Multi-Agent Model of Trust in a Human Game

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Summary. Individual-level trust is formalized within the context of a multi-agent system that models human behaviour with respect to trust in the Trust and Tracing game. This is a trade game on commodity supply chains and networks, designed as a research tool and to be played by human players. The model of trust is characterised by its learning ability, its probabilistic nature, and how experience influences trust. The validity of the trust model is tested by comparing simulation results with aggregated results of human players. More specifically the simulations show the same effects as human plays on selected parameters like confidence, tracing cost, and the trust update coefficient on observable game statistics like number of cheats, traces, certificates, and guarantees.

1 Introduction

People from different cultures differ significantly with respect to uncertainty avoidance, individualism, mutual caretaking and other traits [1]. Personal traits and human relations affect the forming and performance of institutional frameworks in society. Important economic institutional forms are supply chains and networks [2]. The Trust and Tracing game [3] is a research tool designed to study human behaviour with respect to trust 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 played numerous times, the number of sessions that can be played with humans is limited. It is expensive and time-consuming to acquire participants [4]. Furthermore one needs many sessions to control for variances between groups [5]. Multi-agent simulation can to some extent overcome these disadvantages 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 we designed was done on the aggregated level using computer simulations. Simulation results were compared to a set of hypotheses based on human games observations and conventional economical rationality.

This paper presents a multi-agent model of the Trust and Tracing game. It is an instrument in the research method presented in Section 2. Section 3 provides a brief description of the game and results from human sessions. Section 4 describes the agent architecture and models for buyer's behaviour and trust. In section 5 we illustrate the validity of the approach by experimental results from multi-agent simulations. Section 6 presents the main conclusions of the paper.

2 Method

Our research uses a methodological cycle as described in figure 1. It started in the upper left corner with the human game environment. The first series of sessions led to a number of observed individual and aggregated tendencies in the human game. On the basis of observed tendencies and conventional economical theories a multi-agent model was designed and implemented in a simulated environment. In this environment sessions were simulated using the same settings as the initial human sessions. Through verification of aggregated tendencies we have been able to prove gross validity of our model, and the fruitfulness of our approach.

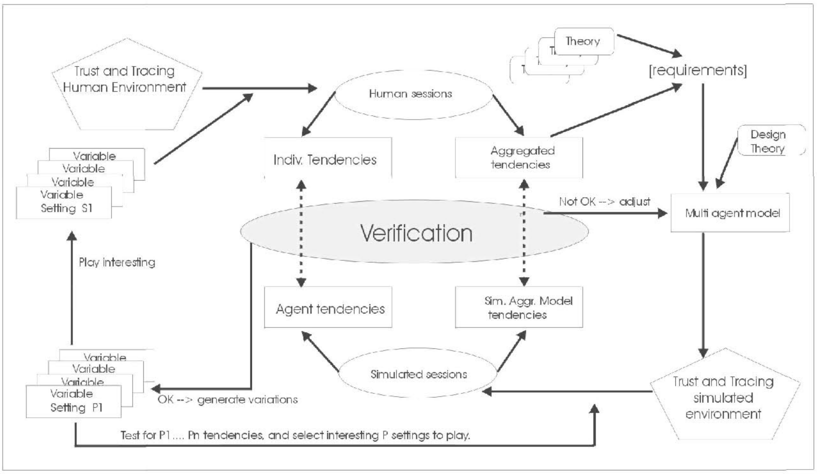

Fig. 1. Methodological cycle

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 agent- and the aggregated level.

3 The Trust and Tracing Game

This section provides a brief description of the Trust and Tracing game; an extensive description is available in [3]. Observations from sessions played are discussed at the end of this section.

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.

The game is played in a group of 12 up to 25 persons Commodities usually flow from producers to middlemen, from middlemen to retailers and from retailers to consumers. Players receive 'monopoly' money upfront. Producers receive sealed envelopes representing lots of commodities. 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

	Type		
Quality	Blue	Red	Yellow
Low	1	2	3
High	2	6	12

Sessions played until 2005 provided many insights. ([3] and unpublished) We mention three applicable here:

1. Dutch groups (with a high uncertainty tolerant culture [1]) tend to forget about tracing and bypass the middlemen and retailers as they don't add value. This gives the producers a large chance to be opportunistic. Few traces lead to more deceits.
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 initial tracing of any lot middlemen start to take samples when relationships establish.

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.

4 Agent Architecture and Buyer's Model

The agent architecture for simulation of the Trust and Tracing game has been described in [6]. The models for cheating are discussed in [7]. 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 and in particular on their behaviour as buyers, entailing the trust-or-trace decision.

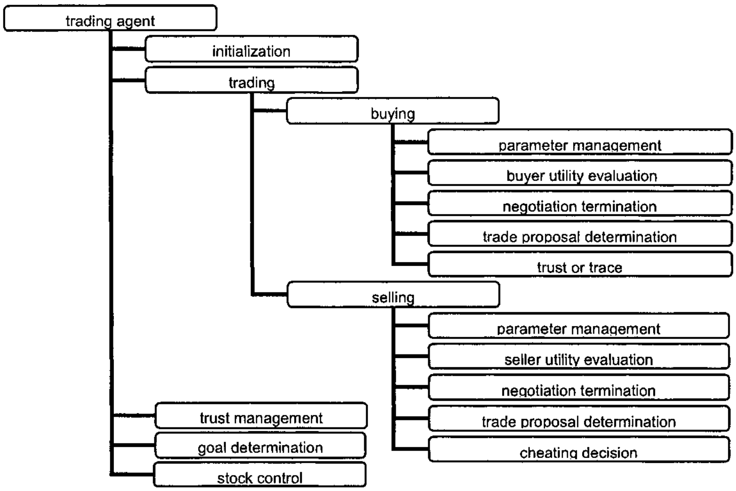

Fig. 2. Agent process composition

Trading agents have processes for *initialization*, *goal determination*, *trading*, which entails the *cheating decision* in case of selling and the *trust-or-trace decision* in case of buying, *trust management* and *stock control.*

In the *goal determination* process agents decide to buy or to sell, depending on their role and stock position, and selects a partner at random, weighted by success or failure of previous negotiations with particular partners.

The *trading* process is based on the algorithm presented in [8]. This approach to multi-attribute simultaneous negotiations is based on utility functions theory. Negotiation partners send complete bids (a set of negotiation object attributes with assigned values) to each other. Once an agent has received a bid it can accept, or respond with an alternative bid, or cancel the negotiation. Agents evaluate their own and their partner's bid using a generalized utility function that is a weighted linear combination of particular attribute evaluation functions. Weights represent preferences of each agent. In this case the utility function uses normalized values of income and risk (which are calculated from the negotiation object attributes) .

The buyer's utility function involves individual experience-based trust in the seller as an argument to estimate the risk of being deceived. Modeling of trust for this purpose and experience-based updating of trust - as part of the *trust management* process - is the subject of subsection 4.1. Subsection 4.2 explains the utility function and the way it can be used to represent agent's preferences or buying strategies. Subsection 4.3 treats the tracing decision.

4.1. Trust Models

In 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, see e.g., [9, 10, 11, 12]. Furthermore, the definitions indicate that trust depends on the context in which interaction occurs or on the observer's point of view.

According to Ramchurn *et al.* [10] trust can be conceptualized in two directions when designing agents and multi-agent systems:

- Individual-level trust – poses agents beliefs over 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.

Defining trust as a probability allows relating it with risk. Jøsang, and Presti [12] 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.

An important subprocess of the agent's *trust management* process is trust update based on tracing results. The current model uses the trust update schema proposed in [13]:

$$g(ev, tv) = d\,tv + (1-d)\,ev \qquad (1)$$

where tv is the current trust value, ev is the experience value, and d is the ratio that introduces the memory effect of the trust update function. This function poses the following properties: monotonicity, positive and negative trust extension, and strict positive and negative progression. This model is suitable, because (1) models learning, necessary, because experience is the only source of information; (2) it has a probabilistic nature, usefull in the calculation of risk; (3) it has a memory effect and allows inflation of experience.

Each agent maintains the level of trust he has in the other agents with respect to their role as a supplier and uses tracing results to update its trust. A trace revealing deceit has a negative effect on trust in the partner as a supplier. If a supplier is found truthful by tracing this will strengthen trust. The tracing agent has two different modes, to be set by the game leader: (1) with confidential reports of deceit to the requesting agent only and (2) with public disgrace of deceivers, where all agents are informed if a deceiver has been punished. Experience values were assigned taking into account empirical data that conclude that "it appears easier to destroy trust than to build trust" [14]. This means that negative experience has stronger impact on trust than positive experience has. This assumption is reflected in appropriate experience evaluation values: $ev(pos) = 0.5$ and $ev(neg)=-1$. The value of d and the initial value of tv are agent parameters set by the game leader. Usually $d = 0.4$ and $tv = 0.5$.

4.2. Buyer's Model

Negotiation skill is an important capability of agents since it enables them to efficiently achieve their goals. In the T&T game the *trading* process is used to achieve trade deals. The negotiation system employed in the simulation is based on utility functions.

The utility function for buyers involves the risk of being deceived when buying (stated) high quality commodities. Depending on trust in seller (belief about the opponent) and risk-attitude (personal trait of buyer), the buyer can try to reduce risk. Risk can be eliminated by demanding a quality certificate or reduced by a money-back guarantee. The attributes of a transaction are product type, stated quality, price, and certificate or money-back guarantee. 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):

$$\begin{aligned} u_{buyer}(bid) = w_1 \cdot f_{price}\left(price_{effective}(bid)\right) + \\ + w_2 f_{expected\_turnover}\left(expected\_turnover(bid')\right) + w_3 f_{risk}\left(risk_{seller}(bid')\right) \end{aligned} \quad (2)$$

The weight factors implement buyer's strategies. 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 high quality for low price but is prepared to accept uncertainty, for instance <0.4, 0.4, 0.2>. The *suspicious* buyer follows an what-you-see-is-what-you-get strategy, represented for instance by <0.4,0.2,0.4>.

Effective price is the total amount of money that the buyer has to pay:

$$price_{effective}(bid') = price_{purchase} + cost_{transaction} \quad (3)$$

where $cost_{transaction}$ represents some extra cost for the buyer that depends on the type of partner and is taken from the transaction cost matrix to be defined by the game leader. (Table 2 gives an example)

Table 2. Example of a transaction cost matrix

	Seller			
Buyer	Producer	Middleman	Retailer	Consumer
Producer	10	100	100	100
Middleman	2	10	100	100
Retailer	4	2	10	100
Consumer	8	4	2	10

Expected turnover is the average of the agent's beliefs about minimal and maximal future selling price of the commodity to be bought. For consumers the expected turnover is changed to satisfaction level.

Buyer's risk represents the estimation of probable losses for a given trade partner and trade conditions. It is calculated as product of probability of deceit and cost in case of deceit.

$$risk_{buyer}(bid) = p_{deceit} \cdot cost_{deceit} \quad (4)$$

Probability of deceit is grater than zero only if 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.

$$p_{deceit}(bid') = q(bid') \cdot c(bid') \cdot (1 - trust(seller)) \quad (5)$$

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 I. The formula for middlemen and retailers is:

$$cost_{deceit}(bid) = fine_{reselling} + loss_{reselling}(bid) \quad (6)$$

where

$$loss_{reselling}(bid) = g(bid) \cdot price_{effective} \cdot \left(1 - ratio_{low/high}(bid)\right) \quad (7)$$

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

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:

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

This subsection presented the buyer's model. The seller's utility function partially reflects the buyer's model. It considers effective price and risk as attributes, see [7].

4.3. Tracing Decision

For buyers, *trading* entails the trust-or-trace decision. In human interaction this decision depends on factors that are not sufficiently well understood to incorporate in a multi-agent system. Hearing a person speak and visual contact significantly influence the estimate of the partner's truthfulness [15]. To not completely disregard these intractable factors the trust-or-trace decision is modeled as a random process instead of as a deterministic process. In our model the agglomerate of all these intractable factors is called the confidence factor. The distribution involves experience-based trust in the seller, the value ratio of high versus low quality, the cost of tracing, and the buyer's confidence factor.

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.

Several factors shown in figure 3 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 seller. Trust is modelled as a subjective evaluation of the probability that the seller would not cheat on the buyer. It is updated using tracing results: positive tracing results increase the trust in seller, negative ones decrease it.

Then *satisfaction ratio* (see Table 1) of the commodity is considered. The buyer would trace more valuable products rather than products with small satisfaction ratio, because damage would be greater.

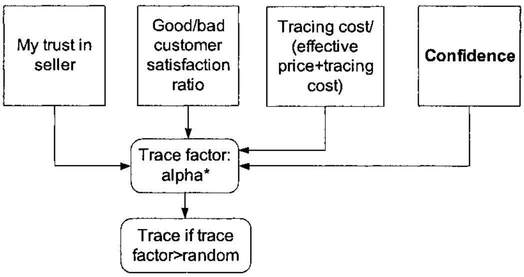

Fig. 3. Tracing decision model

Tracing costs also influences the decision, so a middleman is more likely to trace than a consumer. The tracing fee depends on the depth to be traced, so for middlemen tracing is cheaper then for consumers.

Confidence is an internal characteristic that determines the preference of a particular player to trust rather than trace, represented as a value on the interval [0,1].

The following expressions are used to make tracing decision:

$$tracing\_level(bid) = (1 - trust(seller(bid)) * (1 - ratio_{low/high}(bid)) * \\ * tracing\_cost\_ratio(bid) * (1 - confidence) \quad (9)$$

where *tracing_level(bid)* – is a value on the interval [0,1] that represents an evaluation of tracing preference of a given *bid* and

$$tracing\_cost\_ratio(bid) = \frac{effective\_price(bid)}{tracing\_cost + effective\_price(bid)} \quad (10)$$

The tracing decision depends on the following rule:

$$if \quad tracing\_level(bid) \geq rnd \quad then \quad trace \quad (11)$$

where *rnd* is a random number in [0,1].

If an agent has decided to trace the product it sends a tracing request message to 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.

5 Experimental Results

A group of experts possessing empirical knowledge of the game formulated the conceptual model of the Trust and Tracing game's system dynamics on an aggregated level using Vennix' group model building [15], and used it to formulate hypotheses about the effect of selected parameters (*confidence, tracing cost,* and *trust update coefficient* $\Delta trust$, represented by *d* in equation 1) on observable game statistics (number of *cheats, traces, certificates,* and *guarantees*).

The experts used experiences from over 40 sessions with the game (during its development, testing and real world application phase) and knowledge from case studies from literature to express the following hypotheses. As an example we present the hypotheses about confidance:

Hypotheses about the effects of confidence.

1. Increasing confidence decreases tracing. A highly confident buyer makes fewer traces as he thinks that his buying mechanism is taking care of risks. Confidence is present in our agent's tracing model and defines threshold for tracing.
2. Increasing confidence increases cheating, because honesty will not be corrected. High confidence means that players perform fewer traces. This means

that sellers experience low numbers of fines that should decrease their level of honesty. Low level of honesty makes cheating more probable.

3. Increasing confidence decreases certificates. Confidence has reverse impact on the tracing rate. High confidence decreases tracing rate and consequently decreases number of found cheats. This keeps average trust high that is in it turn decreases number of certificates.
4. Increasing confidence increases guarantees. Because high confidence makes average trust higher it reduces risk of providing a guarantee and consequently increases number of guarantees provided.

Computer simulations were performed with populations of 15 agents: 3 producers, 3 middlemen, 3 retailers, 6 consumers. Game sessions are performed in continuous real-time and depend only on the performance of the computer. Agents can be involved in only one transaction a time. This organization allows (future) combining of artificial and human agents in one game session. Values of free parameters were selected uniformly from their definition intervals to confirm the models capability to reproduce desired input-output relationships and explore their sensitivities.

Figure 5 presents results of experiments performed for two values of *confidence*: 0.1 and 0.9 across populations with various risk-taking attitude, respectively: no increased-risk-takers (denoted as "neutral" on the X-axis of the charts on figures 3,4,5), 1 out of 3 risk-takers (denoted as "2:1"), 2 out of 3 risk-takers (denoted as "1:2"), and all risk-takers (denoted as "high"). For risk-taking agents weights in (1) were set to: $w_1 = 0.4; w_2 = 0.4; w_3 = 0.2$, for agents with neutral risk attitude weights were $w_1 = 0.2; w_2 = 0.4; w_3 = 0.4$.

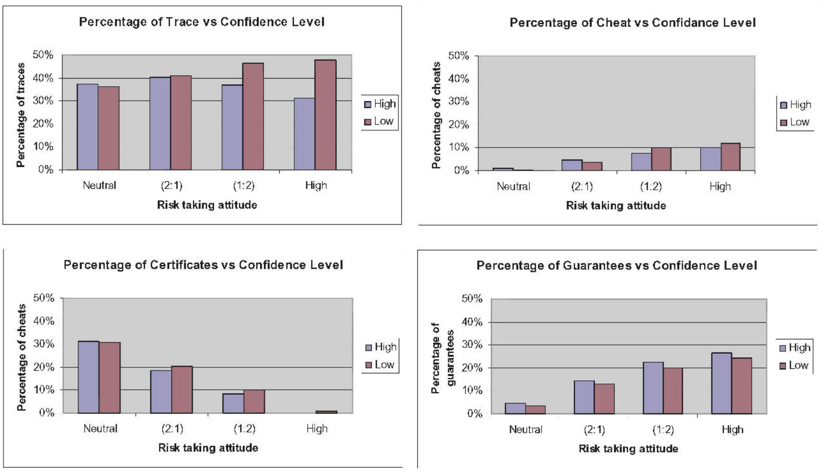

Fig. 5. Results of experiments with different levels of confidence

The difference in output variables with respect to high and low level of confidence is not significant for neutral risk-taking agents. For high-risk-taking agents the amount of traces decreases for highly confident players and increases for lowly confident players. This supports hypothesis #1 only in cases with players possessing high risk-taking value. Number of cheats is high for highly confident players in games with dominating number of risk-neutral players. This partly confirms hypothesis #2. Surprisingly, the results show the opposite for risk-seeking players: some dishonest sellers do not get traced and punished in highly risk-seeking game configurations, so they are encouraged to continue their fraudulent practices. The results confirm the hypotheses about certificates (#3) and guarantees (#4). Increase in number of guarantees for highly confident agents testifies that feedback link through tracing trust. High confidence leads to lower number of traces that means less deceptions are discovered and consequently higher average tracing trust.

In all experiments, effects of risk-taking attitude are consistent: high risk-taking leads to more cheating, less certificates and increased willingness to give guarantees and to rely on them. Differences in risk-taking attitude outweigh changes in other parameters. This result corresponds with observations from human games.

6 Conclusion

This paper presents a partially validated model of trust in a trade network environment. At this point in the research project we are not able to validate the model on the agent-level. The model presented approaches the complex dilemma of trust in a trade network environment to the extent that it is able to parallel real human behavior. The cycle (figure 1) has been completed once for the aggregated level only, and for one particular setting of the game. The main contribution is that by defining (simple) models on the individual level we can produce similar outcomes to human sessions on the macro level. Given the number of free variables when using real human participants these aggregated results are most important to compare. Rigorous testing for more settings will lead to a refinemented model that matches aggregated results for all settings. Only then our individual agent model will be looked upon to see if it models individual decisions accurately.

Following the falsification theory of Popper [17], even if our approach does not lead to new models of trust, the attempt to test current theories via a model (hypothesis of being similar in behavior to a real human participant) using a well-defined new empirical basis is worthwhile. In the worst case it will lead to reimbursement of existing models. In the best case it could lead to better insights in the use of trust.

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