



# Group size in social-ecological systems

Marco Casari<sup>a,b,c,1</sup> and Claudio Tagliapietra<sup>a</sup>

<sup>a</sup>Department of Economics, University of Bologna, 40126 Bologna, Italy; <sup>b</sup>Institute of Labor Economics (IZA), 53113 Bonn, Germany; and <sup>c</sup>Department of Economics, European University Institute, 50014 San Domenico di Fiesole (FI), Italy

Edited by Mark Isaac, Florida State University, Tallahassee, FL, and accepted by Editorial Board Member B. L. Turner January 24, 2018 (received for review July 30, 2017)

**Cooperation becomes more difficult as a group becomes larger, but it is unclear where it will break down. Here, we study group size within well-functioning social-ecological systems. We consider centuries-old evidence from hundreds of communities in the Alps that harvested common property resources. Results show that the average group size remained remarkably stable over about six centuries, in contrast to a general increase in the regional population. The population more than doubled, but although single groups experienced fluctuations over time, the average group size remained stable. Ecological factors, such as managing forest instead of pasture land, played a minor role in determining group size. The evidence instead indicates that factors related to social interactions had a significant role in determining group size. We discuss possible interpretations of the findings based on constraints in individual cognition and obstacles in collective decision making.**

cooperation | group size | common property resources | transaction costs | social brain hypothesis

**B**y sustaining high levels of cooperation, human societies can avoid the tragedies of excessive fishing, deforestation, and climate change and achieve successful management of social-ecological systems. A broad consensus exists that the ability to cooperate, and thus to avoid the tragedy of the commons, critically depends on group size (1–3). However, the exact association between group size and cooperation is a topic of ongoing debate in the empirical literature (4–7). We add insights on questions raised by this debate, including the following: (i) What is the size of human groups in well-functioning social-ecological systems, (ii) has such group size been historically stable, and (iii) are the determinants of group size social or ecological?

Cooperation is difficult to achieve in a group, in part, because each individual has an incentive to “free-ride” on others’ efforts. From a theoretical perspective, the larger the group, the more likely it is for coordination and cooperation to fail (8). The empirical literature has considered this classic Olsonian hypothesis through a variety of field, behavioral and experimental data, but it has not clearly identified the relationship between group size and successful cooperation (9–11). A multiplicity of factors can affect cooperation, and these factors not only vary with group size but also affect it (12, 13). Prior research shows that two clusters of factors, ecological and social, can determine the observed group size (10, 13, 14). One of the ecological factors is production technology, which characterizes the group task. A group may be large because the payoffs from cooperation increase with scale to the extent that they offset, at least in part, the incentive to free-ride. Among the social factors, the literature has focused on group heterogeneity: Its role in the successful management of the commons has been found to be negative or positive depending on the type of heterogeneity and the specific task (15, 16). For instance, in attaining a group agreement, the existence of high diversity in economic interests may be an obstacle. However, some public goods could be provided through the contributions of just a few individuals in the group, and, in this case, their provision may be easier in a group that is heterogeneous in terms of prosociality than in a homogeneous group (17). This study integrates different streams of literature into a unified

framework and marks a step forward in understanding group size and successful cooperation.

Here, we study the average size of groups, their stability, and the determinants by considering the management of common property resources in the Alps (18, 19). We follow hundreds of communities over a time span of about six centuries (13th–19th centuries). The overall population in the region more than doubled during this period, and we are interested in discovering how this increase influenced the size of groups. The cases considered represent instances of a general pattern of self-governance to avert the tragedy of the commons that has been documented worldwide by Ostrom (20) and others (21, 22). More specifically, our dataset contains observations on 248 groups in the Trentino region of Italy, each of which is a community owning pastures and forests in common (23). This dataset has three distinctive aspects. First, ecological conditions varied widely across groups, which allowed controlling for the role of production technology. Second, endogeneity exists in the selection of group size as resource users self-organized from the bottom up, and they were free to cluster within or across villages, largely autonomous from the central government. The endogeneity in group size allows the observation of how group size evolved over time in these alpine communities and identification of the presence of attraction points. Third, coverage throughout several centuries is provided by a reliable, homogeneous data source. Having such a notable long-term perspective enables the observation of resilient social-ecological systems. Through six centuries, the systems experienced a wide range of political, demographic, cultural, and climatic shocks. We perform a longitudinal analysis on group size, which nicely complements existing cross-sectional studies that compare different groups at a specific point in time (12, 24–26).

This study proposes an analytical framework for thinking about cooperation and group size, as well as a unique dataset of

## Significance

**What is the size of human groups for successful cooperation? Theoretically, the larger the group, the more difficult it is to sustain cooperation. We studied hundreds of villages in the Alps that harvested common property resources for almost six centuries. In the field, the average size of successful villages was around 176 individuals, although the variance was considerable. Overall, however, this average remained stable over time despite a doubling of the region’s population. Multiple social and ecological factors could, in principle, drive group size. Here, we report the predominance of social factors, such as group heterogeneity, over ecological ones, such as managing forest instead of pasture land.**

Author contributions: M.C. designed research; M.C. and C.T. performed research; C.T. analyzed data; and M.C. and C.T. wrote the paper.

The authors declare no conflict of interest.

This article is a PNAS Direct Submission. M.I. is a guest editor invited by the Editorial Board.

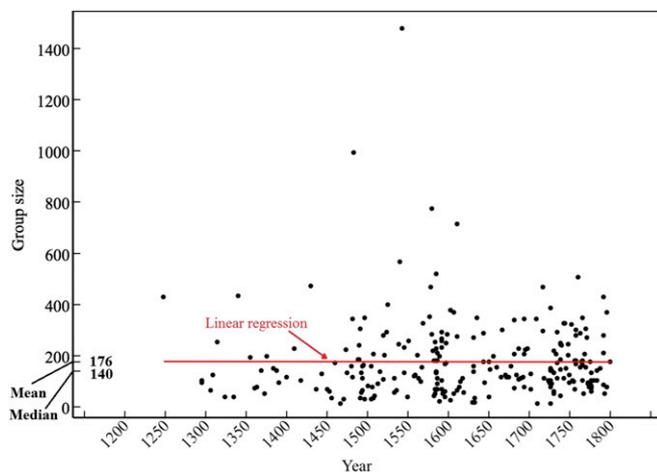
Published under the PNAS license.

<sup>1</sup>To whom correspondence should be addressed. Email: marco.casari@unibo.it.

This article contains supporting information online at [www.pnas.org/lookup/suppl/doi:10.1073/pnas.1713496115/-DCSupplemental](http://www.pnas.org/lookup/suppl/doi:10.1073/pnas.1713496115/-DCSupplemental).

Published online February 22, 2018.





**Fig. 2.** Group size over six centuries. The analysis of 248 documents with listed assembly attendants shows that group size has a constant trend during 1249–1801. The trend estimation (red line) is shown in Table 1 (column 1). The observations refer to 156 different communities.

median group sizes show no statistically significant difference (Kruskal–Wallis rank test:  $\chi^2 = 1.354$ ,  $df = 5$ ,  $P = 0.929$ ,  $n = 248$ ). We note that this conclusion, and the following ones, are based on groups that succeeded in averting the tragedy of the commons. Owing to data limitations, we cannot observe cases of failed adaptation or collapse. Recall that the model does not define an optimal group size, even when all groups have an identical cost structure, but rather a range of possible values for organized groups. The data exhibit some dispersion with group size between 10 and 1,476, which may be compatible with the above prediction, especially when allowing for heterogeneity in bargaining, monitoring, and conflict resolution costs across communities (12, 18).

The observed long-term stability in the average group size of appropriators stands in sharp contrast to the patterns of population growth in Trentino. The regional population grew by about 275% from 1312 to 1810. During the same period, the general Italian population also exhibited similarly substantial growth (*Supporting Information*). Larger groups pose a greater challenge for cooperation and for reaching a durable consensus, as exemplified by anecdotal evidence regarding the citation from a charter highlighting the difficulties of face-to-face debates (*Supporting Information*). The documents from several communities show that groups enacted fissions along geographical lines (23, 33). One example is the community composed of Coredo, Smarano, and Sfruz, which jointly managed its commons in 1437. The community split into two in 1582 and subsequently into

three in 1696. A fission usually divided both the common land and the group into two parts, with no apparent production specialization across subgroups. Fissions allowed maintaining a constant group size despite population growth.

Another piece of evidence comes from the following dynamic analysis of group size. We focus on a subset of observations with repeated recordings for the same community ( $n = 92$ ). One can exploit the direction of change in group size (up or down) to identify an attraction point, which is an evolutionary stable point for the size of the group. Single groups experienced variations in size over time (the median absolute variation was of 61.5 appropriators over a 32.5-y interval) due to a variety of external shocks and internal population dynamics. One of the possible forces at play was also the need to maintain a group size suitable for the successful management of the commons. The evidence presented below is compatible with this factor having played a detectable role in shaping group size. To estimate this attraction point, we locate the threshold at which the direction of change reverses: Groups below the threshold tend to increase in size, while those above the threshold tend to decrease in size. First, we ordered groups from smallest to largest in terms of initial size, irrespective of their geographical location. We then computed the share of groups that remained constant or grew in size (Fig. 3). When the sample is split in half, this share is lower for large groups than for small ones (34% vs. 73%;  $\chi^2$  test,  $z = 14.19$ ,  $P < 0.001$ ,  $n_1 = 46$ ,  $n_2 = 46$ ). One can refine the analysis by constructing a moving average of groups that are the most similar in size. In fact, single groups are likely affected by both idiosyncratic and common random shocks. By averaging across groups, the idiosyncratic shocks will wash out, and thus cleaner evidence results.

The moving average tends to decline as group size increases (solid line in Fig. 3). Its crossing point at 50% estimates the location of the attraction point because it signals a balance between the groups that have grown in size and those that have become smaller. The estimated attraction point is 154. When performing a similar dynamic analysis, including the magnitude of the change in addition to its direction, we obtain an estimated attraction point of 150 (*Supporting Information*). These estimates are between the median and mean group size that we obtained from the cross-sectional analysis. Hence, the stability of the average group size over time is in line with evidence showing (i) the time invariance of mean and median sizes over the centuries, (ii) the active engagement in fissions to counterbalance internal population growth, and (iii) the existence of an attraction point in the evolution of group sizes.

### Ecological Versus Social Determinants

A central question is whether the forces shaping group size are ecological or social (34). The observed size could depend on the specific type of natural resource under management, or it could

**Table 1.** Stability of average group size

Dependent variable: Group size	(1)	(2)	(3)
Year (time trend)	−0.003 (0.066)	−0.001 (0.066)	0.002 (0.061)
Resource endowment is forest-rich (yes/no)		0.110 (26.23)	−9.617 (22.11)
Resource endowment is pasture-rich (yes/no)		−4.695 (23.99)	−3.160 (20.08)
Altitude greater than 750 m above sea level (yes/no)		−24.69 (18.66)	−20.75 (15.79)
Surname diversity within the group			791.3*** (164.8)
Constant	182.0 (111.2)	187.6 (115.6)	181.8 (107.2)
<i>N</i>	248	248	236
<i>R</i> <sup>2</sup>	0.000	0.006	0.205

Panel generalized least squares regression with random effects and robust SEs clustered at the community level. The variable “surname diversity within the group” is mean-centered. Land use data are time-invariant (*Supporting Information*). Column 3 represents a smaller sample because of missing values for surname diversity; 1 SD in surname diversity corresponds to a group that is 37% larger (+67 individuals); the correlation may imply that larger groups are necessarily more diverse, or vice versa, that surname diversity determines group size. Statistical significance level: \*\*\* $P < 0.001$ .



**Table 2. Institutional complexity**

Dependent variable: No. of assembly roles	(1)	(2)
Group size	0.261*** (0.0581)	0.156* (0.071)
Surname diversity within the group		4.852*** (0.872)
Resource endowment is forest-rich (yes/no)		−0.274 (0.238)
Resource endowment is pasture-rich (yes/no)		−0.101 (0.225)
Year (time trend)		0.005*** (0.001)
Altitude greater than 750 m above sea level (yes/no)		0.316 (0.189)
Constant	3.172*** (0.141)	−5.117*** (0.982)
Observations	236	236
Overall $R^2$	0.065	0.358

Panel generalized least squares regression with random effects and robust SEs clustered at the community level. The variable “surname diversity within the group” is mean-centered, and “group size” was divided by 100. Statistical significance levels: \* $P < 0.05$ ; \*\*\* $P < 0.001$ .

The CCH instead refers to obstacles to the coherent functioning of the group in terms of decision making. When preferences over outcomes are heterogeneous, merging individual wants and needs into a collective will can be problematic (27). If unanimity is required, a diverse group may be incapable of coming to an agreement, for instance, in approving a new charter. If a simple majority is required, the collective decision making could be volatile and subject to endless revisions because of repeated reversals in voting outcomes (28). Already in 1785, Condorcet (40) showed that incoherencies in majority voting could emerge even within groups as small as three members. These results are consolidated within economics and political science, although no agreed-upon quantitative predictions about group size have emerged.

According to this line of interpretation, to function well, the Trentino groups should respect size limitations originating from both the SBH and CCH. Our evidence on group size from Trentino offers partial support for the SBH. The 95% confidence interval of our mean group size estimate for the users of collective pasture and forest is 157–196 individuals ( $n = 248$ ). Dunbar (41) estimates a range of 100.2–231.1 individuals, and Killworth and coworkers (25) estimate a mean of 291. Large shares of the Trentino groups are below these levels: 76% and 85%, respectively. Groups also actively engage in fissions, which is a typical strategy within the SBH, aiming to maintain group size within a manageable cognitive load (23, 33). Some groups appear to be too large to be compatible with the SBH. We will later discuss the possible role of institutional strategies in these large groups.

However, a careful examination of the data reveals the explanatory power of the CCH, which focuses on the number of people with voting rights and on their similarity in interests and preferences. On the one hand, the CCH redefines what constitutes a group in terms of the assembly participants instead of the resource users. On the other hand, it highlights heterogeneity, which the SBH does not explicitly mention.

Two pieces of evidence specifically point toward a role for the CCH: the empirical relevance of group heterogeneity and the type of organizational strategies adopted. As already noted, larger groups are more heterogeneous than smaller ones. However, after controlling for group size, we find that higher heterogeneity in terms of surnames consistently correlates with more complex institutions (Table 2). Moreover, under a nominal unity, some groups adopted organizational strategies other than fission to cope with the challenges of increasing group size: a multiple-tiers or group-clustering strategy.

Under a multiple-tiers strategy, resource appropriators met face to face in smaller subgroups. In those meetings, they selected representatives, who would later meet with representatives of other subgroups. For instance, in the year 1544, Comun Comunale, a community with 1,476 appropriators, approved new regulations in a plenary assembly (Fig. 1). In 1611, appropriators structured

themselves into four subgroups and sent only representatives to the general assembly.

Large communities could also follow a group-clustering strategy, which entailed partitioning the common land into multiple commons. Each individual appropriator was assigned to only one of the commons. For instance, in 1480, the community of Fiemme organized into four clusters. These institutional changes attempted to reduce the size of the group that interacted face to face and to account for the presence of groups that persistently remained nominally large.

Although both strategies make sense under the CCH, only group clustering is in line with the SBH. A multiple-tiers strategy reduces the assembly size but not the number of resource users.

## Discussion

Group size is a critical feature of social-ecological systems whose performance largely depends on the ability to cooperate (11, 20, 42). This article documents the analysis of a unique dataset spanning almost six centuries and including hundreds of communities that managed their common resources (18, 23, 29). We report a considerable stability of average group size. Estimates from multiple perspectives converge on similar figures at around 140–176 members per group, or in a larger range between 109 and 215 when performing a sensitivity analysis (*Supporting Information*).

The evidence from Trentino and other parts of the world suggests that successful cooperation takes place in rather small groups. In these systems, institutions can serve as a powerful technology to overcome social dilemmas by lowering the transaction costs of social interaction and by facilitating collective decision making (43). However, the extension of our findings to other social dilemmas requires important qualifications.

The ability to generalize these findings to other situations relies on understanding some overriding features of the Trentino settings. Our study is about what one could call “operational” groups, in which members were simultaneously resource appropriators and rule makers, and in both harvesting and voting activities, the interaction took place face to face. As appropriators, group members engaged in peer monitoring and sanctioning, which were instrumental activities to enforce the social and legal norms in place to prevent the tragedy of the commons. If an individual was unable to recognize whether another resource appropriator was an insider or outsider, or failed to recall his or her individual history or reputation, the group had potentially become dysfunctional. For this reason, large groups may experience steep increases in transaction costs in monitoring and sanctioning.

As rule makers, group members voted to identify solutions to controversies and to craft shared rules for the appropriation of the resource. A successful mechanism for group decision making should merge individual preferences into adaptive and coherent group choices. Failures can result in collective choices that prevent

