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Population uncertainty in voluntary contributions of public goods☆

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ABSTRACT

I examine how uncertainty in the size of the relevant population affects the voluntary contribution of public goods. I analyze a case where the marginal production of public goods is decreasing and convex, and agents' social preferences are irrelevant to the population size. The voluntary contribution level in Nash equilibrium is higher when the number of players is random than when the number of players is fixed at the mean of the population distribution. The findings from a controlled experiment are consistent with this theoretical prediction. I also analyze a case where the production function is linear and the agents' social preferences are modeled in the form of a warm-glow utility function which could be increasing concave in the population size. The experimental findings reject the hypothesis that warm glow is congestible: when the public-goods production function is linear, uncertainty in the population size does not lead to changes in the contribution level.

1. Introduction

I examine how individuals contribute to the production of public goods when they do not know the exact number of participants in the contributor pool. Previous research has used lab experiments to determine what factors encourage individuals to contribute to the provision of public goods.[1] The voluntary-contributions mechanism (VCM), including variations thereof, has been repeatedly revisited by verifying observations,[2] extending ideas,[3] or extrapolating results[4] from the exist-

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[1] Experimental studies of private provision of public goods include, but are not limited to, Marwell and Ames (1979), Isaac et al. (1994), Smith et al. (1995), Palfrey and Prisbrey (1997), Isaac and Walker (1988), Bagnoli and McKee (1991), Fehr and Gächter (2000), and Croson (2007).

[2] Andreoni (1995a) found that, on average, about half of all voluntary contributions in the laboratory comes from subjects who understand that non-cooperation maximizes their payoffs but choose to cooperate out of some form of kindness. Brandts and Schram (2001) found that subjects' behavior cannot be explained exclusively as the result of errors in making choices. Fischbacher et al. (2001) found in a one-shot public-goods game that half of the subjects were conditional cooperators. Harbaugh and Krause (2000) conducted a public-goods game with children and found that older children's behavior was similar to that of adults.

[3] Andreoni (1995b) found asymmetries in subjects' behavior between provision of public goods and provision of public "bads." Messer et al. (2007) studied how contextual factors can produce sustained efficiencies in a voluntary-contribution game. Morgan (2000) considered a way to increase contributions by introducing a certain feature of lotteries, and Morgan and Sefton (2000) tested the idea experimentally. Zhang et al. (2011) investigated the effect of group size in a natural field experiment via the Chinese Wikipedia site.

[4] Andreoni (1993) and Andreoni and Payne (2003) tested the proposition that government contributions via lump-sum taxation will completely crowd out voluntary contributions to the production of public goods and found that such crowding-out was incomplete. Fehr and Gächter (2000) and Masclet et al.

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ing literature. One common result found in the vast majority of previous studies is that some subjects seem to feel a "warm glow," which can be modeled by additional utility derived from the very act of giving (Cornes and Sandler, 1984; Andreoni, 1989, 1990). In terms of experimental design, another noticeable similarity of previous studies is that all experiment participants knew exactly how many other individuals were making their decisions simultaneously, and accordingly knew exactly how influential their contributions were. However, in many real-world situations, a potential contributor does not know how many other contributors there are: A voter does not know how many people with voting rights will consider turning out for an election, a charitable giver does not know how many others will consider making donations of aid to needy children, a voluntary participant in a Neighborhood Watch group does not know how many neighbors would consider filling in—on short notice—for members who are out of town during the summer vacation period, and potluck party organizers do not know how many others will contribute since they do not know how many will consider coming.[5] Does this uncertainty change the behavior of individuals? If so, how does the uncertainty change it?

The main contribution of this paper is to provide theoretical and experimental evidence that population uncertainty is one of the driving factors behind voluntary contributions. If the production function of the public goods is increasing concave, individuals contribute more when the population size is uncertain than when the population size is fixed at the mean of the population distribution. The warm glow utility, at least for the group sizes being tested, does not get affected by population uncertainty.

To be more specific, I modeled a voluntary contribution game with population uncertainty. A player in this game knows the population distribution of the players but not the exact number of players. This randomness is referred to as population uncertainty. Though population uncertainty has been adopted in many other fields in applied microeconomics,[6] to the best of my knowledge it has not been emphasized in the literature on voluntary contributions of public goods.

Two issues on which consensus has not been reached are (1) whether voluntary contributions increase or decrease with group size, and (2) whether people strategically contribute conditional on the structure of public-goods production. To answer them efficiently, I considered two models, each of which closes off one channel through which population uncertainty could affect the players' contribution decisions. With a model that features an increasing concave public-goods production function, with a convex marginal production[7] and a constant marginal warm-glow utility function in terms of population size, I show that when the number of players is random, the voluntary contribution level in a symmetric Nash equilibrium is *higher* than when the number of players is fixed at the mean number of players. Another model focuses more on the warm-glow utility (Cornes and Sandler, 1984; Andreoni, 1989, 1990). If the warm-glow utility can be described by a function which is increasing concave in the group size and the marginal utility of public goods is constant in the group size, then, unlike with the first model, population uncertainty serves to *decrease* the individual contribution level in equilibrium. However, this prediction depends strongly on the assumption made about the shape of the warm-glow utility function in the group size.

While these theoretical predictions of the effect of population uncertainty for each model are evident, it is still unclear how people actually respond to population uncertainty. Though the two channels I considered are undoubtedly important, there could be other factors that affect the individual contribution level under population uncertainty. If some players regard the uncertainty in the population size as a cognitive barrier that hampers them from calculating a strategically optimal contribution, they might want to increase their allocation to the consumption of private goods so that their utility will come from a more certain source. On the other hand, if risk-averse subjects worry more about the worst-case scenario, where the population size turns out to be small, or their risk aversion drives them to put more weight on the possibility that the contributor pool is small, they may want to contribute more in order not to forgo the higher marginal utility of public goods. Another possibility is that the salience of population uncertainty would change a subject's decision process, by implicitly encouraging him to recognize the strategic aspects of the game. My laboratory experiments are designed to correspond to my models, but they also serve to examine whether certain other factors affect the individual contribution level.

I conducted a series of experiments designed to test hypotheses about how population uncertainty affects voluntary contributions of public goods. I employed a 2-by-2 between-subject treatment design. The four treatments differed in two dimensions: the functional form of public-goods production (linear or nonlinear) and where the group size was certain or uncertain. That is, the treatment effect of the group-size uncertainty was examined both with a linear production function and with one that is increasing and concave. Subjects in the uncertainty treatment chose their contribution level without knowing the actual group size, which was either 3 or 9 with equal probability. Their earnings in each round were determined after the group size was revealed. The linear-treatment sessions investigated whether and how people respond to population

(2003) added some forms of punishment for people who did not contribute voluntarily. Duffy et al. (2007) and Fischbacher and Gächter (2010) investigated how the dynamics of public-goods games affected subjects' behavior. Keser and Van Winden (2000) and Andreoni and Croson (2008) studied whether subjects' behavior changes when they play with partners instead of with strangers (or vice versa).

[5] I distinguish the uncertainty in the number of players from the uncertainty in how a known number of other players would act. I will discuss further the distinction between population uncertainty and changes in population size.

[6] Since Myerson (1998b) introduced the notion of population uncertainty in games, studies in political economy have actively used the concept of population uncertainty to understand voter turnout (Myerson, 1998a; Piketty, 2000; Dhillon and Peralta, 2002; Bendor et al., 2003; Spenkuch, 2013). In the context of contests, population uncertainty has also played an important role (Myerson and Wärneryd, 2006; Münster, 2006; Lim and Matros, 2009).

[7] It is known that public goods provision with diminishing marginal returns yields an interior solution. See, for example, Keser (1996), Sefton and Steinberg (1996), and Laury et al. (1999).