Trust-Based Coalition Formation: A Multiagent-Based Simulation

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Abstract. In multiagent systems, agents may form coalitions in order to achieve their goals or to maximize their net group utility. Assuming that agents are self-interested, or potentially unreliable, they should implement some mechanism to deal with the uncertainty arising from interactions. Trust is usually chosen as the mechanism for modeling and reasoning about agents' reliability. Hence, we present an agent-based simulation model adapted to simulate a land expropriation scenario. Such model is composed of landowners who play the spatial prisoner's dilemma game and take into account the notion of trust to form coalitions. Moreover, the mechanism that landowners use to remain or to leave coalitions in accordance with their trust degree on their leader is described, giving details of how trust may influence their individual decision making. Finally, based on results of simulation experiments, we provide an analysis of how trust influences the coalition formation in such land expropriation scenario.

1 Introduction

The paradigm of multiagent systems (MAS) presents several characteristics suitable for the representation of human societies. Some of these features can be identified in the definition proposed by Wooldridge [17], where MAS consist of a set of autonomous, sometimes self-interested agents, situated in a shared environment, which interact with each other in order to achieve their goals. Also, these agents may organize themselves, for instance by forming coalitions, i.e., creating groups to pursuit common goals, either to achieve goals that cannot be achieved by a single agent or to maximize their net group utility [6].

Nonetheless, this kind of situation involves risks arising from uncertainties associated with the needed interactions among autonomous and self-interested agents, which makes the society susceptible to a social dilemma called *Tragedy of the Commons* [7]. Such social dilemma arises from the situation in which multiple self-interested agents, acting independently and rationally, are faced with prioritizing either short-term selfish interests or the long-term interests of a group. Some researchers [12,4] propose the use of the concept of *trust* as a mechanism to prevent or to mitigate the risks associated with such interactions.

In this context, trust may be defined as an estimate that an agent has about the actions to be carried out by another agent, which directly affects itself and are unknown at the time it needs to choose its own action [5].

Real human societies have plenty of examples of social dilemmas. One example of such situation may be observed in some countries that face a rapid economic development of the society. In those countries, there is a growing need for land in order to expand the cities' occupancy rate, thus making inevitable some land expropriation. In such scenario, the State usually stipulates a compensation that does not correspond to the current market land value, causing a conflict between the State and landowners interests. Therefore, in order to increase their bargaining power, landowners may act together by grouping themselves into coalitions, and hence making the society susceptible to the *Tragedy of the Commons* dilemma.

In this work, we present a simulation model proposed by Nardin and Sichman [10] adapted to model a land expropriation scenario. Such model integrates both concepts of coalition and trust, allowing the analysis of how trust influences the coalition formation in the case of land expropriation. Such analysis is carried out by means of a multiagent-based simulation, whose environment consists of a population of self-interested landowners agents positioned in a square lattice which represents the land properties. Each landowner agent interacts with its neighbors by choosing either to cooperate or to defect. These agents may decide to play independently, or they may decide to join (or leave) a coalition. When an agent belongs to a coalition, it cooperates with landowners from its own coalition and defects with either independent or landowners that belong to other coalitions. The decision to remain or to leave a coalition is largely based on trust information that the landowner has gathered about its coalition leader. Such trust is mainly based on the received payoff from its coalition leader.

Thus, the main objective of this work is to identify the influences that trust exerts on landowners coalition formation by varying the trust input parameter values and analyzing the coalition formation macroscopic patterns.

The remainder of the article is organized as follows. In section 2, we present some related work, followed by a brief introduction to the concepts of coalition formation and trust in section 3. We then present in section 4 a brief description of the adapted simulation model for land expropriation considering the use of the coalition and trust concepts. In section 5, we describe and analyze the results of some experiments, aiming to investigate the influence of trust in coalition formation. Finally, in section 6 we present our conclusions and future work.

2 Related Work

According to Griffiths and Luck [6], existing models of coalition formation do not generally consider trust except for a small number that regard it for individual tasks or for very specific constrained situations. At the best of our knowledge, there are just a few works available in the literature that relates both concepts, which are Breban and Vassileva [2], Griffiths and Luck [6], and Nardin and Sichman [10].

Breban and Vassileva [2] studied long-term coalitions among customer and vendor agents based on trust relationships in the domain of electronic marketplace. Hence, they proposed a coalition formation mechanism designed at microscopic level and they compared agent strategies (individual vs. social) in order to analyze the system behavior under different circumstances. They concluded that their mechanism reduces the dynamics of the system and that it is also beneficial for the individual agents. Despite the fact that they have studied the influence of trust in coalition formation, their focus is domain dependent.

Griffiths and Luck [6] introduced the concept of a particular coalition formation named *clan*, which is a group of agents who trust each other and have similar objectives. They have also described mechanisms for agents to form, maintain, and dissolve clans in accordance with their self-interested nature, and provided details of how clan membership influences individual decision making. However, their focus was on how clan membership influences individual decision making while ours is on how past experiences with the leader influences individual decision making.

A first attempt to consider the effect of coalition formation in the Spatial Prisoner's Dilemma [15] was proposed by Burguillo-Rial [3], where agents could play independently or decide to join/leave a coalition. He has conducted some experiments using either *Standard* or *Altered* values in the payoff matrix[1]. His results have shown that in certain conditions, following a leader is better than individual learning techniques. However, the notion of trust was not taken into account in this work.

Inspired on Burguillo-Rial's work, Nardin and Sichman [10] proposed a simulation model and some experiments in order to allow the analysis whether the fact of taking into account the notion of trust would affect coalition formation in the Spatial Prisoner's Dilemma. These experiments can be classified according to two dimensions as depicted in Figure 1:

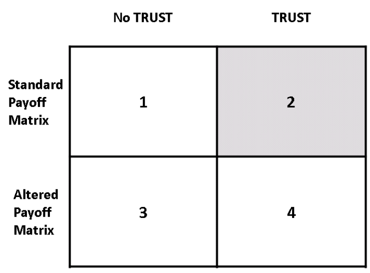

Fig. 1. Classification of the experiments in Payoff and Trust dimensions

[1] Since we will also adopt these values, their meanings and differences are explained in Section 4.

- *Payoff Matrix* dimension, which indicates the payoff matrix applied (*Standard* or *Altered*) in the Spatial PD game;
- *Trust* dimension, which indicates whether the notion of trust was or not used in any proportion by the agents in coalition formation.

As a conclusion, Nardin and Sichman noticed that the notion of trust influenced coalition formation only when the simulation used the *Altered* PD game payoff matrix (Quadrants 3 and 4), but not when it used the *Standard* PD game payoff matrix (Quadrants 1 and 2). Consequently, they concluded that *Trust* is relevant for coalition formation whenever belonging to a coalition brings more benefits rather than playing independently, which is represented by the simulations related to Quadrants 3 and 4.

Hence, the motivation of this work is to explore further the influence that trust exerts on coalition formation when considering the *Standard* PD game payoff. Thus, the focus of this work is on experiments placed in Quadrant 2, represented in grey in Figure 1. Since the experiments placed in Quadrant 1 does not consider trust on coalition formation, they are irrelevant for this study. Furthermore, the simulation is contextualized in a land expropriation scenario in order to clarify the results presentation.

3 Background Work

In this section, we briefly introduce the concepts of Coalition Formation and Trust.

3.1 Coalition Formation

The concept of a coalition of agents has been studied for several decades and it has proven usefulness in MAS. In this context, if a population of agents A is represented as a set, then each subset of A is a potential coalition [8]. Coalition formation is a mechanism which concerns with establishing a group of agents to pursuit a common goal, either to achieve goals that cannot be achieved alone or to maximize their net group utility [6]. For example, in an economic domain, agent coalition formation can bring benefits to its members by increasing the power of persuasion or providing monetary gain. According to Breban and Vassileva [1], coalition formation can be analyzed from two different perspectives: a *microscopic* or a *macroscopic* one. The *microscopic* perspective has the agent as its central unit. In this case of individual rationality, the agent has a tendency to join the coalition that maximizes its payoff. In the other hand, the *macroscopic* perspective has the coalition as its fundamental unit, therefore, the decision is based on the system welfare. The first work related to the coalition formation in MAS was proposed by Ketchpell [9], which presents a mechanism for the distribution of gain designed to operate in situations where there is uncertainty in the coalition gain. The proposed mechanism assigns to one agent of the coalition the responsibility for managing the group. This agent has the functions of representing the coalition and splitting the coalition payoff among its members, keeping the residual payoff when the total gain of the coalition is greater than the sum of the payments made to the coalition members. Like Burguillo-Rial [3], we have adopted this notion of coalition leader in our work.

3.2 Trust

As already said, cooperation involves risks arising from uncertainties associated with the needed interactions among autonomous and self-interested agents. The notion of trust has been recognized by some researchers [12,4] as a mechanism to prevent the risks associated with such interactions.

According to Sabater and Sierra [14], the conceptual model of reference characterizes trust as *cognitive* or *game-theoretical*. In the *cognitive* approach, all the mental states that lead to trust another agent and their mental consequences are an essential part of the model. On the other hand, in the *game-theoretical* approach, trust is the result of a utility function and a numerical aggregation of past interactions performed by the agent.

Based on the *game-theoretical* approach, there are various definitions of trust in the literature; however, the definition adopted in this work is the following:

> Trust is an estimate that an agent has about the actions to be taken by another agent, which directly affects itself and are unknown at the time it needs to decide about taking an action [5].

According to Ramchurn et al. [13], the concept of trust permeates multiagent interactions at different levels, and can be distinguished in two types:

- *Individual Trust* - the agent has beliefs about the honesty or reciprocity of its interactions with third-parties;
- *System Trust* - the agent is forced by system rules (i.e. communication protocols) to be trustworthy.

In our simulation model, we will use individual trust, as described next.

4 Simulation Model

As mentioned in the introduction, the simulation model presented in this work is the Spatial PD game model proposed by Nardin and Sichman [10], but contextualized to a land expropriation scenario. Such model is an extension of the model proposed by Burguillo-Rial [3], who has adapted a spatial and iterative game approach first proposed by Nowak and May [11]. The latter approach states that the interactions among agents consider the spatial structure of the population and they are performed simultaneously by all the agents at each iteration. The simultaneous interactions indicate that neither agent knows previously the others' actions.

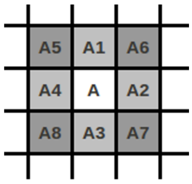

Fig. 2. Agent (A) with two neighborhoods: 4 cells $\{A_1,..,A_4\}$ and 8 cells $\{A_1,..,A_8\}$

Considering the land expropriation scenario, the spatial structure is represented as a two-dimensional lattice composed of N nodes (Fig. 2), which respectively represents the expropriation area and the land properties. Each node representing a land property is controlled by a landowner. Each landowner A_i can only interact directly with its neighbors, where the neighborhood notion may consider 4 or 8 land properties. Such restriction is feasible since in such scenario the interaction and coalition formation are performed among adjacent land properties.

Since the simulation is based on a Spatial PD game, it considers that each landowner A_i has two options for acting with its neighbors at each iteration: Cooperate (C) or Defect (D). Playing against the A_j landowner, the outcome of this interaction depends on the actions chosen by both landowners. The interaction's result of the game with two participants is represented by a standard payoff matrix (Fig. 3) and the parameters values adopted are $T = 5$, $R = 3$, $P = 1$ and $S = 0$.

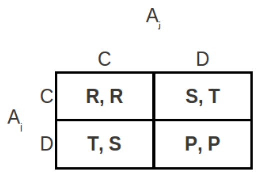

Fig. 3. Payoff matrix for 2-player game

The simulation model adopts a *microscopic* perspective for coalition formation [1]. Hence, landowners follow simple rules to make decisions about coalition formation. Coalitions have a two-level organizational structure. One of the coalition's members leads the group and is called the *Coalition Leader*, while the other members are called *Coalition Parts*. Moreover, if a landowner does not belong to any coalition, it is called *Independent*. Therefore, landowners can play three different roles:

- *Independent*: The landowner can either act as a cooperator or a defector with respect to its neighbors, depending on its own strategy. After each play, it may join a coalition or remain independent. The landowners' strategies

are fixed and set at the beginning of each simulation. In this work, the possible strategies are *Tit-for-Tat* (TFT), *Probabilistic Tit-for-Tat* (pTFT) and *Random*;
- *Coalition Part*: The landowner cooperates with other neighbors belonging to its coalition and defects with neighbors who are not part of its coalition. It can become an *Independent* landowner if its trust value on its leader drops below a threshold value;
- *Coalition Leader*: The leader acts like its parts; however, the leader cannot decide to become independent at anytime: it can take this decision only when there is no other *Coalition Part* landowners in the coalition that it leads. It also imposes a tax percentage to the payoff of the *Coalition Part* landowners at each iteration, since it represents the whole coalition during the negotiation procedure with the State.

In order to take into account the impact of the coalition strength on the Spatial PD game, the simulation model allows the use of an altered payoff matrix. Such altered payoff matrix was proposed by Burguillo-Rial [3] and it requires the integration of one rule from the game "pay or else" in the simulation model. This rule states that when landowners from two different coalitions confront, both suffer some type of loss, but the landowner belonging to the smallest coalition is more impacted than the one that belongs to the biggest coalition. This adaptation requires an adjustment in the PD game payoff matrix presented in Figure 3, where Sucker (S) and Punishment (P) payoffs are changed to consider the natural logarithm of the number of landowners in the opposing coalition as presented in [10]. In the land expropriation scenario, it indicates that the larger the coalition a landowner belongs to, greater is the landowner persuasion power over its opponents.

Furthermore, the simulation model also adopts an *individual trust* approach [13] for trust modeling. Hence, each landowner implements a simple trust model to evaluate its *Coalition Leader*'s trust when playing the role of *Coalition Part*. In such a trust model, a trust value is represented by a single integer number between 0 and 100, where values close to 0 represent a low trust, and values close to 100 represent a high trust on the *Coalition Leader*. As the landowners progress through the game, they update their trust value on their leader based on their past experiences. Thus, by using such information, a landowner can decide to remain in or to leave the coalition.

Since landowners have group rationality, they join a coalition only if they can benefit at least as much as the sum of their personal benefits outside of the coalition [1]. However, in order to leave a coalition, their decision is based on their trust in their *Coalition Leader*, whose value is directly related to the payoff received from the latter.

When a landowner belongs to a coalition, it cooperates with landowners in its coalition and defect with all others. During each iteration, the *Coalition Leader* receives the payoff of all landowners who belong to its coalition, subtracts the tax percentage and evenly redistributes the remaining payoff among all the *Coalition Part* agents. Since each landowner may consider to use or not trust to make decisions related to coalition formation, two algorithms are proposed. In those algorithms, A_m and A_k are respectively the landowners who received the highest/lowest payoff among the neighboring landowners of A_i.

Algorithm 1 Coalition Formation Algorithm With Trust

1: **if** HasLeader(A_i) **then**
2:   **if** Payoff(A_i) $\geq$ Payoff(A_m) **then**
3:     trustLeader = Min(100, (trustLeader + deltaTrust))
4:   **else**
5:     trustLeader = Max(0, (trustLeader - deltaTrust))
6:     **if** trustLeader < trustThreshold **then**
7:       Independence(A_i)
8:     **end if**
9:   **end if**
10: **else**
11:   **if** Payoff(A_i) $\leq$ Payoff(A_k) **then**
12:     JoinCoalition(A_m)
13:   **end if**
14: **end if**

In Algorithm 1, landowner A_i is setup to use trust. Let us consider that it is a *Coalition Part* landowner. The landowner first checks if its payoff is greater than or equal to A_m's payoff. If so, it increases its trust on the leader by a delta value; otherwise, it decreases its trust on the leader. The delta value corresponds to how much volatile the landowner is regarding its trust on its leader. Then, it checks if its trust value dropped below a specified threshold, which corresponds to how much intolerant the landowner is with respect to the leader in order to remain in a coalition. If so, it becomes independent from the coalition. On the other hand, when the landowner A_i is *Independent*, it checks whether its payoff is less than or equal to A_k's payoff. If so, it decides to join the A_m's coalition, otherwise it remains *Independent*.

In the other algorithm, the landowners A_i disregard trust, therefore its decision to leave the coalition is not based on the trust threshold (*trustThreshold*), but it leaves the coalition if its payoff is less than half of the A_m's payoff. Its difference to the Algorithm 1 is the replacement of lines 2−9 by

if Payoff(A_i) < (Payoff(A_m) / 2) **then**
  Independence(A_i)
end if

5 Experiments

In this section, we investigate the effects of trust in coalition formation in a land expropriation scenario by performing simulations using the model presented in Section 4.

All simulations were performed using NetLogo 4.1.2 [16] running on a PC (Intel i5 2.53 GHz with 4 GB of memory) with Linux Ubuntu 10.10.

At the beginning of the simulations, each agent representing a landowner randomly selected a number between 0 and 100, which was compared to the value of a parameter (*considerTrust*) that represented the probability of taking the notion of trust into account to form coalitions. If this random number was smaller than this parameter value, then the landowner selected the Algorithm 1 (with trust), otherwise it selected the algorithm that disregards trust to play. Furthermore, each landowner's role was initially setup to *Independent*, and its strategy was randomly chosen among the three available strategies (TFT, pTFT and Random). Thus, as long as the landowner remained *Independent*, this strategy was used to decide how to play against its neighbors.

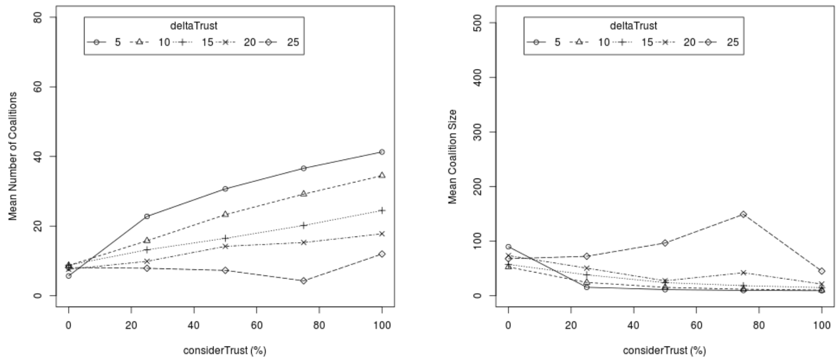

Fig. 4. Number and size of coalitions x *considerTrust* [*tax* = 25% and *trustThreshold* = 25]

Some of the parameters were set with a fixed value for all the simulations: the lattice size representing the number of land properties was set to 21 x 21 = 441 land properties; the number of iterations was set equal to 1000 (*rounds*); all landowners used the *Standard* PD game payoff matrix (*coalitionStrength* disabled); the possible strategies that landowners could use were pTFT, TFT, and Random (*strategy*), which were randomly chosen at the simulation initialization; and the neighborhood was set to 8 (*numNeighbors*). These parameters were arbitrarily chosen, but, since they were fixed for all simulations, we assumed that their selection did not interfere in the results and consequently in the analysis. The parameter *rounds* was set to 1000 because we observed that most of the simulation experiments stabilized before this iteration.

The simulation scenarios were setup combining the following parameters: the tax percentage imposed by the leader to its coalition parts (*tax* = {25, 50, 75}); the probability landowners used trust in order to remain or to leave a coalition (*considerTrust* = {0, 25, 50, 75, 100}); the variation of trust (*deltaTrust* = {5, 10, 15, 20, 25}), which corresponds to how much volatile the landowner is regarding its trust on its leader; and the trust threshold (*trustThreshold* = {25, 50, 75}), which corresponds to how much intolerant the landowner is with respect to the leader in order to remain in a coalition. Each simulation scenario was executed 10 times, therefore, we performed 2250 simulation executions.

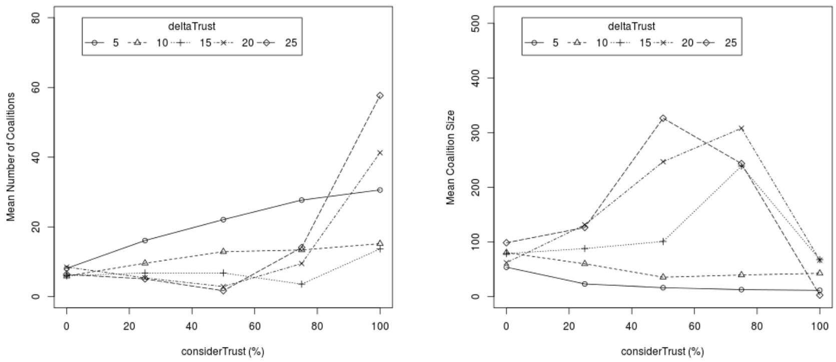

Fig. 5. Number and size of coalitions x *considerTrust* [*tax* = 25% and *trustThreshold* = 50]

The simulation model allowed the monitoring of several coalition formation macroscopic pattern values, and each one of them was calculated by considering the average value of the 10 executions of each simulation scenario. Nonetheless, in this work we concentrated specifically on three macroscopic patterns: number of coalitions, coalition size, and number of *Independent* landowners. Based on these patterns, we have carried out some analysis based on the three levels of trust intolerance indicated by the *trustThreshold* parameter: 25 is liberal, 50 is moderate, and 75 is conservator.

Initially, we could identify that when the *tax* was set to 50% or 75% the macroscopic behavior of the system was similar for all the combinations of *deltaTrust*, *trustThreshold* and *considerTrust* values. In these scenarios, the system was very dynamic, where dynamic means rapid formation and dissolution of small coalitions, with a great number of independent landowners. Moreover, we observed that increasing the *trustThreshold* and *considerTrust* values reduced the number of coalitions, reduced the size of the coalitions, and increased the number of *Independent* landowners. Moreover, we observed that increasing the trust intolerance level and the use of trust worsen the coalition formation. Thus, we may conclude that in conservative landowners and high tax scenarios the use of trust is less beneficial to coalition formation than in more liberal landowners and high tax scenarios.

However, when the *tax* was set to 25%, the macroscopic behavior varied depending on the combination of *deltaTrust*, *trustThreshold*, and *considerTrust* values, as depicted on the Figures 4, 5 and 6. Analyzing these figures we observed that the best macroscopic pattern of coalition formation is identified in a fully heterogeneous (*considerTrust* = 50%) landowners scenarios when the trust intolerance level and trust volatility are high, respectively 75 and 20 (cf. Figure 6). Thus, we may conclude that in conservative landowners and low tax scenarios the moderate use of trust is beneficial to the formation of bigger coalitions.

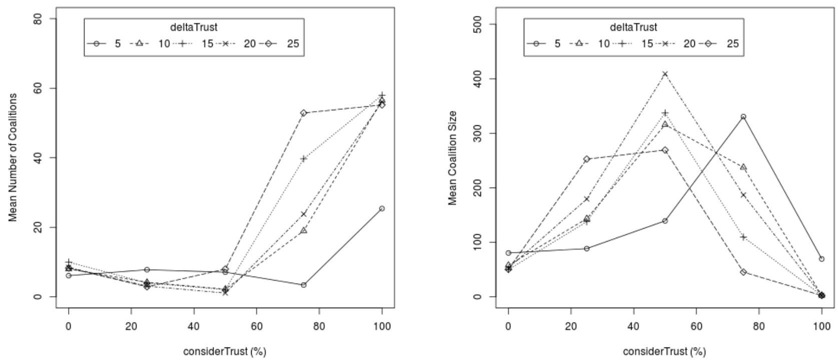

Fig. 6. Number and size of coalitions x *considerTrust* [*tax* = 25% and *trustThreshold* = 75]

6 Conclusions and Future Work

This paper presents a simulation model that adopts a microscopic approach to simulate a Spatial PD game, integrating both the concepts of coalition formation and trust. In this game, players can either act independently or form coalitions; additionally, coalition formation can be influenced by the notion of trust. We conducted some experiments to identify the influence of trust in coalition formation in a land expropriation scenario. We identified that high *tax* values make the system more dynamic and trust is irrelevant for coalition formation, corroborating with the analysis previously made in Nardin and Sichman [10]. On the other hand, when considering low *tax* values, the system behavior becomes more dependent on trust, being the best macroscopic pattern of coalition formation observed in a fully heterogeneous scenario with high values for trust intolerance level and trust volatility. As future work, we intend to specify formally the notion of coalition stability in order to analyze the dynamics of coalition formation. Moreover, we intend to allow to set different trust threshold values to the agents.

Acknowledgements

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