Instability in the voluntary contribution mechanism with a quasi-linear payoff function: An experimental analysis

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Abstract

We conduct experiments to investigate the convergence of contributions in the voluntary contribution mechanism (VCM) with two quasi-linear payoff functions. One is linear with respect to private goods and nonlinear with respect to public goods; we call it “QL1.” The other is linear with respect to public goods and nonlinear with respect to private goods; we call it “QL2.” The system with QL1, built on the assumption of self-interested players and myopic Cournot best response dynamics, is not stable, but the system with QL2 has a dominant Nash equilibrium. This theoretical result predicts a “pulsing” of contributions in the VCM with QL1. Our experimental observations demonstrate that individual contributions are certainly converging to the dominant Nash equilibrium in the experiment with QL2. In the experiments with QL1, however, the dispersion of individual contributions increases progressively with repeated trials, and the contributions are still volatile in the experiments’ last periods, although we do not find a clearly unstable pulsing in the group’s total contribution.

1. Introduction

The voluntary contribution mechanism (VCM) has been investigated by experimental economists for many years in order to understand the public goods provision problem. Most researchers in this field use linear payoff functions such as \( u(x, y) = x + by \), where \( x \) is a private good of player \( i \), \( y \) is a public good, and \( b \) is a positive constant. However, several scholars argue that this linear payoff setting cannot represent real-world situations of the VCM environment because the self-interested choice (Nash equilibrium) and the optimal social choice are located at opposite boundaries of the feasible choice set (see, e.g., Sefton and Steinberg, 1996; Lab and Holt, 2008).

One way to address this problem is to adopt nonlinear payoff functions to provide an interior solution for the self-interested choice and the optimal social choice. Thus, two quasi-linear payoff functions are introduced in the literature. The economic rationale of the first payoff function is that private good \( x_i \) is money; therefore, its marginal return could be assumed to be constant. However, the marginal return from specific public good \( y \) is nonlinear. That is, \( π(x, y) = x_i + (ty) \) (see Isaac et al., 1985; Isaac and Walker, 1991; Sefton and Steinberg, 1996; Isaac and Walker, 1998; Laury et al., 1999; Hichri and Kirman, 2007).

We call this “QL1.” Conversely, the second payoff function is linear with respect to \( y \) and nonlinear with respect to \( x_i \). Thus, the function is \( π(x, y) = h(x_i) + y \) (see Sefton and Steinberg, 1996; Keser, 1996; Falkinger et al., 2000; Willinger and Ziegelmeyer, 2001; van Dijk et al., 2002; Uler, 2011; Maurice et al., 2013; Cason and Gangadharan, 2014). We call this “QL2.” The second payoff function is used to model a relatively rare situation in which the marginal return from the private good decreases, whereas it is constant for the public good.

These two designs lead to completely different theoretical predictions. The VCM with QL1 induces multiple static Nash equilibria, which produces a coordination problem. By contrast, the VCM with QL2 induces a unique dominant equilibrium, which is similar to the VCM with linear payoff functions. Sefton and Steinberg (1996) compared contribution levels across QL1 and QL2 environments using a randomly re-matched group setting to suppress the feedback from the results of previous periods in the experiments. They predicted that the presence of the coordination problem should partially explain why the average of individual contributions is significantly above the Nash prediction in their design of the VCM with QL1, although their experimental results indicated only a slight difference in contribution levels between the two experiments.
In contrast to Sefton and Steinberg (1996), we are interested in the VCM experiments with QL1 and QL2 using a fixed group setting. Since the fixed group setting transforms the game into a super game, subjects might be motivated to play strategically in such an environment (for details, see the discussion in Sefton and Steinberg (1996)). Furthermore, because the group members are fixed, the feedback from preceding periods contributes to belief formation much more directly in the fixed group setting than it does in the randomly re-matched group setting. Healy (2006) provides experimental evidence that subjects appear to best respond to recent observations in the VCM experiment with QL1 using a fixed group setting.

Recently, Sajo (2014) showed that, if subjects follow the assumptions of self-interested players and myopic best response dynamics, all Nash equilibria are not asymptotically stable in the system of the VCM with QL1.2 This leads to a pulse of contributions (alternating between contributing nothing and contributing everything). This dynamic analysis predicts that the feedback from repeated trials will worsen the coordination problem in the VCM with QL1. On the other hand, Laury et al. (1999) found that the symmetric Nash equilibrium was a poor predictor of individual contributions and that mean contributions also varied widely among individuals, even within a single experiment. This result was confirmed by Hichri and Kirman (2007). These observations and the instability result suggest a complex interaction among subjects in the VCM with QL1.

Analogous arguments of instability were discussed concerning oligopoly competition in the field of industrial organization (see Cox and Walker, 1998; Rassenti et al., 2000; Huck, et al., 2002). Nevertheless, the instability problem in the VCM with QL1 differs from that examined in those discussions. As Andreoni (1995) pointed out, subjects are called upon to generate positive externalities in the VCM environment, whereas they are asked to generate negative externalities in the experiment of oligopoly competition.3 The positive and negative framing will lead to different effects on cooperation (see Andreoni, 1995; Sonnemans et al., 1998; Cookson, 2000; Bowles and Polania-Reyes, 2012). Cooperative behavior is widely observed in the VCM experiments (for a survey, see Chaudhuri, 2011). Therefore, an investigation in the VCM environment might provide a new understanding of the effect of instability in an environment that includes cooperation.

More importantly, most experimental studies in the field of VCM experiment have used the linear payoff function and the same endowment E. A simple quadratic specification is the following:
\[ \pi_i = E - s_i + aS - bS^2, \]
where a and b are positive constants, \( s_i \) denotes player i’s individual contribution, and \( S = \sum_{i} s_i \) represents the group’s total contribution. For this simple linear, a list of individual contributions \( \tilde{s} = (\tilde{s}_1, \tilde{s}_2, \ldots, \tilde{s}_n) \) is a Nash equilibrium if, for all i, \( \pi_i(\tilde{s}_i, \tilde{s}_{-i}) \geq \pi_i(s_i, \tilde{s}_{-i}) \) for all \( s_i \in [0, E] \), where \( \tilde{s}_{-i} = \sum_{j \neq i} \tilde{s}_j \). Therefore, from the first-order condition, the sum of Nash equilibrium contributions is given as
\[ \tilde{S} = \frac{a - 1}{2b}, \tilde{S} \in [0, nE]. \]
This result indicates that any combination of individual contributions constitutes a static Nash equilibrium as long as the total contribution equals \( \tilde{S} \) (Bergstrom et al., 1986).

Anderson et al. (1998) introduce decision errors into this model. They show that, though there is a continuum of Nash equilibria, a unique logit equilibrium exists that is symmetric across players. The equilibrium density is a (truncated at the boundary of the choice set) normal density for the quadratic public goods game (the VCM with QL1).4 Furthermore, they suggest that the quadratic model can easily be generalized to allow for individual differences in error parameters. The unique symmetric logit equilibrium thus becomes a unique asymmetric logit equilibrium. Moreover, because the distribution is truncated by the boundary of the choice set, the expected contribution of the logit equilibrium is also sandwiched between the symmetric Nash

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2. Theories of the VCM with QL1 and QL2

2.1. VCM with QL1

Suppose that, in an n-player VCM with QL1, all players have the same payoff function and the same endowment E. A simple quadratic specification is the following:
\[ \pi_i = E - s_i + aS - bS^2, \]
where a and b are positive constants, \( s_i \) denotes player i’s individual contribution, and \( S = \sum_{i} s_i \) represents the group’s total contribution. For this simple linear, a list of individual contributions \( \tilde{s} = (\tilde{s}_1, \tilde{s}_2, \ldots, \tilde{s}_n) \) is a Nash equilibrium if, for all i, \( \pi_i(\tilde{s}_i, \tilde{s}_{-i}) \geq \pi_i(s_i, \tilde{s}_{-i}) \) for all \( s_i \in [0, E] \), where \( \tilde{s}_{-i} = \sum_{j \neq i} \tilde{s}_j \). Therefore, from the first-order condition, the sum of Nash equilibrium contributions is given as
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2 An intuitive explanation of asymptotic stability is that an equilibrium \( \tilde{x} \) is asymptotically stable if all nearby solutions not only stay nearby but also tend to converge. An analogous argument of instability was discussed concerning oligopoly experiments usually frame the subject’s choice as providing a product, which will lower the market price and result in a disbenefit to others within the group.

3 The VCM experiments usually frame the subject’s choice as contributing to the provision of public goods, which could benefit other players within the group, whereas the oligopoly experiments usually frame the subject’s choice as providing a product, which will lower the market price and result in a disbenefit to others within the group.

4 Absolute changes are the absolute values of the first-order differences of individual contributions.

5 See Proposition 3 in Anderson et al. (1998).
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