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Cost heterogeneity and peak prediction in collective actions

Peng Lu

Department of Sociology, Central South University, PR China

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The peak of participants indicates the success probability of collective actions. The mathematical model is built to explore the mechanism and prediction values of peaks. Besides of utility heterogeneity, cost heterogeneity is added into to simulate the situation of multiple heterogeneities in reality. Each simulation is run one hundred times repeatedly to get stable expectations and standard deviations of peaks under each combination of parameter values. Based on results of simulation, effects of related factors on peaks is investigated and estimated statistically, making it possible to predict peaks. In addition to forecasting the mean of peaks, the variability of peaks is estimated as well. Therefore, the distribution of peaks is predicted. Utility heterogeneity, cost heterogeneity and the Jointness of supply (J) exert significant effects on the distribution of peaks. It indicates that both utility heterogeneity and cost heterogeneity reduce the values and increase the variability (standard deviation) of peaks. Facilitating chain actions among individuals, heterogeneity promotes the outbreak of collective actions. However, it reduces the peaks and decreases the success probability of collective actions, while homogeneity increases the peak of participants and enhances the success chance of collective actions.

1. Introduction

The collective action refers to the social phenomenon that people gather and act together to achieve specific collective goals (Olson, 1965; Willer, 2009), such as strikes, protests, occupying, demonstrating, etc. For societal impacts and political implications (Meyer, 2004; Polletta & Jasper, 2001; Willer, 2009), collective action is the foundation of the society as human beings often cooperate with each other (Meyer, 2004; Olson, 1965). Collective actions are investigated via three clusters of methods: (a) The qualitative approach refers to theoretical analysis based on observations and case study (Benford & Snow, 2000; Chant, 2007; Goldstone, 1980; Hardin, 1968; Jenkins, 1983; Marx & Wood, 1975; McCarthy & Zald, 1977; Semann, 2009; Tarrow, 1988; Voss & Williams, 2012; Wright, 2009; Zhou, 1993; Zomeren & Spears, 2009); (b) the empirical approach refers to statistically evaluating empirical data (Bennett & Segerberg, 2011; Eisinger, 1973; Ellmers & Barreto, 2009; Hornsey, Fielding, Mavor, & Morton, 2006; Mannarini & Talo, 2011; Qiu, Lin, Chiu, & Liu, 2015; Stroebe, 2013; Willer, 2009; Yu & Zhao, 2006; Zaal, Laar, Stahl, Ellemers, & Derks, 2012; Fernandez & McAdam, 1988); and (c) the mathematical approach refers to mathematical models and simulations to discover features and properties of collective action (Centola, 2010; Centola, 2013; Granovetter, 1978; Hu, Cui, Lin, & Qian, 2014; Myatt & Wallace, 2009; Oliver, 1993; Ostrom, 2003; Siegal, 2009; Sigmund, Hauert, Traulsen, & Silva, 2010; Jin, et al., 2014). Although the mechanisms and processes are heavily investigated, the distribution of participants is paid less attention, especially the phenomenon of peaks. The collective action follows a common regularity that it owns the peak of participants that can be mobilized. The peak varies depending on different cases.

The number of mobilized participants measures the success of collective actions like strikes, protests, and revolutions (Centola, 2013; Granovetter, 1978; Polletta & Jasper, 2001). The peak number of participants reflects the maximum power, influence, and impact of collective actions and therefore becomes a key indicator to predict the success rate. Despite the importance and potential applications, little attention has been paid to the peaks. Fortunately, related mathematical models or formal models of collective actions indirectly pave the way for the exploration and even prediction of the peak, such as the threshold model (Granovetter, 1978, 1986), standing ovation model (Miller & Page, 2004), network model (Alba, 1981; Gould, 1993; Snow, Louis, & Sheldon, 1980; Fernandez & McAdam, 1988), stochastic learning model (Macy, 1990, 1991a, b; Macy & Flache, 1998, 2002, Flache & Macy, 2002), critical mass model (Marwell, Oliver, & Ralph, 1988; Oliver, Marwell, & Teixeira, 1985; Pamela, Oliver, & Marwell, 1988) or freezing period model (Wang, Liu, Wang, Zhang, & Wang, 2014), and game theory model (Heckathorn, 1988, 1990; Wang, Wang, & Perc, 2014; Wang, Wang, & Szolnoki, 2015; Jin et al., 2014). It suggests in these researches that there are two factors influencing the peak: (a) The Jointness of supply (J) measuring how the size of group affects the

E-mail address: lvpeng.tsinghua@hotmail.com

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individual payoffs. In general, the growing of J facilitates the payoff of individuals. Zero jointness of supply (J = 0) reduces participants and results into the group size paradox in large groups (Hardin, 1988; Olson, 1965). The paradox can be fixed by the "pure jointness of supply" (J = 1) where the size does not reduce individual payoffs and will not undermine participations (Pamela et al., 1988). Binary values of J (0 or 1) cannot capture features of all collective actions. Macy (1990, 1991a, b) expands J to the unit interval [0,1] and makes it continuous. It shows that J raises the number of participants and therefore facilitates the emergence of critical mass (Macy, 1990; Oliver et al., 1985); (b) the heterogeneity (Centola, 2013; Granovetter, 1986; Miller & Page, 2004; Oliver et al., 1985; Yu & Zhao, 2006) among members makes it harder to organize collective actions, playing a negative role in mobilizing individuals to participate (Centola, 2013; Schelling, 2005). However, the homogeneity increases participations of collective actions (Centola, 2011, 2013).

Following the mathematical approach, this paper focuses on the dynamic process and therefore prediction of peak, constructing a formal model based on the existing finding that both J and heterogeneity have negative effects on participations. Besides of the utility heterogeneity (Marwell, Oliver & Ralph, 1988; Oliver et al., 1985; Pamela et al., 1988), the cost heterogeneity should be considered as well because cost varies across different people. Therefore, this paper includes three factors such as cost heterogeneity, utility heterogeneity, and Jointness of supply to explore and predict the peaks. The cost heterogeneity refers to that participants have different costs to take part in the same collective action, and the cost homogeneity means that they share the same cost; Similarly, the utility heterogeneity refers to that agents have different subject scorings or feelings of their incomes, and the utility homogeneity means the same score of them. Under the joint homogeneity of cost and utility, ideal peaks can be obtained. Real peaks will be evaluated under cost heterogeneity or utility heterogeneity. Why we study the peak in collective actions? As more participants raise the success probability (Centola, 2011, 2013; Granovetter, 1978; Pamela et al., 1988), the dynamics and success rate of a certain collective action can be forecasted in advance, which is meaningful for both the organizers and opponents of the collective action. Our target is to estimate and predict the distribution traits (mean and SD) of real peaks. Via comparison effects of utility and cost heterogeneity, a higher fitness of estimation is achieved.

2. The model

2.1. Jointness of supply

The collective goods is the aim or pursuit of collective actions perceived by all members, including participants and nonparticipants. The collective goods take on different forms and meanings in reality, such as justice (Tallman & Ihinger-Tallman, 1979), equality (Sarah, Soule & Olzak, 2004), human or civil rights (Luders, 2006; Suárez & Bromley, 2012), anti–genetic (Schurman & Munro, 2009), environmental issues (Roser-Renouf, Maibach, Leiserowitz, & Zhao, 2014), resent and grievances (Opp, 1988) and so on. The term V_g is used to measure the value of this collective pursuit. The relationship between individuals' utilities (V_i) and collective goods (V_g) mainly explains why people participate or not (Macy, 1990; Marwell, Oliver & Ralph, 1988; Oliver et al., 1985; Olson, 1965; Pamela et al., 1988). This relationship is captured by jointness of supply (J) in Eq. (1). The individual payoff V_i equals collective good V_g divided by the group size N when J = 0. The increasing sharing of collective good by people reduces individual payoffs. Once the individual payoff goes below the cost of participation, individual will quit as a free rider. Besides, the individual payoff is independent of N when J = 1 (Macy, 1990; Pamela et al., 1988). As the V_i permanently equals V_g that is much higher than the cost, people are not expected to quit and there might be no peak. As J < 1, V_i declines as the group size grows and the peak exists. When the individual payoff is less than the cost, the agent quits. As the aim is to solve the peak, we set that J < 1 in Eq. (1).

$$V_i = \frac{V_g}{N^{1-J}} \quad s.t. \quad J < 1 \tag{1}$$

2.2. Utility heterogeneity and cost heterogeneity

The participation cost of collective action is inevitable (Centola, 2013): Pressures from the side of countermovement (Goodwin, 1997; Luders, 2006; Meyer & Staggenborg, 1996), such as governments and corporations, prevent someone from taking part in collective actions; subjective feelings of risk or fear (Riezler, 1944; Vasi & King, 2012) and social cost (Benewitz, 1956) may reduce people's willingness to participate. Therefore, we define S_i as individual's net utility, which means the utility minus the cost.

$$\begin{aligned} &S_i = v_i V_i - c_i = \frac{v_i \cdot V_g}{N^{(1-J)}} - c_i \\ &s.t.\ v_i \sim N\left(v,\ \sigma_v^2\right),\ c_i \sim N\left(c, \sigma_c^2\right) \end{aligned} \tag{2}$$

Individuals or participants are heterogeneous (Karaivanov, 2009; Oliver et al., 1985) with different attributes, features, or thresholds in collective actions (Granovetter, 1978, 1986; Simons et al., 2011). Some of them are more active and aggressive, while others stay calm and conservative. As the differential susceptibility perspective posits, some individuals are more susceptible to environmental influence than others (Simons et al., 2011). Some are simply commons and followers (Granovetter, 1978; Margetts, John, Hale, & Reissfelder, 2013; Minkoff, 1997), while others are elites, starters or leaders (Centola, 2011; Granovetter, 1978; Lindsay, 2008; Fernandez & McAdam, 1988). Heterogeneity of utility v_i is initially introduced in the critical mass model (Marwell, Oliver & Ralph, 1988; Oliver et al., 1985; Pamela et al., 1988), and v_i measures how each individual feels about the payoff acquired V_i (Oliver et al., 1985). Thus, individual's utility equals $v_i V_i$. In the previous model, heterogeneity of utility is the sole source of heterogeneity, which is not enough. Hence, heterogeneity of cost is introduced into the model as the second source of heterogeneity. In accordance with previous studies, it is assumed that both v_i and c_i are normally distributed with variances σ_v^2 and σ_c^2. In general, the standard deviation is chosen to indicate heterogeneity (Granovetter, 1978; Oliver et al., 1985). Therefore, σ_v indicates the utility heterogeneity and σ_c refers to heterogeneity of participating cost. Under both homogeneities of utility and cost ($\sigma_v = 0$ and $\sigma_c = 0$), each v_i and c_i equals the mean values of v and c. Therefore, the net payoff S_i is determined by v_i, V_g, N, and J in Eq. (2).

2.3. Decision rule and parameter settings

The process of collective action is dynamic and not all the participants emerge simultaneously (Granovetter, 1978, 1986; Minkoff, 1997; Opp, 1991). To inspect this evolutionary processes, we set the group size N to grow by one at each iteration t in Eq. (3), i.e. $N = N_t$ and the group size N_t equals t. So the net payoff S_{it} varies across individuals and times. The net payoff S_{it} is defined as utility minus cost at each time, and S_{it} dominates the decision rule. At each t, each individual checks S_{it} and makes choice A_{it}. Each one decides to take part in the collective action ($A_{it} = 1$) if and only if the net payoff is positive ($S_{it} > 0$). If the net payoff is not positive ($S_{it} \leq 0$), individual feels meaningless and therefore quits ($A_{it} = 0$).

$$N = N_t = t, \quad t \in \{1,\ 2,\ 3,\ 4,\ \ldots,\ T\} \tag{3}$$