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agent-based model of cooperation**

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Sense making and information in an agent-based model of cooperation

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Abstract

This paper studies the profile of cooperation emerging in a context in which agents may choose to join one of two groups or stay on their own, in a world where similarity across peers matters. In particular, we investigate the role of heterogeneity in individual contributions, of the level of information and of in-group processes of convergence in values (*sense making*) in fostering higher levels of cooperation, assessed through higher participation rates to groups. Starting from the result that more heterogeneity reduces participation, we show that increasing the level of information available to subjects and activating sense-making dynamics are able to support higher cooperation levels, which, however, come at the cost of increased radicalization of agent types within group.

Keywords: Similarity, Sense making, Cooperation, Groups.

JEL Classification Numbers: B41; D74; D85.

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1 Introduction

Economic and organizational research dedicated significant attention to the study of cooperative dynamics, addressing its drivers through a plurality of methods and tools. Among others, Agent-based literature and Game Theory contributed to this field, modeling possible explanations for the emergence and evolution of cooperation among utility-maximizing agents resorting to *reciprocation* (direct or indirect) [Axelrod, 1984, Nowak and Sigmund, 1998] or other forms of *shadow of the future* supporting cooperative actions in exchange for a future chance of reciprocation [Axelrod and Dion, 1988].

This paper focuses on cooperation emerging in a context in which agents may choose to join one of two groups or stay on their own, in a world where similarity across peers matters. Membership is informal, as there are no entry or exit costs from groups. Agents joining a group commit their own resources to it, thus participation to a group can ultimately be considered a form of cooperation. Similarity across agents is measured through individual views on core (*salient values*) and negotiable issues (*general values*) and enters as a non-material component of the utility function of agents alongside a share of the total contributions to a group.

In particular, we investigate which cooperation rates may emerge in a world characterized by heterogeneity in individual contributions, when the level of information available to subjects are varied and in-group processes of convergence in values in fostering higher levels of cooperation, assessed through higher participation rates to groups, are activated. The term *information* refers to the quantity of data that can be processed by agents to know more about the features of the other members of a group. The in-group processes of value convergence will be modeled as a form of *collective sense-making* (SM), which is referred to in organizational literature as “the process whereby groups interactively create social reality, [...] develop a body of universally shared meaning and act on the basis of that shared meaning” [Boyce, 1995]. Economic literature refers to similar dynamics in the investigation of the emergence of cultural habits, while other studies grounded in cognitive psychology theories use concepts such as social propagation, social learning, or cultural contagion [Conte and Paolucci, 2001, Bandura, 1986].

This model shows features that characterize standard social dilemmas in which cooperation is classically studied. Individuals choose to participate in a group anticipating they will experience a participation premium that is available to members only. This participation premium has an immaterial component depending on similarity, which has features of non rivalry among group members, although naturally it is excludable to non-members. Moreover, in order to participate in a group, individuals have to overcome the fear of being worse off after joining, as they will end up sharing their endowments with others. Due to

this uncertainty regarding others' individual endowments and to the structure of the utility functions, relative free riding takes place *within* the group: richer individuals bring relatively more material resources to the common pie but reap only an equal share of it, thus risking to be relatively free ridden upon by less wealthy members.

Indeed, our work will confirm in passing the general result that heterogeneity is detrimental for cooperation, an outcome that is not novel and already discussed in the literature [Alesina and La Ferrara, 2000, Dayton-Johnson and Bardhan, 2002, Molinas, 1998]. In particular, we focus on whether and to what extent the degree of heterogeneity in individual contributions within the population affects the development of cooperation in informal groups, when in-group sense making takes place and more, compared to less, information is available.

Similarity across individuals is measured along a vector of individual characteristics (salient and general values), pertaining to their individual preferences. Values enter into the computation of individual utilities alongside the material endowment, building on the idea of *homophily*, the tendency of social actors to form ties with other actors similar to themselves [McPherson et al., 2001]. As in [Alesina and La Ferrara, 2000], we assume that “if preferences are correlated with these characteristics, [this] is equivalent to saying that individuals prefer to join groups composed of individuals with preferences similar to their own”.

The utility function developed in this model is inspired from a concept found initially within the risk management literature, that of *Salient Value Similarity*, which introduces salient values as the relevant dimension for the perception of similarity. These values represent core standpoints of agents and are not subject to any adaptive processes. The potential for the development of in-group processes, such as SM, lies in the inclusion of another dimension in the similarity function -*general values*- which can adapt through continued interaction. General values may be seen as more volatile positions than salient values, representing the perception of agents regarding the environment they are interacting in. As agents experience cooperative or uncooperative behavior, their idea of the world they are living in updates, changing their general values. In particular, depending on the time an agent spent in one group, we assume that general values will be tilted towards the ones of the other members. As an example, the reader can think to potential cooperators of different race and diverse cultures, where the similarity among agents depends on an immutable trait (race) and on another cultural attribute that can be adjusted and blended through repeated interaction and “contamination”.

Given the setup of this model, we expect the following results to hold:

1. A greater heterogeneity in endowments reduces participation to groups, because it

makes comparatively more risky for rich individuals to join (they are likely to be better off outside groups and are afraid of being free ridden upon by the other members of the group);

2. The increase in the level of information accessible to agents increases cooperation as it allows agents to identify in a more precise way the benefits from joining a group;
3. The introduction of SM increases participation, because it helps in making members more and more similar (strengthening their incentive to stick together) and might compensate for the effect of increased heterogeneity.

In fact, increased information, as well as SM, improve the trade-off between the risk of being exploited and the benefits coming from working with similar agents. Interestingly, even though any increment in cooperation comes at the expenses of a reduced variability within the groups, information and SM have different effects. We will show that SM can trim the “radicalization” that would otherwise arise in the presence of abundant information.

This paper is organized as follows. Section 2 introduces the modeling framework and discusses the utility function of the agents. Some effects on cooperation of an increase in available information and of the activation of SM dynamics are presented in Sect. 3, where we focus on the possible interactions between the two mechanisms. Finally, Sect. 4 draws conclusions.

2 The model

In the presentation of the model, capital letters are assumed to denote quantities that stay constant, whereas small letters are assumed to denote variables that change with time.

Assume K agents have N salient values $S_{ij}, i = 1, \dots, K, j = 1, \dots, N$. The stable, on-off nature of the salient values is stressed by supposing that they are drawn from the binary set $\{0, 1\}$ and denote with $\bar{S}_i = (S_{i1}, S_{i2}, \dots, S_{iN})$ the vector of salient values of the i -th subject. Agents are also equipped with adjustable general values that are represented by a real variable $0 \leq v_i \leq 1$.

This formalization of values allows to think of the agents as types (looking at the stable similar values) with an adjustable component - the general value parameter v_i . It is exactly through this modifiable component that the SM described below will be implemented. Moreover, even if salient values are fixed, the processes of increased information and SM will entail interesting effects that will affect also the types' composition within groups - a feature that can only be appreciated by keeping salient values into the formalization of agents' values.

At any time, at no cost, agents can decide to stay alone or join one of two groups, depending on a noisy estimate of the benefits of participation in a group. If one agent takes the decision to enter a group, he will commit and share with other members the (exogenously fixed) contribution $E_i, i = 1, \dots, K$. In what follows, we sometimes denote E_i with the term *endowment*.

Define a similarity function between agents i_1 and i_2

$$\text{sim}(i_1, i_2) = \sum_{j=1}^N \mathbf{1}(S_{i_1, j} = S_{i_2, j}) - \frac{N}{2} - (v_{i_1} - v_{i_2})^2. \quad (1)$$

The first term in the similarity counts the number of equal salient values; the second term subtracts $N/2$, so that the sum of the first two terms is nonnegative when at least 50% of the salient values are concordant; finally, the third term is the squared difference of the general values of the agents.

Assume that the i -th agent at some time t is included in the group formed by agents whose indexes are in A_{it} . The utility derived from cooperation is then:

$$p_{it} = \frac{1}{|A_{it}|} \sum_{i \in A_{it}} E_i + \sum_{k \in A_{it}, k \neq i} \text{sim}(k, i).$$

While the first term redistributes equal shares of the total amount of resources, the second term adds up the total sum of the pairwise similarities and is positive only when the agreement on salient values exceeds the disagreement on general ones. Clearly, if the agent stays on his own, his utility for the current period is limited to his own contribution (or effort) E_i , as $A_{it} = \{i\}$. Possible alternative formulations of the utility to members are discussed in [Mesterton-Gibbons et al., 2011].

At (the end of) each period, in order to take membership decision for next round, every agent randomly and independently meets P other agents, exchanging information about the size of groups they belong, their endowment and the reciprocal similarity. Observe that information about values, salient or general, is not disclosed but can only be indirectly and partially assessed through the measure of similarity with the sampled agents. In the model, P proxies the information flow available to agents, which we assume is gathered at no cost. Low (high) values of P would represent situations where limited (plenty of) information is at hand on the relevant characteristics of the other agents, inside or outside the group that is chosen for the present time.

The sample is used to compute an estimate of the utility of being in a given group. Dropping i to simplify the notation, the set of sampled individuals $\mathcal{A}_t$ is the union of the picked agents belonging to group 1, 2 and 0 (marking the decision to stay out): $\mathcal{A}_t = \mathcal{A}_t^1 \cup$

$\mathcal{A}_t^2 \cup \mathcal{A}_t^0$. The agent can trivially work out the sample averages of endowments, $\hat{e}_t^w$, and similarities, $\hat{m}_t^w$ for all groups, based on his encounters:

$$\begin{aligned}\hat{e}_t^w &= \frac{1}{|\mathcal{A}_t^w|} \sum_{j \in \mathcal{A}_t^w} E_j; \\ \hat{m}_t^w &= \frac{1}{|\mathcal{A}_t^w|} \sum_{j \in \mathcal{A}_t^w} \text{sim}(i, j).\end{aligned}$$

Using this information, an agent estimates the utility that would result from switching to one group, myopically assuming the sample averages are representative of the whole group, as far as contributions and similarities are concerned. Denoting with Z_{tw} , $w \in \{1, 2\}$, the size of group w at time t , the estimated utilities in the three foreseen situations are

$$\pi_t^w = \hat{e}_t^w + Z_{tw}\hat{m}_t^w, w = 1, 2 \text{ and } \pi_t^0 = E_i,$$

and agent i -th will select the highest value, moving to group w at time $t + 1$ if

$$\pi_t^w = \max\{\pi_t^1, \pi_t^2, \pi_t^0\}.$$

SM is represented by the adaptation of general values that, as previously discussed, are adjustable and can be modified towards the group average. We assume that all agents modify their v smoothly depending on the seniority, so that senior members are more likely to change than newcomers. Formally, for fixed i and t , if τ is the time the agent has continuously spent in one group, his general value at $t + 1$ is given by

$$v_{i,t+1} = bv_{it} + (1 - b)\bar{v}_t,$$

where $b = \tau^{-\gamma}$, $\gamma \geq 0$ shapes the speed of adjustment and $\bar{v}_t$ is the general value of a randomly sampled member of the group to which agent i belongs to at time t . SM is expected to increase similarity among the members of the same group, building a shared interpretation of facts and issues, and effectively reducing the members' difference in opinions on tradable matters.

3 Results

This section presents some results describing participation rates to the groups that emerge from simulations of the model discussed in the previous section. To the best of our knowledge, in fact, it is impossible to determine equilibria or analytical solutions. We will focus

in particular on three aspects: the distribution of individual contributions in the population of agents, the level of information availability and the role of SM dynamics.

Regarding the personal contributions, it is convenient to assume that agents are willing to commit an amount E_i that is identically and independently distributed as a Beta random variable: $E_i \sim \text{Beta}(\beta, \beta)$. For $\beta = 1$, this parametrization produces the uniform distribution, which will be used as a benchmark. Moreover, when $\beta < 1$ ($\beta > 1$) the contributions are more (less) dispersed than in the uniform case, with a bimodal (unimodal) density. To single out three representative cases, we picked the values $\beta = 2, 1, 1/2$, in increasing order of heterogeneity.

In the model the level of information is controlled by the number P of agents that are (randomly) selected in computing the myopic estimates of utility used by individuals to decide whether to join or abandon a group. In the simulations, P was uniformly drawn from the set $\{2, 3, \dots, 8\}$: at one extreme, estimates are noisy and volatile whereas, at the other end, the sample error is limited and this allows for a much higher accuracy in the assessment of the potential benefits and risks of joining a group.

Finally, we investigate the effects of SM, activating or deactivating the process in every configuration of the previously mentioned cases (three distributions for individual contributions times eight levels of the information parameter P , for a total of 24 cases).

Our environment is characterized by the following configuration of other parameters, which were chosen after some experimentation and taking into account the results of [Cruciani et al., 2012]: $K = 50$, $N = 2$, $\gamma = 0.5$, $T = 200$. Salient values are randomly sampled in the set $\{0, 1\}$ and the general values are drawn at the beginning of each simulation from the uniform distribution with support $]0, 1[$. All the results we report are based on 700 independent simulations.

It is worth noticing that $N = 2$ implies that there are 4 combinations of salient values. Hence, keeping into account that agents have the option to join only 2 groups, cooperation is likely to be possible only in the presence of (limited) dissimilarity. As an example, the combinations of salient values can be interpreted as four different ethnic groups such as White, Blacks, Asian and Latinos. The problem of cooperation arises from having the possibility to join only one of the two available organizations, which cannot perfectly resemble racial divisions. We feel this is a realistic feature of the model that would otherwise yield trivial results if the number of groups could accommodate all the different types with negligible discordance.

The following three subsections will be devoted to the implications of heterogeneity in individual contributions, different information levels and SM, respectively.

3.1 Heterogeneity in contributions

Table 1 shows the detrimental effects of the diversity of committed endowment on participation. Average measures are shown, for the different groups, named “Small”, “Large” and “Out”, as β changes. The “Size” column shows that the number of agents deciding to stay on their own increases with heterogeneity, reaching 15.21 when endowments are sampled from a bimodal distribution with higher variance. The large number of agents opting not to cooperate affects group sizes, which are accordingly reduced. Moreover, the negative effects of lower participation levels are reflected also on the payoffs of cooperating agents, which are increasing in β (i.e., declining with heterogeneity).

β	Group	Size	E	Pay
2	Small	16.31	0.95	1.46
	Large	19.84	0.98	1.69
	Out	13.85	1.08	1.08
1	Small	16.03	0.94	1.40
	Large	19.65	0.96	1.67
	Out	14.33	1.12	1.12
0.5	Small	15.35	0.90	1.30
	Large	19.44	0.94	1.60
	Out	15.21	1.17	1.17

Table 1: Effects of contribution heterogeneity on cooperation

The column reporting the average contribution (E), normalized for the average endowment of the population, underlines how wealthier agents are more likely to stay out of any groups. The higher the heterogeneity, the more marked is the difference between the average contributions of cooperative and non cooperative agents: this result mirrors our expectations, given the higher risk of exploitation borne by the wealthier agents within groups of individuals who are less able to contribute. In fact, as the number of agents with lower endowment increases, joining a group whose average payoff is above one’s endowment becomes less likely for the wealthier individuals, see [Benenson et al., 2009] for experimental evidence in line with our findings.

3.2 Increasing information

In our setting, the parameter P indicates the number of sampled individuals used to compute expected payoffs of joining either group. Thus, a natural way of implementing a situation in which agents have better information about their environment is increasing the value of P .

We expect a higher degree of information available to agents to increase participation, reducing the number of agents that decide to stay out of either group. Figure 1 shows the number of agents staying on their own as a function of P . The upper part of the graph (solid lines), relative to the absence of SM, shows how this conclusion holds for all distributions of E . Large values of P improve the ability of the agents to identify the most promising partnership, through a more accurate assessment of the anticipated benefits and risks. As a result, agents are better able to choose whether (and with whom) to cooperate, for all levels of contribution heterogeneity.

Figure 1: Effects of information and SM on participation for different values of β

Looking more in depth at the features of the groups that are formed for higher levels of P , we come across an interesting (although undesirable) characteristic: the members of distinct groups become increasingly more different. The left part of Figure 2 depicts the distribution of the average similarity, as defined in (1), of the members of different groups when $\beta = 1$. We plot one boxplot for each value of P . The right panel shows the average number of salient values' configurations (i.e., *types*) in the groups, as P increases.

The increased ability of agents to accurately estimate the payoff of joining one group has the consequence of “radicalizing” both groups, which typically become more similar within and more different across as P grows, see the left graph. Another facet of the same occurrence is shown on the right panel: for low P , at least three different types appear in every group, whereas more information brings a much smaller variety in the composition of the cooperators. Hence, on the one side, larger values of P allow to overcome heterogeneity and increase participation but, on the other side, cooperative agents become highly racially

divided, to refer again to our previous exemplification. Similar results hold also for other distributions of individual endowments and are not shown for brevity.

Figure 2: Similarity of members of groups 1 and 2 (left). Number of types found in cooperators' groups (right). Both graphs refer to uniformly distributed contributions.

3.3 Sense making

As mentioned in the introduction, we expect that within-group dynamics such as SM, by which individuals smooth their dissimilarities on tradable issues, are likely to increase participation.

		$\beta = 2$			$\beta = 1$			$\beta = 0.5$		
SM	Group	Size	E	Pay	Size	E	Pay	Size	E	Pay
Off	Small	16.31	0.95	1.46	16.03	0.94	1.4	15.35	0.9	1.30
	Large	19.84	0.98	1.69	19.65	0.96	1.67	19.44	0.94	1.60
	Out	13.85	1.08	1.08	14.33	1.12	1.12	15.21	1.17	1.17
On	Small	18.46	0.97	1.76	18.43	0.95	1.70	18.04	0.94	1.66
	Large	23.80	0.98	2.10	23.41	0.97	2.02	23.33	0.96	2.00
	Out	7.74	1.13	1.13	8.16	1.18	1.18	8.63	1.24	1.24

Table 2: Effects of Sense Making for different endowment's distributions.

Table 2 shows the effect of sense-making dynamics when P is set to 5 for all β s distributions, from the least (left) to the most heterogeneous (right). Results indicate that SM significantly increases participation in all cases, with the numbers of people staying out dropping from 13.85 to 7.74, when $\beta = 2$, and from 15.21 to 8.63, for $\beta = 1/2$. As shown in the

columns reporting E , cooperators are again among the less wealthy individuals, confirming that richer agents tend to remain out of all groups. Payoffs are often substantially bigger when SM is switched on and this effect is clearly related to the higher participation premium that is obtained through the reduction of the differences in general values within groups. Analogous findings for values of P different from 5 are not shown to save space.

The introduction of SM, moreover, produces effects that are relatively insensitive to the distribution of individual endowments, as can be gleaned from the inspection of the bottom three lines of Figure 1, where SM is activated.

Figure 3: Similarity of members of groups 1 and 2 (left). Number of types found in cooperators' groups (right), with and without SM. On the left, boxplots are relative to the absence of SM, a solid line refers to SM. Both graphs depict simulations with uniformly distributed contributions.

As the results presented so far have shown, both the increment of the information available to agents and the activation of SM can help overcome the reduction in participation rates induced by greater heterogeneity in endowments.

The previous subsection, however, highlighted how increasing participation through information spreading could have radicalization as an unintended effect. Figure 3 shows the repercussions of information and SM on in-group radicalization. The left panel displays the similarity of members of different groups. To minimize visual clutter, while there is one boxplot for each P when SM is off, a single line represents the average similarities with SM. The plot shows that, for any P , SM is beneficial as the (average) similarity of members of distinct groups increases uniformly. A somewhat different result is exhibited in the right panel, which shows the number of types in the groups: with respect to the absence of any SM (dashed line), more variety in types appears when SM (solid line) is coupled with values of $P \leq 5$, but more “radical” coalitions instead form when $P > 5$.

Such a complex interaction of SM with the amount of information available to agents

looks unexpected and surprising. Preliminary investigations show that this result is related to the emergence of two disjoint sets of general values when SM is active and information is plentiful.

4 Conclusions

In this paper we describe a model of cooperation in which agents may decide to participate in one of two groups in an informal environment. Agents choose membership on the basis of a mixture of material and non material considerations, the latter being based on an idea of similarity comprising both adjustable (general values) and immutable (salient values) components. This model addresses the classic issues arising in the setups in which cooperation is traditionally studied; in fact, it features both (potential) free riding and the creation of an immaterial participation premium.

In a context of contributions' heterogeneity, we have shown how participation can be supported by improving the ability of agents to spot better potential partnership (increasing the information available to agents regarding potential group members) or by the presence of sense-making dynamics (an in-group process that affects the general value parameter of the members). Although both effects induce similar changes in the magnitude of cooperation rates for all levels of contributions' heterogeneity, increasing the level of information available to individuals beyond a certain threshold comes at the price of remarkable in-group radicalization.

The analysis included in this paper also showed that when implementing processes aimed at supporting cooperation, one must pay particular attention to second-order effects that might aggravate dissimilarities across individuals. In this respect, radicalization of groups composition along similar values was a somewhat surprising result, as salient values represent issues that are not subject to any adaptive process; yet, increasing information always induces this negative result and the activation of sense making, which is a process of convergence of the general value component, mitigates this outcome only when the available information is below a certain threshold ($P \leq 5$).

Using a novel combination of modeling features, and including the informality of the environment and the characterization of semi-adjustable types (with fixed salient values and moving general values), this model is able to replicate effects that are present in slightly different forms in the literature, such as the higher likelihood of poorer agents to cooperate or the existence for wealthier agents of the risk of being free ridden when cooperating. The emergence of unintended second-order effects regarding the radicalization of types, entailed by the effort to increase participation in a world of higher heterogeneity, points to the need to

further investigate the dynamics underlying some features of the model. In particular, future extensions of this work may consider even proportions of salient values' vectors and provide a deeper understanding of the reasons and implications of the divergence, across the two groups, of the average general value occurring in the presence of a rich flow of information.

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