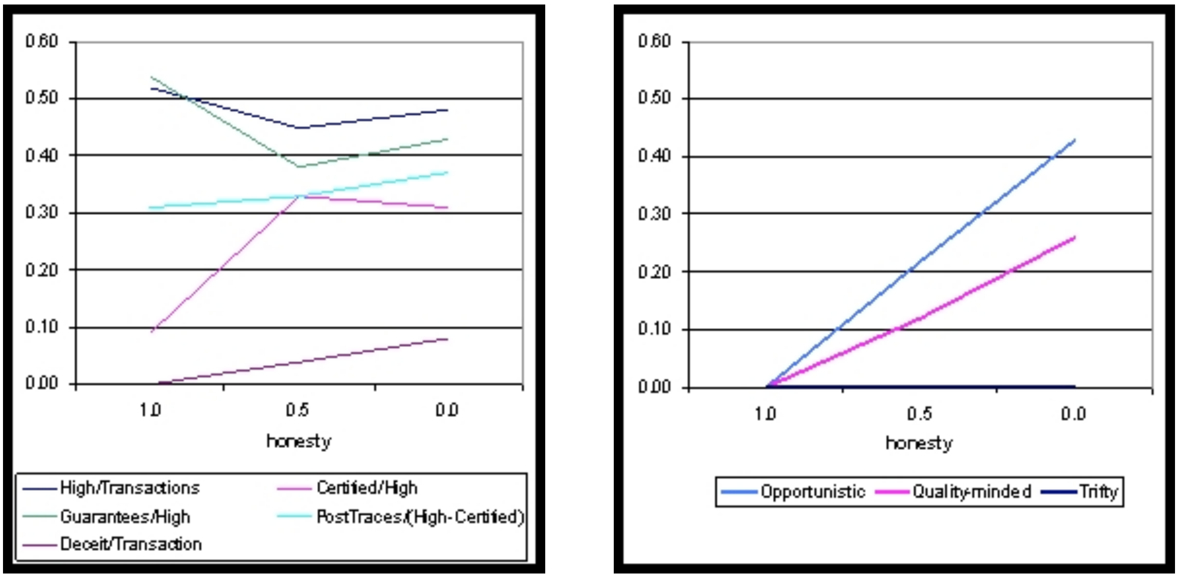

Figure 6. Sensitivity of honesty: a — game statistics for different honesty levels, b — deceit frequency for opportunistic, quality-minded and thrifty agent for different honesty levels

Endowment effect

5.15

The fourth series of simulation results demonstrate the sensitivity of the simulated game statistics for the so-called endowment effect: people experience loosing something they possessed as more painful than not gaining the same thing if they did not possess it. The endowment effect entails a high value of trust update after a negative experience and a low value of trust update after a positive experience.

5.16

We expect the endowment effect to lower the average trust level, so in games with endowment effect the proportion of high quality transactions will be lower, the frequency of certificates and guarantees will be higher, and the tracing frequency will be higher than in games without endowment effect.

5.17

Simulation of the endowment effect requires the introduction of dishonest agents. Figure 7 (see also Table A5) presents statistics of simulated games in which all agents have initial honesty = 0.5 and minimal honesty = 0.5. Other settings are unchanged with respect to the previous subsection, except for the update parameters represented in the Table A5.

5.18

As expected, the endowment effect is shown to decrease the proportion of high quality transactions (H/N= 0.17, 0.18 with endowment effect versus 0.26, 0.23 without endowment effect). The cheating frequency (D/N) is lower in games with endowment effect, because it takes a long time to heal the negative experience of punishment. Yet the endowment effect decreases the proportion of high quality transactions, because average trust is lower. Once deceived it takes long to regain trust. Variance is high in games with strong endowment effect or high sensitivity (δ^+=1 and δ^-=1), due to the fickle behaviour of the agents. Statistics of these games of a limited number of transactions are more sensitive to the coincidental revelation of deceit early in the game.

5.19

The impact of the endowment effect on certificates and guarantees is not that obvious as we expected (C/H+G/H=0.86, 0.76 with endowment effect, versus 0.74, 0.74 without endowment effect), probably because the number of certificates and guarantees is high anyway given the settings of the other parameters used in these games. Tracing frequency, as expected, is higher in games with endowment effect (P/(H-C)=0.36, 0.34 with endowment effect versus 0.24, 0.25 without endowment effect).

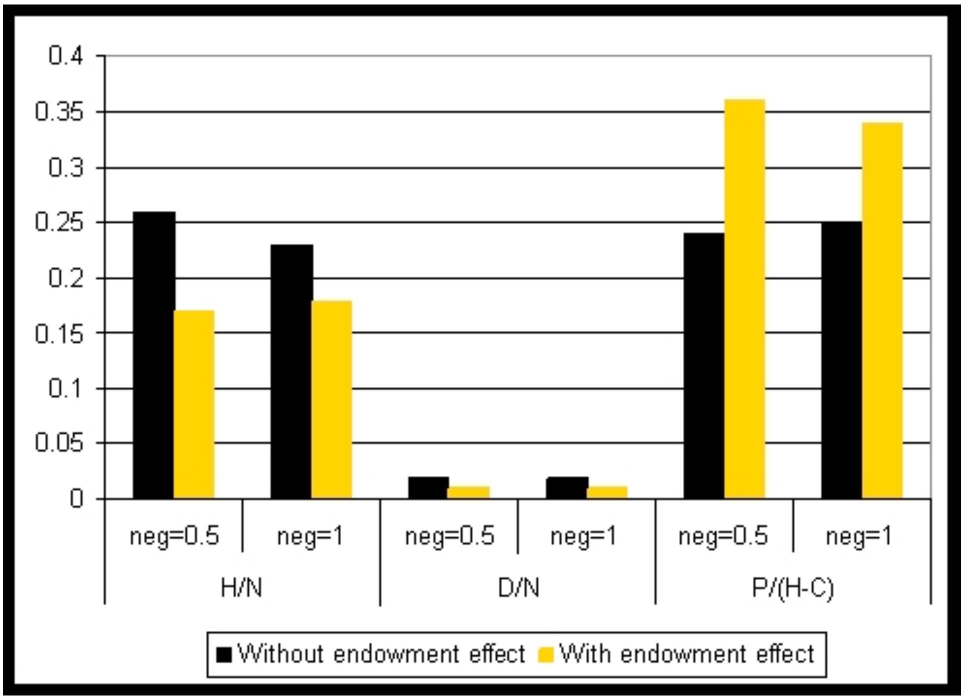

Figure 7. Sensitivity of endowment effect

Testing of the hypotheses

5.20

This subsection offers a preliminary validation of tendencies reflected by the multi-agent simulation. We compare tendencies in multi-agent simulations with tendencies observed in human games, as formulated in the hypotheses in section 3.

5.21

Hypothesis 1: *When the initial willingness to trust is high the percentage of high quality products sold will be higher than when the initial willingness to trust is low.*

Hypothesis 1 is directly confirmed by the data in Figure 5: The aggregated statistics of games with initial trust set to zero, 0.5, and 1.0 show an increasing trend for the proportion of high quality transactions (H/N=0.43, 0.47, and 0.55, respectively).

For the purpose of testing the remaining hypotheses, the results from Table A2 are aggregated per strategy in Table A6.

5.22

Hypothesis 2: *In a homogeneous environment with all opportunistic agents there are more cheats than with other profiles.*

Hypothesis 2 is confirmed by the results: D/N=0.07 for the opportunists, 0.04 for the quality-minded, and 0.00 for the thrifty agents, the latter simply giving little opportunity for deceit (Figure 8). Thrifty agents prefer low quality unless they can get certified or guaranteed high quality products for a very good price. Quality-minded agents prefer to avoid the risk of deceit by trading certified products, thus reducing the possibility of deceit at the cost of up-front tracing, but unlike the thrifty agents they will buy high quality even if a risk remains. Opportunistic agents prefer high quality and in addition they prefer a good price over certainty. In the buyer role they take an increased risk of being deceived; in the seller role they are easily tempted to deceive. As a consequence deceit occurs most frequently in games with opportunists.

5.23

Hypothesis 3: *In a homogeneous environment in which all agents are thrifty, i.e., who want to be certain about value for money, there will be more traces than with other profiles.*

Hypothesis 3 is confirmed by the results for (Q+P)/H in Figure 8 (i.e., the sum of up-front and post-transaction tracing requests relative to the number of high quality transactions). The absolute number of traces is low in games with thrifty agents, because they trade little high-quality products (column H/N in Table A6). However, relative to the number of high quality transactions, they have the highest tracing level. The tracing frequencies found in simulated games with quality-minded agents are not as high as for thrifty agents, but relatively high compared to the opportunists, due to up-front tracing in order to certify products before selling them. This increases price, but the quality-minded are willing to pay for the certainty that comes with it.

5.24

Hypothesis 4: *Thrifty agents buy less high quality products than opportunistic and quality-minded agents.*

Hypothesis 4 is confirmed by the detailed data in column (Q+P)/H of Figure 5 (the aggregation level of Figure 8 does not give sufficient information to compare with hypothesis 4). The proportion of high-quality transactions is less sensitive for trust in the quality-minded games than it is for the other strategies. The quality-minded prefer high quality and if they distrust they likely compensate the risk by either up-front or post-transaction tracing (high values of (Q+P)/H and P/(H-C) in the lower rows for quality-minded in Table A3). They are prepared to pay a higher price to reduce uncertainty.

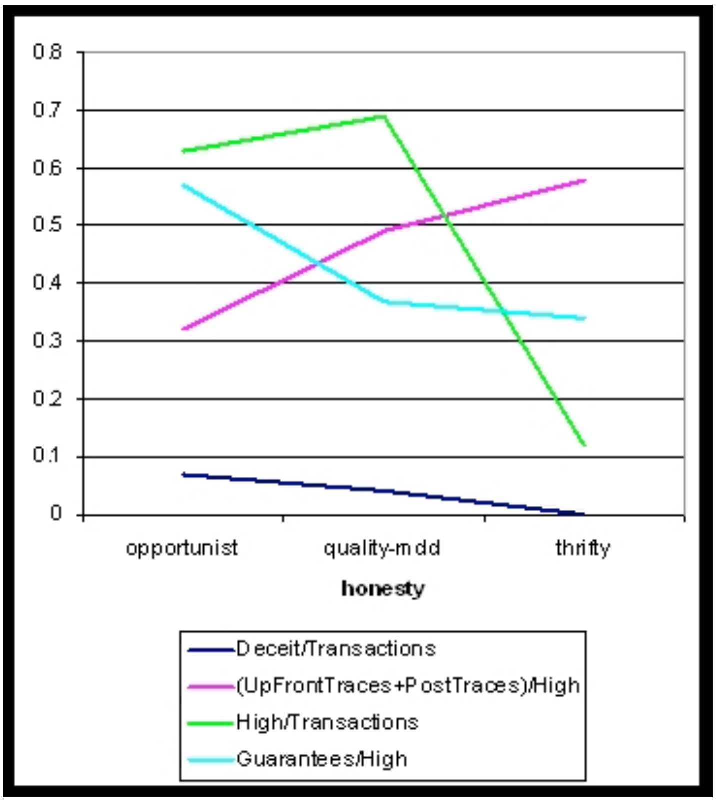

Figure 8. Sensitivity of strategies

Opportunists also trade many high-quality products, but they pay for it in a different way. They accept the risk of deceit more easily. This is an effect of the low weight of risk evaluation in their utility functions that makes opportunist negotiate about price or potential profits. The latter makes them trade more high-quality products. Opportunists agree to trade with a money-back guarantee (column G/H) more often than agents with other strategies, that prefer a certificate (column G/H). This is due to lower cost of guarantees with respect to certification and the low weight of risk evaluation in the negotiation models of opportunists.

Agents following a thrifty negotiation strategy prefer to pay a low price, so they will not easily agree on buying with certificates or guarantees. In addition, they avoid the risk of being deceived. This results in a low ratio of high quality products (H/N) being traded.

The simulation results presented so far concerned games with homogeneous agent populations. Hypothesis 5 is about games with differently configured agents in the same game.

5.25

Hypothesis 5: *In a mixed setting with opportunistic and thrifty agents, the opportunistic agents cheat less than in a mixed setting with opportunistic and quality-minded agents.*

This hypothesis reflects observations of human simulation games that reveal extreme values of deceit frequency between games with mixed populations of opportunists and quality-minded on the one extreme and games with mixed populations of opportunists and thrifty agents on the other extreme. Figure 9 (see also Table A7) presents statistics of simulated games populated with agents with different strategies. Some agents were configured to follow an opportunistic strategy. The others were following a quality-minded strategy in the first series of games, and a thrifty strategy in the second series of games. The simulation statistics confirm hypothesis 5: much deceit in the first series (D=114), little deceit in the second series (D=23), although all agents are configured as dishonest.

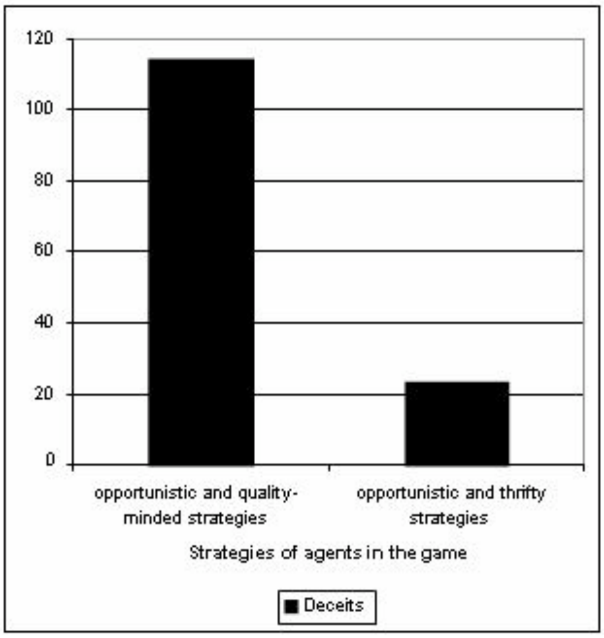

Figure 9. Deceits in games with mixed strategies

5.26

The experiments confirm the validity of the models against the five hypotheses based on experience in human gaming simulations, formulated in section 3. Thus one cycle of the research approach presented in figure 2 was completed. So far we only validated the tendencies, like "thrifty agents buy less high quality commodities than other agents". A quantitative calibration of the model would require additional cycles.

Conclusions and discussion

6.1

The research method for the development and validation of agent-based simulation of economic institutional forms consists of a cycle of steps, that can be started anywhere in the cycle depending on the state of data, theories, and hypotheses available. Human gaming simulation is used to obtain reliable data about the economic institutional form being studied. The advantage of this approach is that different variable settings can be tested in experimental setups, something that is generally impossible to do in real situations. The data obtained is analyzed, leading to the conclusions about tendencies on the aggregated level. Theories are formed on the basis of those tendencies and learned from literature. The theories and design of the gaming simulation are translated into multi-agent models that are then incorporated into a computer simulation of the same game. Within the computer simulation the same variable settings can be loaded as were used to play the human games. As a result the tendencies in the data obtained from the computer simulations can be compared to those obtained from the human games. Observed differences lead to adjustments of theories, with which the cycle can be repeated.

6.2

Furthermore, exploring various variable settings is much easier and faster for the computer simulation than for the human game. Therefore, one of the steps in the method is a systematic exploration of variable settings in the computer simulation, to a level of exhaustiveness as deemed necessary. The exploration is used to determine variable settings that are worth while to play out using humans. The exploration of various variable settings is also of importance for verifying that the models correctly represent the theories about individual behaviour. For instance, it is possible to rapidly generate results for different institutional settings (size of the products supply, cheating fine, publication of tracing results, number of agents per role) and produce results similar to Figure 3-9 (Table A1-A7). Strategies of human game players can be analyzed by running agent simulation with various player strategies.

6.3

The approach is illustrated by applying it to commodity supply chains, and more specifically to the Trust and Tracing game. This is a trade game on commodity supply chains and networks, designed as a research tool for human behaviour with respect to trust and deceit in different institutional and cultural settings. Using the approach, individual-level agent models have been developed that simulate the trust, deception and negotiation behaviour of humans playing the Trust and Tracing game. The models presented have been verified and validated by a series of experiments performed by the implemented simulation system, of which the outcomes are compared on the system level to the outcomes of games played by humans. The experiments cover in a systematic way the important variations in parameter settings possible in the Trust and Tracing game and in the characteristics of the agents. The simulation results show the same tendencies of behaviour as the observed human games.

6.4

Aside from showing the validity of the research method introduced here, the paper also presents the agent models that simulate trust, deception, and negotiation behaviour of humans when playing the Trust and Tracing game, with respect to a number of hypotheses and theories.

6.5

In an environment of perfectly honest traders, the speed with which agents learn that they are dealing with perfectly honest traders is directly related to the trust update parameters. As observed in human gaming simulations and in computer simulations, the higher the trust update parameters, the higher the proportion of high quality transactions, the lower the proportion of certificates and guarantees, and the lower the tracing frequency.

6.6

The endowment effect is the hypothesized effect that people experience loosing something they possessed as more painful than not gaining the same thing if they did not possess it. As expected, including the endowment effect in the computer simulations is shown to decrease the proportion of high quality transactions, to lower the cheating frequency and to increase the tracing frequency. Explanations are that in such games average trust is lower, and that once deceived it takes a long period to regain trust.

6.7

Finally, the research confirms the following hypotheses: there is more deceit in games with opportunistic agents than with other strategies, there is more tracing in games with thrifty agents, and games with quality minded agents have lower tracing frequencies if trust is higher. During the validation phase also two series of games were compared. In the first series some agents are opportunistic and others are quality-minded. The other series of games had opportunistic agents and thrifty agents. In all series agents were configured as dishonest. The level of deceit was higher in the first series than in the second series.

6.8

In current and future work more variations of the setting (including the current one) will be tested in both the human and simulated environment. This will lead either to further adjustments of the multi-agent model or to more variations to test. By testing large numbers of settings quickly in the simulated environment we can select more interesting settings for the human sessions, and thus save research time. The long-term result will, hopefully, be a fully validated model of trust with respect to situations comparable to the Trust and Tracing game, where validation is reached for the individual and the aggregated level.

6.9

Finally, the research method introduced in this paper, shows promise to bridge the gap between agent-based economics and new institutional economics by the use of human simulation games as intermediate steps. In human games, transactions can be monitored in much more detail than in real life trade. That way it is much easier to collect the necessary data to set up dependable agent-based simulations of the situations enacted in the human games. The agent-based simulation will be informative for the more generic case in as far as the human game is a proper reflection of real life trade processes. The results presented in this paper show that an agent-based simulation of the Trust and Tracing Game is indeed possible. The approach furthermore opens up the possibility of modelling specific groups of humans in trade situations (e.g., traders from different cultures). This will lead to agent-models that reflect the background of the group under consideration, and improve the accuracy of the models.

Appendix A: Simulation Results

trust update		N	H	L	Q	C	G	P	D	H/N	C/H	G/H	(Q+P) /H	P/ (H-C)	D/N
0,1		375	250	125	0	29	196	89	0	0,67	0,12	0,78	0,36	0,40	0,00
0,1		366	232	134	0	18	180	84	0	0,63	0,08	0,78	0,36	0,39	0,00
0,1		364	220	144	0	25	167	81	0	0,60	0,11	0,76	0,37	0,42	0,00
	total	**1105**	**702**	**403**	**0**	**72**	**543**	**254**	**0**	**0,64**	**0,10**	**0,77**	**0,36**	**0,40**	**0,00**
0,5		376	266	110	0	23	141	62	0	0,71	0,09	0,53	0,23	0,26	0,00
0,5		465	356	109	0	18	186	69	0	0,77	0,05	0,52	0,19	0,20	0,00
0,5		500	369	131	0	21	208	58	0	0,74	0,06	0,56	0,16	0,17	0,00
	total	**1341**	**991**	**350**	**0**	**62**	**535**	**189**	**0**	**0,74**	**0,06**	**0,54**	**0,19**	**0,20**	**0,00**
0,9		500	385	115	0	17	201	47	0	0,77	0,04	0,52	0,12	0,13	0,00
0,9		500	386	114	0	26	177	47	0	0,77	0,07	0,46	0,12	0,13	0,00
0,9		500	396	104	0	11	206	50	0	0,79	0,03	0,52	0,13	0,13	0,00
	total	**1500**	**1167**	**333**	**0**	**54**	**584**	**144**	**0**	**0,78**	**0,05**	**0,50**	**0,12**	**0,13**	**0,00**

Legend:		
	N	Number of Transactions
	H	Number of High Quality Transactions
	L	Number of Low Quality Transactions
	Q	Number of Certification Traces
	C	Number of Certified Transactions
	G	Number of Guarantees
	P	Number of Post-Transaction Traces
	D	Number of Deceptions
	H/N	Proportion of High Quality Transactions
	C/H	Proportion of Certified Transactions wrt High Quality Transactions
	G/H	Proportion of Guarantees wrt High Quality Transactions
	(Q+P)/H	Total Tracing Frequency wrt High Quality Transactions
	P/(H-C)	Post-Transaction Tracing Frequency
	D/N	Deceit Frequency

Table A1. Statistics of simulated games with varying values of trust update. Positive trust update=negative trust update; strategy neutral; initial trust 0,5; initial and minimal honesty 1.0; confidence 0.95.

initial trust	hone-sty	N	H	L	Q	C	G	P	D	H/N	C/H	G/H	(Q+P) /H	P/ (H-C)	D/N
opportunistic															
1,0	1,0	200	164	36	0	0	69	7	0	0,82	0,00	0,42	0,04	0,04	0,00
1,0	0,5	200	147	53	0	0	64	8	20	0,74	0,00	0,44	0,05	0,05	0,10
1,0	0,0	200	124	76	0	0	61	6	39	0,62	0,00	0,49	0,05	0,05	0,20
0,5	1,0	200	133	67	0	10	81	49	0	0,67	0,08	0,61	0,37	0,40	0,00
0,5	0,5	200	121	79	0	1	68	34	13	0,61	0,01	0,56	0,28	0,28	0,07
0,5	0,0	200	131	69	0	3	80	55	31	0,66	0,02	0,61	0,42	0,43	0,16
0,0	1,0	200	116	84	0	19	78	69	0	0,58	0,16	0,67	0,59	0,71	0,00
0,0	0,5	200	107	93	0	8	80	72	10	0,54	0,07	0,75	0,67	0,73	0,05
0,0	0,0	200	99	101	0	4	72	69	14	0,50	0,04	0,73	0,70	0,73	0,07
quality-minded															
1,0	1,0	200	154	46	5	5	32	6	0	0,77	0,03	0,21	0,07	0,04	0,00
1,0	0,5	200	148	52	60	63	22	9	9	0,74	0,43	0,15	0,47	0,11	0,05
1,0	0,0	200	155	45	34	35	54	7	24	0,78	0,23	0,35	0,26	0,06	0,12
0,5	1,0	200	133	67	6	23	82	38	0	0,67	0,17	0,62	0,33	0,35	0,00
0,5	0,5	200	135	65	67	91	25	17	12	0,68	0,67	0,19	0,62	0,39	0,06
0,5	0,0	200	144	56	49	73	54	34	18	0,72	0,51	0,38	0,58	0,48	0,09
0,0	1,0	200	122	78	2	18	99	71	0	0,61	0,15	0,81	0,60	0,68	0,00
0,0	0,5	200	116	84	65	79	34	31	2	0,58	0,68	0,29	0,83	0,84	0,01
0,0	0,0	200	132	68	53	73	52	50	9	0,66	0,55	0,39	0,78	0,85	0,05
thrifty															
1,0	1,0	200	65	135	0	1	32	4	0	0,33	0,02	0,49	0,06	0,06	0,00
1,0	0,5	200	7	193	4	4	3	1	0	0,04	0,57	0,43	0,71	0,33	0,00
1,0	0,0	200	24	176	24	24	0	0	0	0,12	1,00	0,00	1,00		0,00
0,5	1,0	200	24	176	0	0	17	4	0	0,12	0,00	0,71	0,17	0,17	0,00
0,5	0,5	200	7	193	4	4	2	2	0	0,04	0,57	0,29	0,86	0,67	0,00
0,5	0,0	200	16	184	16	16	0	0	0	0,08	1,00	0,00	1,00		0,00
0,0	1,0	200	17	183	1	3	14	12	0	0,09	0,18	0,82	0,76	0,86	0,00
0,0	0,5	200	19	181	13	13	6	5	0	0,10	0,68	0,32	0,95	0,83	0,00
0,0	0,0	200	37	163	36	37	0	0	0	0,19	1,00	0,00	0,97		0,00

Table A2. Statistics of simulated games with varying values of initial trust and honesty for different negotiation strategies. Minimal honesty=initial honesty; positive trust update=0.3, negative trust update=1.0; confidence=0.95. Tables 5, 6, and 7 present aggregated views of the data.

initial trust		N	H	L	Q	C	G	P	D	H/N	C/H	G/H	(Q+P) /H	P/ (H-C)	D/N
1,0		1800	988	812	127	132	337	48	92	0,55	0,13	0,34	0,18	0,06	0,05
0,5		1800	844	956	142	221	409	233	74	0,47	0,26	0,48	0,44	0,37	0,04
0,0		1800	765	1035	170	254	435	379	35	0,43	0,33	0,57	0,72	0,74	0,02

Table A3. Aggregated statistics of 3×9 simulated games with varying values of initial trust the ratios H/N, … ,D/N are calculated on the rows of the table, so they are a weighted average of the ratios in table A2, applying the ratio's denominator as weight factor

honesty		N	H	L	Q	C	G	P	D	H/N	C/H	G/H	(Q+P) /H	P/ (H-C)	D/N
1,0		1800	928	872	14	79	504	260	0	0,52	0,09	0,54	0,30	0,31	0,00
0,5		1800	807	993	213	263	304	179	66	0,45	0,33	0,38	0,49	0,33	0,04
0,0		1800	862	938	212	265	373	221	135	0,48	0,31	0,43	0,50	0,37	0,08

Table A4. Aggregated statistics of 3×9 simulated games with varying values of honesty (minimal honesty and initial honesty both set equal to the value in the first column).

delta trust pos	neg	N	H	L	Q	C	G	P	D	H/N	C/H	G/H	(Q+P) /H	P/ (H-C)	D/N
0,05	0,5	500	67	433	21	30	22	9	1	0,13	0,45	0,33	0,45	0,24	0,00
0,05	0,5	500	125	375	70	91	23	13	6	0,25	0,73	0,18	0,66	0,38	0,01
0,05	0,5	500	67	433	28	37	19	14	4	0,13	0,55	0,28	0,63	0,47	0,01
	total	**1500**	**259**	**1241**	**119**	**158**	**64**	**36**	**11**	**0,17**	**0,61**	**0,25**	**0,60**	**0,36**	**0,01**
0,5	0,5	500	136	364	59	82	33	15	8	0,27	0,60	0,24	0,54	0,28	0,02
0,5	0,5	500	125	375	24	35	54	24	10	0,25	0,28	0,43	0,38	0,27	0,02
0,5	0,5	500	128	372	28	47	36	14	8	0,26	0,37	0,28	0,33	0,17	0,02
	total	**1500**	**389**	**1111**	**111**	**164**	**123**	**53**	**26**	**0,26**	**0,42**	**0,32**	**0,42**	**0,24**	**0,02**
0,1	1,0	500	100	400	17	37	37	22	3	0,20	0,37	0,37	0,39	0,35	0,01
0,1	1,0	500	76	424	24	33	25	14	0	0,15	0,43	0,33	0,50	0,33	0,00
0,1	1,0	500	88	412	30	40	27	17	8	0,18	0,45	0,31	0,53	0,35	0,02
	total	**1500**	**264**	**1236**	**71**	**110**	**89**	**53**	**11**	**0,18**	**0,42**	**0,34**	**0,47**	**0,34**	**0,01**
1,0	1,0	500	143	357	37	57	57	24	15	0,29	0,40	0,40	0,43	0,28	0,03
1,0	1,0	500	90	410	27	40	28	10	2	0,18	0,44	0,31	0,41	0,20	0,00
1,0	1,0	500	119	381	25	39	39	20	11	0,24	0,33	0,33	0,38	0,25	0,02
	total	**1500**	**352**	**1148**	**89**	**136**	**124**	**54**	**28**	**0,23**	**0,39**	**0,35**	**0,41**	**0,25**	**0,02**

Table A5. Statistics of simulated games with varying values of trust update. Strategy=neutral; initial trust=0,5; initial and minimal honesty=1.0; confidence=0.95.

strategy	N	H	L	Q	C	G	P	D	H/N	C/H	G/H	(Q+P) /H	P/ (H-C)	D/N
opportunist	**1800**	**1142**	**658**	**0**	**45**	**653**	**369**	**127**	**0,63**	**0,04**	**0,57**	**0,32**	**0,34**	**0,07**
quality-mdd	**1800**	**1239**	**561**	**341**	**460**	**454**	**263**	**74**	**0,69**	**0,37**	**0,37**	**0,49**	**0,34**	**0,04**
thrifty	**1800**	**216**	**1584**	**98**	**102**	**74**	**28**	**0**	**0,12**	**0,47**	**0,34**	**0,58**	**0,25**	**0,00**

Table A6. Aggregated statistics of 3×9 simulated games with different strategies defined in section 5.

		N	H	L	Q	C	G	P	D	H/N	C/H	G/H	(Q+P) /H	P/ (H-C)	D/N
opportunistic and quality-minded strategies															
		500	195	305	13	26	101	49	40	0,39	0,13	0,52	0,32	0,29	0,08
		500	169	331	8	22	72	33	24	0,34	0,13	0,43	0,24	0,22	0,05
		500	213	287	6	20	113	58	50	0,43	0,09	0,53	0,30	0,30	0,10
	total	**1500**	**577**	**923**	**27**	**68**	**286**	**140**	**114**	**0,38**	**0,12**	**0,50**	**0,29**	**0,28**	**0,08**
opportunistic and thrifty strategies															
		500	64	436	4	8	35	7	6	0,13	0,13	0,55	0,17	0,13	0,01
		500	59	441	0	5	32	11	6	0,12	0,08	0,54	0,19	0,20	0,01
		500	60	440	2	7	33	12	11	0,12	0,12	0,55	0,23	0,23	0,02
	total	**1500**	**183**	**1317**	**6**	**20**	**100**	**30**	**23**	**0,12**	**0,11**	**0,55**	**0,20**	**0,18**	**0,02**

Table A7. Statistics of simulated games with different mixed strategies. Minimal honesty=intitial honesty=0.5; initial trust=0.5; positive trust update=0.3, negative trust update=1.0; confidence=0.95.

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