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MODELING PARTICIPATION IN RESIDENTIAL RECYCLING PROGRAMS

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ABSTRACT

A dynamic iteration model, similar to models introduced by Heckathorn [1-3] is developed and applied to residential recycling programs. The model simulates the iterative decision choices of individuals in a group who have an opportunity to participate in an action. In turn, each actor "becomes ego" and chooses his behavior at three different levels, based on the payoffs resulting from these choices and the current behavior of the other actors. "Ego" can choose to participate in the action, influence others to participate in the action, and/or influence others not to influence still others to participate in the action. The model is used to simulate a number of residential recycling scenarios, including groups that produce only personal benefits, groups producing collective goods but with no social interaction, and groups producing collective goods with social interaction. Group heterogeneity is found to be necessary in most cases to obtain reasonable results.

INTRODUCTION AND OBJECTIVES

Engineers are most accustomed to solving environmental problems with physical technologies: developing processes which create less pollution or collect materials with pollution potential before their release to the environment; designing facilities to store, treat or destroy contaminants; and overseeing the cleanup of contaminated environments. Treating exhaust gases from a power plant or municipal solid waste incinerator with a bag house or scrubber, for example, represents a typical and acceptable engineering solution which protects the environment.

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Some of modern society's environmental problems, however, are not amenable to solutions which are solely facility-oriented, i.e., where solutions are achieved solely using machines. Some solutions require an understanding of, and often an ability to influence, human behavior. Because some practical solutions necessitate widespread behavior change, either engineers must adapt and use the social sciences—along with physics, mathematics, biology, chemistry, etc.—to design and operate environmental protection programs, or social scientists must be involved in engineering solutions.

Environmental solutions involving behavior change are desirable when the behavior change is required to make the overall process technically or economically feasible. Such solutions involve blends of physical components and behavior change. For example, the residential curbside collection recycling program requires equipment to collect, transport, and process recyclable material and make new products from the collected material, but it also requires individuals to adopt new behaviors to separate, store, and make available these same materials. Such programs can be described as *individual level environmental collective actions: individual level,* because success requires widespread participation of individuals in particular behaviors; *environmental,* because protecting, maintaining, or improving the physical environment is a prime concern; and *collective action,* because the production of collective goods is involved [4]. Collective goods are defined as any good ". . . such that, if any person X_i in a group X_1, $X_2, \ldots, X_i, \ldots, X_n$ consumes it, it cannot be feasibly withheld from others in that group" [5].

Some collective goods have what is called "jointness of supply," meaning that the consumption of the collective good by one person does not reduce the ability of other persons to enjoy it. Examples of environmental collective goods include clean air and water, and lower solid waste disposal bills. Clean air and water can have jointness of supply; if the air or water is clean, the enjoyment of it by one person does not reduce the enjoyment of it by others. A lower solid waste disposal bill is a collective good which does not have jointness of supply. The entire collective good, in this case, is divided up and distributed among the community population. The more people to which it is distributed, the less the average share becomes. In this case, "free riders" are of special concern, i.e., individuals who do not contribute to the production of a collective good, but who share in its benefit.

The goal of this article is to increase our understanding of participation in individual level environmental collective actions by exploring a number of scenarios using dynamic iteration modeling. The specific environmental collective action considered is the residential recycling program. The objectives are to:

- review literature concerning residential curbside collection recycling;
- develop a dynamic iteration model capable of exploring hypotheses concerning participation in residential recycling programs;

- use the model to explore appropriate hypotheses and present results; and
- present conclusions.

RESIDENTIAL RECYCLING

Individual level environmental collective actions involve widespread adoption of particular individual level behaviors, protection of the environment, and the production of collective goods. Some important individual level environmental collective actions are solid waste management programs.

The integrated solid waste management hierarchy is defined as: source reduction and re-use; recycling and composting; and incineration and landfilling [6]. Many communities have implemented unit pricing schemes, in which residents are not charged a flat fee, but are charged according to the amount of waste set out for collection [7]. Unit pricing programs are intended to encourage source reduction and re-use, recycling, and composting. The number of communities operating curbside recycling programs in the United States increased from 177 in 1977 to more than 7,200 in 1994 [8, 9], while similar increases occurred for yard waste composting and drop-off recycling programs.

Residential recycling programs collect recyclable materials that have been separated in homes. Such programs are individual-level environmental collective actions because they: require individuals to adopt new behaviors concerning household material management; protect the environment by diverting materials from landfills or incinerators and by reducing the need for the extraction of raw materials; and provide collective goods in the form of cleaner air, water, and soil, and perhaps, community-wide lower disposal bills.

However, the recovery of residential recyclables can also be accomplished by a centrally located mechanical processing facility, requiring no change in behavior. Central mechanical separation uses mechanical equipment—such as shredders, magnets, trommels, screens, and air classifiers—and hand sorting to separate municipal sold waste into usable fractions. This system is quite different from residential recycling programs, where the waste generators themselves separate recyclable materials from non-recyclables at home or at work for separate collection. The advantages of residential recycling over central-mechanical separation can be lower costs and cleaner recovered material. The disadvantage is dependence on widespread voluntary or coerced participation.

Understanding, predicting, and influencing participation is crucial to residential recycling programs, the success of which depends on high participation rates, as influenced by program characteristics, local attitudes, and program promotion. Important design issues include the effect of voluntary versus mandatory participation, appropriate collection frequency, the potential effect of the provision of home storage containers, commingled versus separate recyclables collection, and promotion effectiveness (see, for example [10-12]). Five factors important to the success of integrated solid waste management programs are market incentives, coercive incentives, convenience strategies, promotional efforts, and attitudinal, belief, and demographic variations. These factors are discussed in the next five subsections.

Market Incentives

Market incentives consist of direct payments for recyclable goods, deposit programs, and unit pricing schemes. Direct payments are often uneconomic and currently are feasible for only a few materials, such as aluminum. Deposits, often created by bottle bills, can be very effective, but can be politically difficult to implement. Volume or weight-based garbage disposal rates, often called unit pricing, can be effective and are used in more and more communities [7].

In unit pricing schemes, households or businesses are charged for waste handling services based on the amount collected from the residence or business, measured by volume or weight of material. Thus, individual households or businesses which produce more waste are assessed higher garbage collection fees, providing a cost-based incentive to minimize the waste stream. There is usually no charge for materials that are recyclable or compostable, if set out for separate collection. Unit pricing systems are implemented at the community scale and, with proper fee rates, are financially self-supporting.

Volume-based or weight-based rates create an incentive to recycle, compost, and source reduce/re-use by rewarding these behaviors with lower waste service charges [13, 14]. Recycling programs in cities with volume-based rates tend to have high recycling program participation levels [15-17] and higher recycling rates [18-21] when compared to cities without volume-based rates. Recent research indicates that unit pricing also encourages waste reduction and may encourage composting [7].

Coercive Incentives

Coercive incentives use the force of law to produce desired behaviors. One popular strategy employed for residential recycling programs is the participation requirement, enforced through warnings, refusal to collect municipal solid waste containing recyclables, or fines. Mandatory program numbers increased from forty-two in 1979 to at least 592 in 1989 [22, 23]. As of 1989, about 50 percent of all residential curbside recycling programs in the United States required residents to recycle select materials. Since then, most new programs have been voluntary in nature.

Reports of the greater effectiveness of mandatory recycling compared to voluntary vary from 30 to 100 percent [22, 24-26]. Research conducted through a nationwide survey of recycling programs found that, among respondents, mandatory programs collecting newspaper, glass, and aluminum collected almost 60 percent more material than voluntary programs collecting the same materials

[11]. The increased effectiveness of mandatory recycling programs may be due to several factors: extra publicity as a result of passing a recycling ordinance; greater government commitment to the program; increased promotional and educational efforts; and enforcement of the ordinance through fines, refusal to pick up municipal solid waste, or warnings [27-29].

Mandatory recycling also has disadvantages: it alters the spirit of voluntary participation; mandatory programs receive greater scrutiny and more is expected of them, especially when they supersede a voluntary program; and enforcement can be difficult and expensive [29-31]. Many communities take a minimalist approach, rarely enforcing their ordinance [30].

Convenience Strategies

Making participation more convenient reduces personal cost, enhancing the value of all incentives, and thus tends to increase participation. Convenience factors mentioned in the literature include delivery methods, separation requirements, provision of containers, collection frequency, and program reliability [10, 11].

In a survey of residents served by a drop-off recycling program, Vining et al. found that a common reason for not recycling was inconvenience [32]. Maximizing convenience is important for drop-off programs. In several studies, the number of and proximity to containers had a significant effect on participation rates [33-37].

The number of materials collected by a recycling program and the number of categories into which the materials must be separated affect convenience. However, multi-material collection programs (perhaps because of increased perceived seriousness) appear to elicit higher participation levels than comparable single material programs [10, 38]. Many curbside collection program participants, however, do not recycle all of the materials collected by their particular program [39] and material category increases could increase this tendency. The number of separate recyclable categories into which one must deliver materials to the curb or central location will affect convenience. This can range from putting all materials in one container (completely commingled) to keeping each separate (completely separated). While still somewhat controversial, it is generally believed that as the number of materials collected separately increases, participation rates will fall due to increased inconvenience.

Providing containers free of charge may increase convenience by providing a storage container. It also provides a visual reminder to recycle [24, 40, 41]. Further reminders can be provided by printing logos, pick-up days, or do's and don'ts on the side of the container. Rigid containers appear to be the most convenient and produce the highest recovery rates. Rigid containers, however, are more expensive and can impose a significant start-up cost [42]. Flexible containers (bags) can be collected on non-compaction vehicles or compaction vehicles, either separate from or with municipal solid waste.

Program effectiveness has been noted to increase with collection frequency [38, 43-45]. However, results from a nationwide survey of recycling programs indicated that collection frequency, in the range of once per week to once per four weeks, is not an important predictor of program success [11]. It has also been suggested that collecting recyclables on the same day as municipal solid waste may increase material collection because it may be easier to remember to recycle on the day that one already puts out garbage [40, 43]. For programs not collecting recyclables every week, but collecting municipal solid waste every week, however, participants must still remember what week to recycle. Thus, same day collection may be more convenient when recyclables collection is every week, but not when collection is once every two or four weeks. Results of a national survey of recycling programs indicate that same day collection has no positive effect on program success among program respondents [11].

Program Promotion

Program promotions serve a vital and necessary role in creating successful recycling programs by: making contact with potential participants and describing where, when, and how to recycle; promoting the benefits of recycling; lowering perceptions about costs; advertising the convenience of the existing programs; and increasing awareness about collective goods associated with programs. Whereas convenience creates incentive by reducing personal cost, promotions communicate information about incentives. Thus, promotions should be designed to foster positive attitudes toward recycling and high valuation of incentives. This constitutes a major difference between market, coercive, and convenience strategies and promotion strategies.

Though it appears that the general population of the United States is in favor of recycling, this does not mean that a majority approve, accept, or are aware of their local recycling program. The same can be said of source reduction and composting programs. In a recent survey conducted by the author, 97 percent of the respondents agreed with the statement, "recycling is good," but only 69 percent set-out recyclable materials for collection during an eight-week period.

Workers in the recycling field stress the importance of using promotion and education before a new program starts, during its early operation phase, and regularly during its operation thereafter to maintain high levels of awareness and acceptance [38, 46-49]. Promotional techniques include reminders printed on containers, reminder signs, enclosures in city billings, direct mail and direct delivery fliers, speeches, television, radio, and newspaper paid advertisements and public service announcements, door-to-door contact, boy and girl scout canvases, newsletters, special articles, calendars, stickers, school curriculums, and mascots.

Recycling coordinators find personal communications, followed by mailed and hand delivered fliers, to be the most effective promotion techniques [10]. All three of these techniques are effective in making contact, as opposed to promotions using newspaper, television, or radio, which depend on subscription and listening or viewing for contact. Personal communication has the added advantage of providing personal contact, with greater flexibility to respond to individual situations.

General awareness and acceptance of residential recycling programs can be transferred through avenues other than program sponsored promotions. For example, media articles on high local disposal costs or imminent landfill closings can produce awareness and acceptance. Acceptance can also be harmed by media reports. Pieters mentions that many households in a Netherlands recycling program ceased to participate after local newspapers reported that materials collected by the program were being disposed of due to operating problems [41].

Attitudes, Beliefs, and Demographics

Pro-environment attitudes have been widespread since at least the 1970s [50]. But while opinion polls typically indicate that recycling is favored by a majority [51, 52], actual program participation rates vary greatly. In some cases, low correlation between expressed intent to recycle and actual recycling behavior have been measured [53, 54]. This is especially important because source reduction, composting, and recycling programs, unlike many other collective activities, require contributions from a high proportion of their potential constituents in order to be successful [55].

The likelihood of participation is related to the strength and nature of an individual's beliefs regarding the collective goods produced through recycling behavior. Because most collective goods produced by recycling programs are difficult to measure—e.g., cleaner air, water, and soil, energy and natural resource conservation, job creation, etc.—individual perceptions concerning these goods are expected to vary widely. For this reason, it is best to refer to positive perception of collective good magnitude as a belief.

Demographic variables such as higher education, higher income, neighborhood stability and social networks, type of building, and age group appear to be associated with recycling behavior [30, 36, 56-58]. For example, the amount of material available for composting may vary with income because wealthier individuals are more likely to own lawns or wooded areas, and thus are more likely to produce compost materials. In addition, persons of particular education or income levels appear to be most likely to recycle. Previous research, however, has not established strong relationships between demographic variation and program successes.

Social networks also affect an individual's decision to recycle. Vining et al. [32] proposed that social pressure might elicit willingness to recycle. Though results were inconclusive when people were directly asked if social pressure was important, recyclers were more likely than non-recyclers to have heard about recycling from friends. Spaccarelli et al., studying a curbside recycling program, found that on residential blocks with block clubs but no recyclers, a personal prompt to recycle resulted in a smaller increase in block recycling than the same prompt administered in blocks with no block club but a few recyclers [59]. The largest increase occurred on blocks with clubs and recyclers. The results from the Spaccarelli study indicate that social pressure can work for or against activities such as recycling. Everett and Peirce also indicate that local social networks appear to influence block recycling rates [56].

Attitudes and beliefs have been linked to source reduction and recycling activities. A sense of being in control of one's life, a sense of personal responsibility for environmental problems, and frugality are all positively correlated with a greater propensity to source reduce and recycle [60, 61]. Normative beliefs, morals, commitment, and compliance with previous requests are also correlated with source reduction and recycling activities [62-65].

MODEL DEVELOPMENT

The basic model presented here is a group-mediated social control model, based on models introduced by Heckathorn [1-3]. The model simulates the iterative decision choices of individuals with an opportunity to participate in a collective action. In turn, each actor becomes ego and chooses his or her behavior at three different levels, based on the payoffs resulting from these choices and the current behavior of the other actors. Ego chooses the combination of behaviors that generates the largest personal gain. After the model has iterated through the entire group several times, an equilibrium is generally reached, in which no actor changes behavior upon becoming ego.

At the first level, ego can choose to participate or not participate in a collective action. *First level compliance* produces individual and group benefit, but also involves costs to ego. *Second level compliance* involves ego exerting control in order to reduce the opportunity of other actors to defect at the first level. By doing this, ego ensures that more of the collective benefit is produced. However, second level compliance also entails personal cost. Finally, *third level compliance* involves ego exerting control to reduce the opportunity of other actors to comply at the second level. By doing this, ego increases his or her opportunity to defect at level 1 and thus avoid level 1 costs. However, level three compliance also involves personal cost.

Each actor's opportunity to comply at the second level—i.e., opportunity to exert control in order to reduce the opportunity of other actors to defect from the collective action—is a function of the compliance of other actors at the third level. Thus,

$$OC2'_a = \prod_{b=1}^{N} (1 - E3_{ab} \cdot IC3_b) \tag{1}$$

where: $\mathbf{OC2'_a}$ = the fractional opportunity of actor **a** to comply at the second level; N = the number of actors in the group; $\mathbf{E3_{ba}}$ = the proportionate reduction in actor **a**'s ability to comply at the second level caused by actor **b**'s compliance at the third level; $\mathbf{E3_{aa}} = 0$, because actor **a** does not influence him or herself; $\mathbf{IC3_b} = 1$ if actor **b** complies at the third level, 0 if actor **b** does not; and the subscripts **a** and **b** refer to individual actors.

Each actor's opportunity to defect at the first level—i.e., to not participate in the collective action—in a function of the opportunity of other actors to comply at the second level and the control they are able to exert. Thus,

$$OD1'_a = \prod_{b=1}^{N} (1 - OC2_b \cdot E2_{ab} \cdot IC2_b) \tag{2}$$

where:$\mathbf{OD1'_a}$ = the fractional opportunity for actor **a** to defect at the first level; $\mathbf{E2_{ab}}$ = the proportionate reduction in actor **a**'s ability to defect at the first level caused by actor **b**'s compliance at the second level; $\mathbf{E2_{aa}} = 0$, because actor **a** does not influence him or herself; and $\mathbf{IC2_b} = 1$ if actor **b** complies at the second level, 0 if actor **b** does not.

The compliance at each level at any point in time is a function of the current choices made by each actor. For example, the number of actors complying at the first level will be a function of those who voluntarily comply and those whose opportunity to defect has been reduced by second level compliance. The number complying at the first level is

$$NC1 = NVC1 + \sum_{a=1}^{N} [(1 - OD1'_a) \cdot ID1_a] \tag{3}$$

where: **NVC1** = the number of actors voluntarily complying at level one; and $\mathbf{ID1_a} = 0$ if actor **a** complies at level 1, and 1 if actor **a** defects at level 1. The number complying at the second level is

$$NC2 = N - NVD2 + \sum_{a=1}^{N} [OC2'_a \cdot IC2_a] \tag{4}$$

where: **NVD2** = the number of actors voluntarily defecting at level two; and $\mathbf{IC2_a} = 1$ if actor **a** complies at level 2, and 0 if actor **a** defects at level 2. The number complying at the third level, **NC3**, is equal to **NVC2**, the number of actors voluntarily complying at level 3, because all actors are completely free to comply or defect at level three.

Ego has two choices at each level, resulting in eight different combinations of ego behavior. However, only six combinations are logical, as ego will not choose to cooperate at both the second and third levels. Given a set of behaviors for all actors other than ego, each possible ego combination causes a unique level 1 group defection rate and ego payoff. The level one defection rates, depending on the behavior of ego are:

$$PD1_{cdd} = \frac{NVC1 + \sum_{a=1}^{N} [(1 - OD1_a) \cdot ID1_a]}{N} \qquad (5)$$

where $\mathbf{PD1_{cdd}}$ = the proportion of the group defecting at level 1 if ego complies at level 1, and defects at level 2 and 3; **NVC1** includes ego; $\mathbf{OD1_a}$ = the opportunity for actor **a** to defect if ego defects at level 2 and 3; $\mathbf{ID1_e} = 0$; and the subscript **e** refers to ego;

$$PD1_{ddd} = \frac{NVC1 + \sum_{a=1}^{N} [(1 - OD1_a) \cdot ID1_a]}{N} \qquad (6)$$

where $\mathbf{PD1_{ddd}}$ = the proportion of the group defecting at level 1 if ego defects at level 1, 2, and 3; **NVC1** does not include ego; and $\mathbf{ID1_e} = 1$;

$$PD1_{ccd} = \frac{NVC1 + \sum_{a=1}^{N} [(1 - OD1'_a) \cdot ID1_a]}{N} \qquad (7)$$

where $\mathbf{PD1_{ccd}}$ = the proportion of the group defecting at level 1 if ego complies at level 1 and 2, and defects at level three; **NVC1** includes ego; $\mathbf{OD1'_a}$ = the opportunity for actor **a** to defect if ego complies at level 2 and defects at level three; and $\mathbf{ID1_e} = 0$.

$$PD1_{dcd} = \frac{NVC1 + \sum_{a=1}^{N} [(1 - OD1'_a) \cdot ID1_a]}{N} \qquad (8)$$

where $\mathbf{PD1_{ccd}}$ = the proportion of the group defecting at level 1 if ego complies at level 1 and 2, and defects at level three; **NVC1** does not include ego; and $\mathbf{ID1_e} = 1$.

$$PD1_{cdc} = \frac{NVC1 + \sum_{a=1}^{N} [(1 - OD1''_a) \cdot ID1_a]}{N} \qquad (9)$$

where $\mathbf{PD1_{ccd}}$ = the proportion of the group defecting at level 1 if ego complies at level 1 and 2, and defects at level three; **NVC1** includes ego; $\mathbf{OD1''_a}$ = the opportunity for actor **a** to defect if ego defects at level 2 and complies at level three; and $\mathbf{ID1_e} = 0$.

$$PD1_{ddc} = \frac{NVC1 + \sum_{a=1}^{N} [(1 - OD1''_a) \cdot ID1_a]}{N} \tag{10}$$

where $\mathbf{PD1_{ccd}}$ = the proportion of the group defecting at level 1 if ego complies at level 1 and 2, and defects at level three; **NVC1** does not include ego; and $\mathbf{ID1_e} = 1$.

Collective actions can produce three different types of goods: collective goods with jointness of supply, $\mathbf{CG_j}$, collective goods without jointness of supply, $\mathbf{CG_{nj}}$, and private goods, **PB**. Unless otherwise stated it will be assumed that individuals use an individual assessment rational in evaluating benefits and cost [4]. This means that individuals participate only if the benefit they personally receive is greater than their personal costs.

The amount of collective good produced is a function of the proportion of actors complying at the first level. Following Heckathorn [2] if the total amount of collective good produced when every actor complies is $\mathbf{CG_j}$, then the amount of collective good with jointness of supply received by ego can be defined as

$$CG_j \cdot (1 - (PD1)^E) \tag{11}$$

where: **PD1** is the proportion of defectors at level 1, which will depend on the compliance strategy chosen by ego; and **E** is an exponent which describes the relationship between the proportion of actors complying at the first level and $\mathbf{CG_j}$ production.

Figure 1 presents the relationship between the proportion of the collective good produced and the proportion of first level compliers for different values of **E**. When **E** equals 1, the relationship is linear. When **E** > 1, collective good production increases quickly at low compliance levels, and almost all of the collective good can be produced at a compliance level below 1. When **E** < 1, collective good production increases slowly at first, then increases quickly as the proportion level approaches 1.

The personal share of collective goods without jointness of supply is a function of the total good produced and the number of members in the group. If the good is divided equally, the amount received by ego is

$$\frac{CG_{nj} \cdot (1 - (PD1)^E)}{N} \tag{12}$$

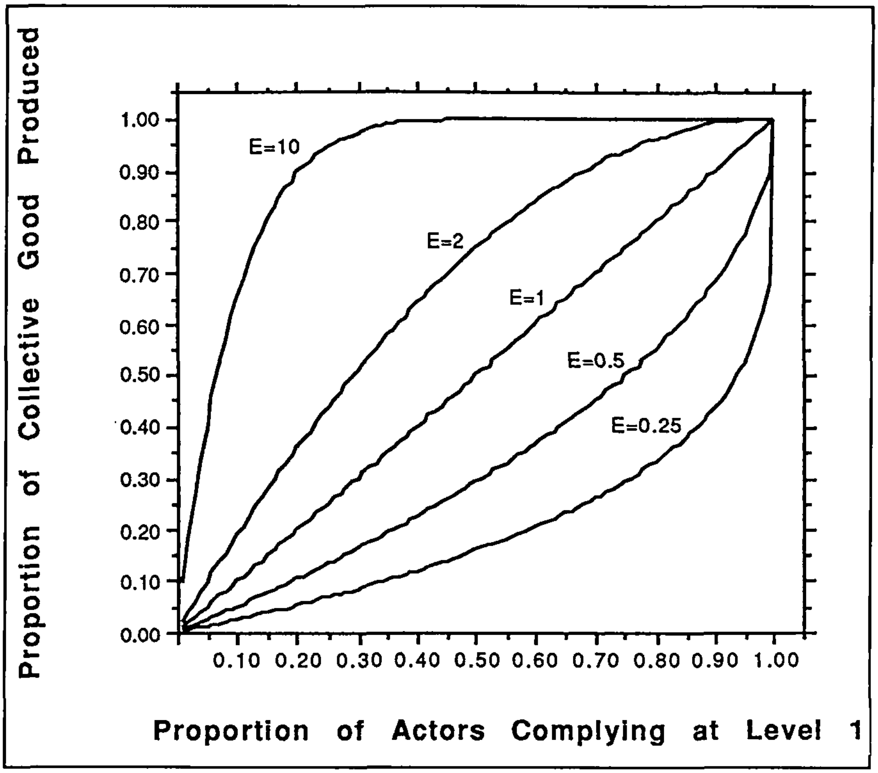

Figure 1. Collective good production.

where: CG_{nj} is the amount of collective good without jointness of supply generated if the entire group participates. Each member receives this amount, regardless of his or her first level behavior.

The costs of complying at the first, second, and third levels are K1, K2, and K3, respectively. However, an ego that chooses to defect at the first level or comply at the second may not have an unrestricted opportunity to do so. Therefore, the costs incurred by ego at the first and second level are

$$K1 \cdot [1 - (OD1'_e \cdot ID1_e)] \tag{13}$$

and

$$K2 \cdot OC2'_e \cdot IC2_e \tag{14}$$

Similarly, because ego's opportunity to defect at level 1 may be reduced, ego will receive a fraction of the personal benefit resulting from participation,

$$PB \cdot [1 - (OD1'_e \cdot ID1_e)] \tag{15}$$

Finally, the costs of punishments applied to actors that do not participate at the first level is

$$M \cdot PUN \tag{16}$$

where: **M** = the probability that level one defection will be detected, and **PUN** = the cost of the punishment.

Based on the preceding discussions, the payoffs to ego are:

$$P_{cdd} = N \cdot CG_j \cdot (1 - (PD1_{cdd})^E) + CG_{nj} \cdot (1 - (PD1_{cdd})^E) + PB - K1 \tag{17}$$

$$\begin{aligned} P_{ddd} = {} & N \cdot CG_j \cdot (1 - (PD1_{ddd})^E) + CG_{nj} \cdot (1 - (PD1_{ddd})^E) \\ & + PB \cdot (1 - OD1_e) - K1 \cdot (1 - OD1_e) - M \cdot PUN \end{aligned} \tag{18}$$

$$\begin{aligned} P_{ccd} = {} & N \cdot CG_j \cdot (1 - (PD1_{ccd})^E) + CG_{nj} \cdot (1 - (PD1_{ccd})^E) \\ & + PB - K1 - K2 \cdot OC2_e \end{aligned} \tag{19}$$

$$\begin{aligned} P_{dcd} = {} & N \cdot CG_j \cdot (1 - (PD1_{dcd})^E) + CG_{nj} \cdot (1 - (PD1_{dcd})^E) \\ & + PB \cdot (1 - OD1'_e) - K1 \cdot (1 - OD1'_e) - K2 \cdot (OC2_e) - M \cdot PUN \end{aligned} \tag{20}$$

$$\begin{aligned} P_{cdc} = {} & N \cdot CG_j \cdot (1 - (PD1_{cdc})^E) + CG_{nj} \cdot (1 - (PD1_{cdc})^E) \\ & + PB - K1 - K3 \end{aligned} \tag{21}$$

$$\begin{aligned} P_{ddc} = {} & N \cdot CG_j \cdot (1 - (PD1_{ddc})^E) + CG_{nj} \cdot (1 - (PD1_{ddc})^E) \\ & + PB \cdot (1 - OD1''_e) - K1 \cdot (1 - OD1''_e) - K3 - M \cdot PUN \end{aligned} \tag{22}$$

where: $\mathbf{P_{cdd}}$ = the payoff to ego if ego complies at the first level and defects at levels 2 and 3; $\mathbf{P_{ddd}}$ = the payoff to ego if ego defects at levels 1, 2, and 3; $\mathbf{P_{ccd}}$ = the payoff to ego if ego complies at levels 1 and 2 and defects at the third level; $\mathbf{P_{dcd}}$ = the payoff to ego if ego defects at the first and third levels and complies at level 2; $\mathbf{P_{cdc}}$ = the payoff to ego if ego complies at the first and third levels and defects at level 2; and $\mathbf{P_{ddc}}$ = the payoff to ego if ego defects at the first and second levels and complies at level 3.

To summarize, ego will choose his or her behavior at each level in order to maximize payoff. Each actor becomes ego in turn; after the model has iterated through the members of the group several times, an equilibrium is reached where egos do not change their behavior upon further iteration. By running the model with different parameters, various hypotheses can be tested.

RESULTS

The model presented in this article can be used to evaluate market, coercive and convenience incentives, and promotions. It can also be used to evaluate the effect of attitudes and beliefs, social interaction, and demographic variables.

Selective Incentives

Market incentives are almost always *selective* incentives, i.e., the benefit of a market incentive is received only by those who participate in a required activity. For example, to receive money for aluminum cans, one must collect and deliver the cans to a buy-back center. A similar statement can be made concerning unit pricing programs. A resident receives the benefit of a lower municipal solid waste disposal fee only if that resident diverts municipal solid waste through source reduction, re-use, recycling, or composting. Thus, the benefit produced by one member's participation is not shared with other members of the group. When savings realized through recycling activities are distributed through a lower community-wide flat-fee for disposal costs, each member of the community receives a monetary benefit, regardless of participation status. In this case, market incentives are a collective good without jointness of supply.

The variable **PB** represents selective market incentives. A situation where participation in a hypothetical action produces selective market incentives only is shown in Figure 2. Because no collective goods are produced, the action is not collective in nature. The solid line in Figure 2 indicates the percentage of members in a homogeneous group that participate in the hypothetical action—at equilibrium—for different values of **PB**. The cost of participation, **K1**, is kept constant at 25 units. When **PB** exceeds **K1**, the entire group participates. As expected, the boundary between zero and full participation occurs abruptly at **PB** equal to 25 units.

While it is reasonable that the entire group might participate at very high and none at very low **PB** values, the abrupt change at 25 units is not realistic. Rather, it is expected that as **PB** increases first a few, then more, and finally all of the group will participate. Such a group cannot be homogeneous, i.e., the members of the group must differ in some way. One way to simulate heterogeneity is to allow the members of the group to have different assessments of the cost of participation. In the case of recycling, the cost associated with participation consists of the cost of separating, storing, and delivering recyclables. For example, an individual with less room available for storage may perceive higher storage costs. Persons with more free time may perceive lower separation costs because they assign less value to their free time.

The effect of heterogeneous perception of participation costs can be simulated by assuming that **K1** differs for each group member. The dotted line in Figure 2 represents a heterogeneous group's response to different **PB** values, where **K1** is a random variable from a normal distribution with mean equal to 25 units and a

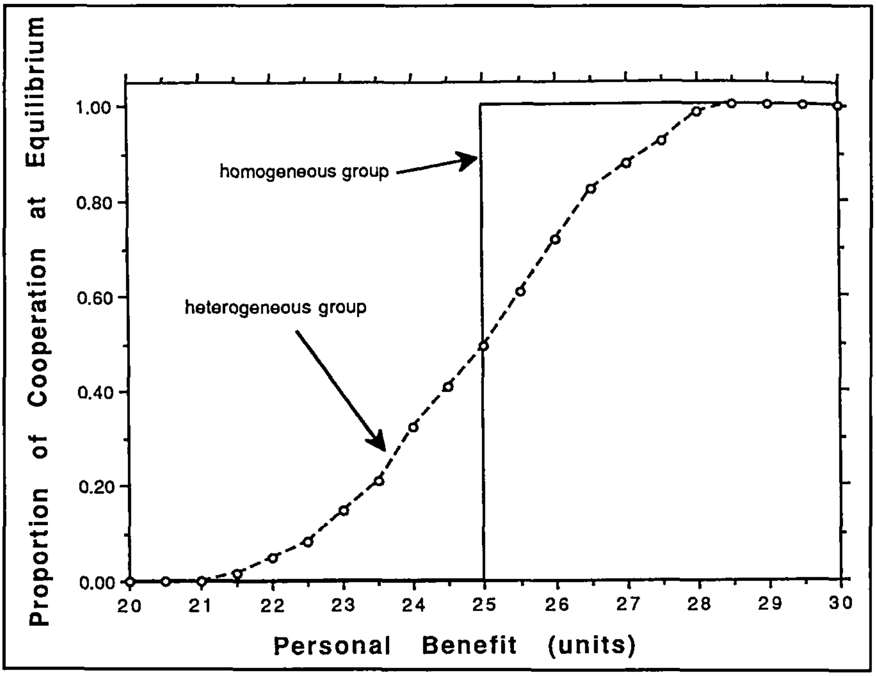

Figure 2. Relationship between participation and personal benefit in the absence of collective benefits.
(Note: CG_j, CG_{nj}, K2, K3, E2, E3 are zero. Solid line: K1 equals 25. Dotted line: K1 is a normally distributed variable with mean 25 and standard deviation 2 units. Each data point represents average of fifty model runs.)

standard deviation of 2 units. The circular data points in Figure 2, connected by a dotted line to aid in interpretation, represent average values from fifty model runs at each **PB** value. The relationship represented by the circles appears more reasonable than the relationship represented by the solid line.

If the circles represent the relationship between participation level and the price of aluminum cans, inspection of the Figure indicates that, when the price paid for aluminum cans increases over 21 units, a small percentage of the group begins to recycle. This would be the portion of the group that considers the cost of aluminum can recycling to be low compared to other available money-making activities. The participation level increases as the benefits of recycling increase, until the entire group recycles at about 28.5 units. However, it is likely that a much higher price would be required before the entire group would recycle, reflecting the fact that some individuals have other, much more desirable, ways to obtain money. This can be taken account of by using a different distribution for **K1**.

The relationships shown in Figure 2 are independent of the ability of members of the group to exert control over level 1 or 2 behavior. In other words, social networks have no effects on participation rate. This is true because it is assumed that the action produces no collective goods.

The relationships shown in Figure 2 can apply to other selective goods, including coercive and convenience incentives. For example, coercive incentives are selective in nature. Where recycling is mandated by a local ordinance, residents that do not recycle may be subject to fines, warnings, or loss of municipal solid waste collection services. The magnitude of this cost is a function of the perceived probability of being observed and the perceived magnitude of the punishment. A member will participate if **PB** – **K1** is perceived to be greater than – **M** · **PUN**. Note that participation can take place even if **PB** – **K1** is negative, indicating that coercive incentives can work even when personal benefit is outweighed by the cost of participation. The coercive incentives discussed here are not collective sanctions, because only the transgressor is punished, not the entire group. Convenience incentives are also selective, in that only participants receive the extra benefit that becomes available as **K1** decreases as a result of more convenient recycling avenues.

Promotions can effect recycling program participation in several different ways. For example, promotions can inform potential constituents of personal benefits associated with recycling and punishments associated with not recycling. Alternatively, promotions may change perceptions of the personal costs associated with recycling. In these cases, the effect of promotions are to increase selective incentives. Thus, the effect of promotions may be handled by changing **PB, K1, M,** or **PUN** as discussed in the preceding discussion. Alternatively, promotions may change perceptions about the value of the collective goods produced by participation, in which case the effect of promotions must be handled as discussed below.

Collective Good Incentives

It should be clear to even the casual observer that selective incentives are often not sufficient to produce the participation levels observed for many residential recycling programs. For example, very few programs offer market incentives of any kind. Of programs that are able to use coercive incentives, many do not enforce the local mandatory participation ordinance, indicating that **M** will be very low. However, mandatory programs—whether enforcement is low or high—tend to have higher participation rates than voluntary programs. Even among voluntary programs, participation rates are relatively high compared to other collective actions, such as social movements. All of this indicates that many recyclers perceive that recycling produces significant amounts of collective goods, represented in the model as $\mathbf{CG_j}$ and $\mathbf{CG_{nj}}$. Promotions, attitudes, beliefs, and demographics all affect perceptions of these two benefits.

Without Inter-Member Influence

For a given set of parameters, if the ability of members to influence each other's behavior is assumed to be negligible, i.e., **E2** and **E3** equal zero, the relationship between group participation rate and the amount of collective good associated with participation will be similar to the relationships shown in Figure 2. For homogeneous groups, the participation rate will jump from 0 to 100 percent as soon as the *extra* share of the collective good received by each member subsequent to participation is greater than the cost of participation, i.e., when each member of the group is *privileged,* following Olson's terminology [5]. If the group is heterogeneous, a relationship similar to that indicated by the dotted line in Figure 2 is likely. There is likely to be significant variability in perceptions, not only of personal costs, but also of collective good generation, in which case $\mathbf{CG_j}$, $\mathbf{CG_{nj}}$, and **K1** can be treated as random variables with specified distributions.

Several important points can be made concerning collective goods and collective action participation. First, the generation of collective goods can be an inducement to participate in the complete absence of social interaction. For example, some individuals will value collective goods generated by recycling activities—such as cleaner air, or energy and natural resource conservation—so highly that they will participate regardless of any expectation that others will recycle also, i.e.,

$$CG_j \cdot \left(1 - \frac{N - 1^E}{N}\right) + \frac{CG_{nj} \cdot \left(1 - \frac{N - 1^E}{N}\right)}{N} > K1 \qquad (23)$$

for collective goods with and without jointness of supply, respectively. Inspection of equation (23) indicates another important point. An individual's valuation of collective goods without jointness of supply is strongly effected by group size. As **N** increases, it becomes less likely that the second term in equation (24), concerning collective goods without jointness of supply, will be greater than **K1**. If $\mathbf{CG_{nj}}$ is linearly related to **N**, as is likely with recycling activities, $\mathbf{CG_{nj}/N}$ remains constant while **1 – [(N–1)/N]** approaches zero as **N** increases. Thus, the share of a collective good without jointness of supply received by an individual member of a group resulting from his or her participation will tend to approach zero as the group size increases.

When **E** is equal to 1, the production of a collective good is linearly related to the proportion of the group participating. In this case, the participation level will not influence each ego's decision to participate. It can easily be shown that, when **E** = 1, the decision to participate can be evaluated using the equation

$$\frac{CG_{nj} \cdot \left(1 - \frac{N-1}{N}\right)}{N} + CG_j \cdot \left(1 - \frac{N-1}{N}\right) + PB > K1 \tag{24}$$

which can be simplified to

$$\frac{CG_{nj}}{N^2} + \frac{CG_j}{N} + PB > K1 \tag{25}$$

regardless of what other actors do. Alternatively, if E is less than 1, late joiners generate more collective good. These two situations are shown in Figure 3, used to present the participation level for a group of fifteen composed of two sub-sets of members: those favorably disposed to participate (**PB > K1**), and those unfavorably disposed to participate (**PB < K1**). When **E** equals 1, it is clear from the Figure that none of the unfavorably disposed members join the favorably disposed members. When **E** = 0.4 and the number of favorably disposed members is thirteen or more, the unfavorably disposed members join the collective action.

The solid line in Figure 3 represents the behavior of a group whose members follow a different participation assessment rationale. In this group, members participate if their own benefit outweighs their cost, i.e., if the equation

$$\frac{CG_{nj} \cdot (1 - PD1^E)}{N} + CG_j \cdot (1 - PD1^E) + PB > K1 \tag{26}$$

is true, where: **PD1** = the proportion of the group defecting at level 1. Individuals using equation (26) to determine participation status are following a group assessment rational [4]. They participate if participation produces a benefit for their group *and* their personal cost does not exceed their personal benefit. This is quite different from the individual assessment rationales; individuals using the individual assessment rationale participate only if their personal net benefit is maximized by participation.

It is clear from equation (26) that the fewer defectors the more likely the equation is true for any individual member. If just two members are predisposed to participate, all of the other members will join in participating, even though they would receive greater personal gain through not participating. Individuals following an individual assessment rationale would not participate.

This represents one explanation of the *Salimando effect.* Salimando [66] observed that, in residential neighborhoods where residents were given official recycling containers, as soon as a significant percentage of households started setting out material in these containers, a large percentage of the remaining houses suddenly joined in setting out material. One explanation for this behavior is that decision makers in the remaining households, perceiving that the program was successful, decided that a recycling effort would be worthwhile, and began to recycle.

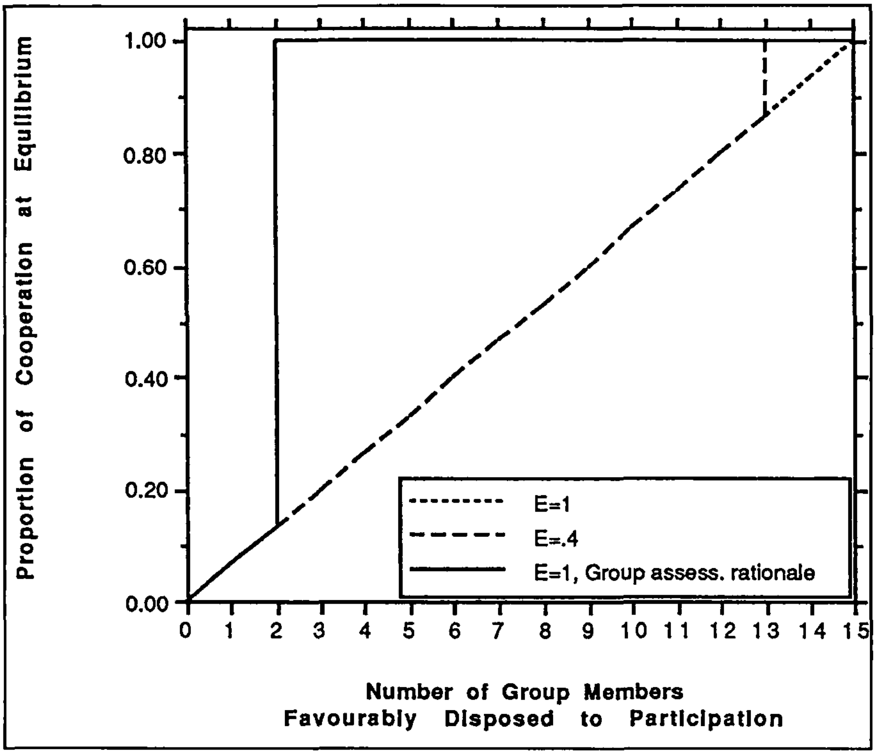

Figure 3. Decision making of ego's less disposed to participate. (Note: PB, CG_j, K2, K3, E2, E3 are zero, CG_{nj} = 3500, K1 = 25, N = 15. Solid line: ego participates if benefits outweigh costs, regardless of whether non-participation would result in higher personal gain.)

With Social Interaction

In the full model it is assumed that social interaction can effect participation level. Group members are able to exert control over other members, reducing the ability of controlled members to defect at the first level or comply at the second level. The specific mechanisms are presented in equations (1) and (2).

In Figure 4, equilibrium conditions for a group of fifteen individuals are shown for a wide range of values for CG_j. When CG_j is above 300 units, each member of the group is privileged, i.e., the benefit produced by the participation of one individual (300 / 15 = 20 units) is greater than the cost of one individual's participation (20 units). Thus, above CG_j = 300 units, the equilibrium condition finds each group member voluntarily complying at the first level. This result is not dependent on inter-member influence.

Below CG_j = 300 units, no group member is privileged. However, for any value of CG_j above 20 units, each group member will profit if the proportion of the group complying at the first level is greater than 20 divided by CG_j. However, inspection of Figure 4 reveals that between CG_j values of 20 and 27 units no participation takes place. In this range, the cost of reducing another individual's opportunity to defect at the first level—which will cause some collective good to be produced—is higher than the individual benefit generated by this behavior. However, this result is dependent on the particular set of parameter values chosen. For example, if the cost of complying at levels 2 and 3 are low and high, respectively, collective good may be produced by groups which are not able to produce a net benefit, even at full participation.

As CG_j increases from 28 to 300 units, a greater percent of the group chooses to exert control over level 1 behavior. This results in higher and higher group cooperation levels. However, it is clear from inspection of Figure 4 that no member of the group voluntarily complies at CG_j levels below 300 units. For the

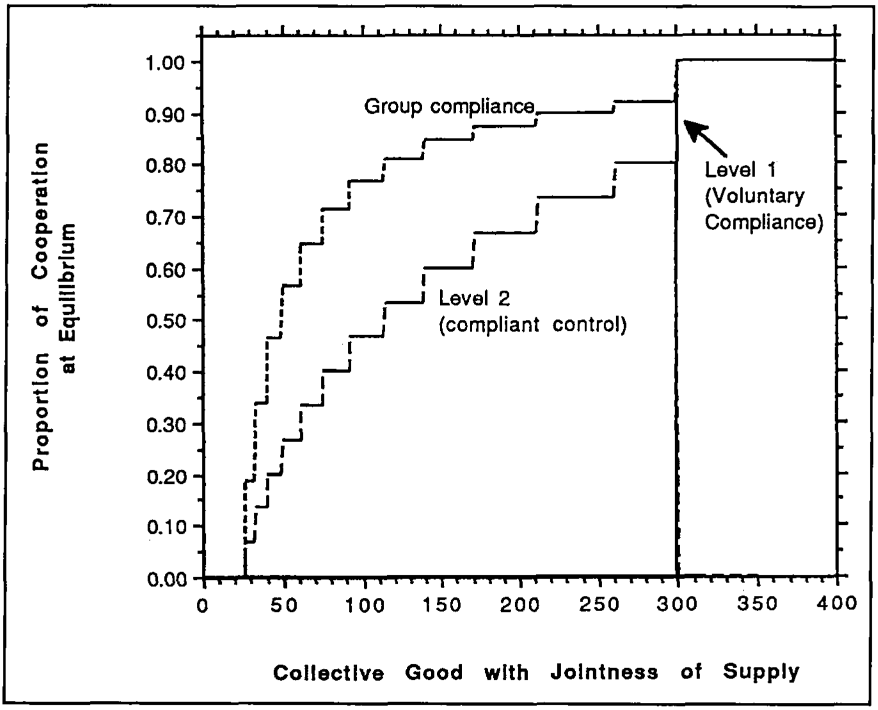

Figure 4.
(Note: PB and CG_{nj} are zero, K1 = 20, K2 and K3 = 5, E2 and E3 = 0.2, E = 1, N = 15.)

set of parameters used to produce Figure 4, level 3 participation is never observed, indicating that it is never in ego's interest to reduce the opportunity of other actors to comply at the second level.

Figures 5 and 6 show two examples of the emergence of cooperation as each actor becomes ego in turn and decides to cooperate or defect at each of the three levels. Each Figure is based on a particular CG_j value, with all other parameters the same as those used for Figure 4. In Figure 5, CG_j is 290 units. Therefore, no group member is privileged. At time zero, no member is cooperating at any level. Initially, each actor, upon becoming ego, decides to defect at levels 1 and 3 and cooperate at level 2. This is called hypocritical cooperation because ego chooses to force others to comply while attempting on a personal level to defect. Hypocritical cooperation is the consistent choice until twelve actors (80%) have chosen this strategy. The remaining actors choose full defection, i.e., they defect at all levels. The equilibrium condition is: 80 percent hypocritical cooperation; 20 percent full defection; and 90 percent total cooperation at the first level. Figure 5

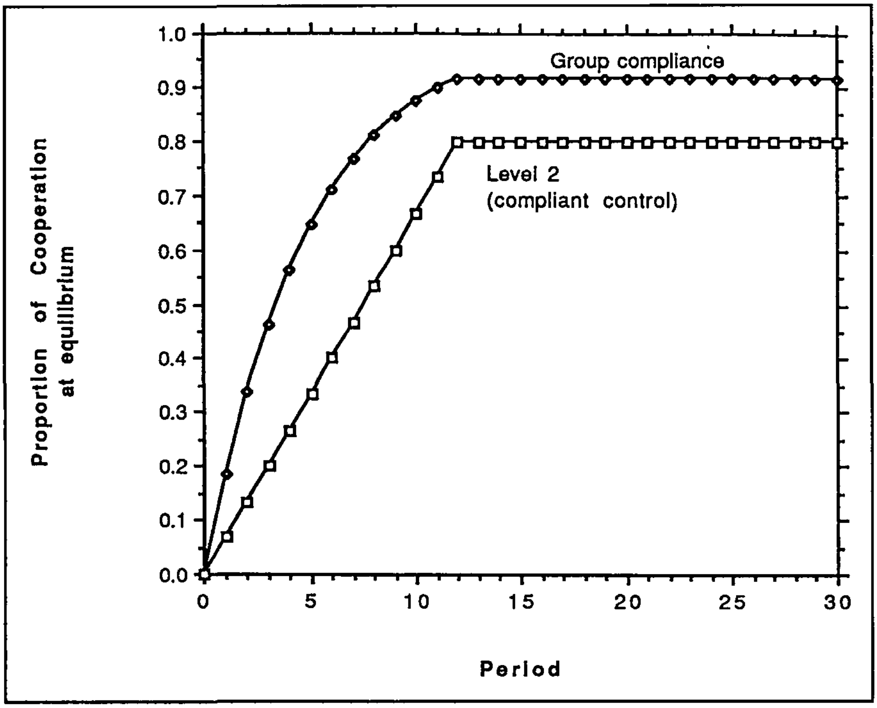

Figure 5. Group in which the members are not privileged.
(**Note:** PB and CG_{nj} are zero, CG_j = 290, K1 = 20, K2 and K3 = 5, E2 and E3 = 0.2, E = 1, N = 15.)

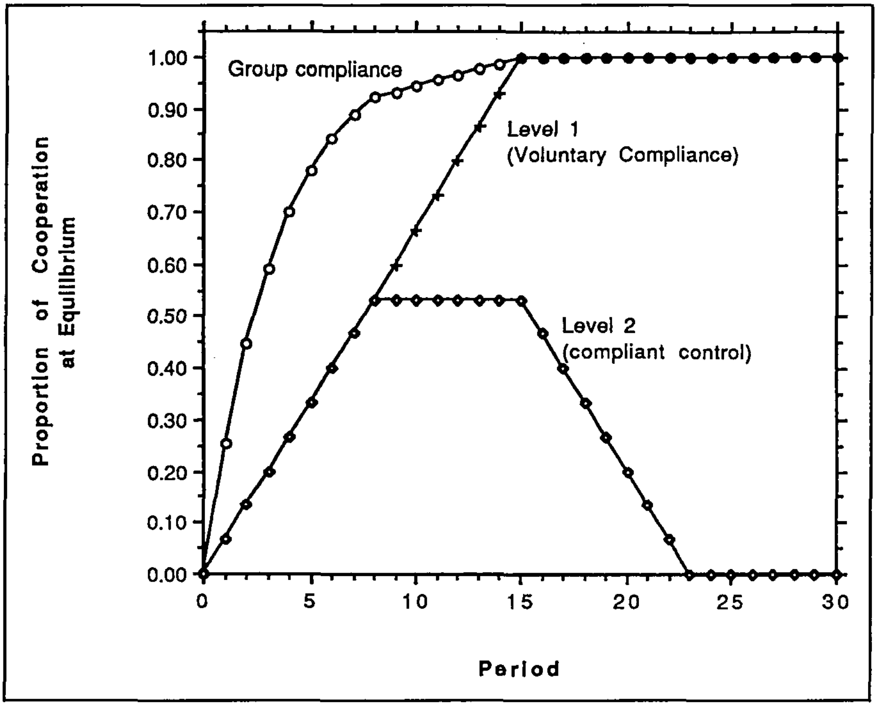

Figure 6. Group in which the members are privileged.
(Note: PB and CG_{nj} are zero, $CG_j = 310$, K1 = 20, K2 and K3 = 5,
E2 and E3 = 0.2, E = 1, N = 15.)

indicates that the permanent use of inter-member influence, as characterized in the model presented here, can result in the production of collective good, with corresponding benefit for individuals, in groups made up of non-privileged individuals.

In Figure 6, CG_j is 310 units. Thus, each member is privileged. However, the first eight actors choose full cooperation rather than private cooperation, where full cooperation is defined as cooperation at levels 1 and 2 and defection at level 3 and private cooperation is defined as compliance at level 1 and defection at levels 2 and 3. By cooperating at the second level, actors reduce the opportunity for others to defect at level one, thus increasing the amount of collective good generated. This strategy is wise as long as the cost of second level compliance is less than the additional benefit produced.

The additional reduction in the opportunity to defect at level 1 caused by successive ego's second level cooperation decreases as more actors join this strategy. This is shown in Figure 7, in which the opportunity to defect at level 1 is plotted verses the number of individuals cooperating at level 2. As the number of actors cooperating at level 2 increases, the opportunity to defect decreases; however, the slope of the line also decreases, indicating that each additional ego complying at level 2 achieves a smaller reduction in the opportunity to defect at level 1. This is a natural consequence of the relationship used to model this, i.e., equation (1). The same will be true of the opportunity to comply at level 2, modeled using equation (2).

Another characteristic of the model also works against hypocritical cooperation as an equilibrium strategy in privileged groups. As more actors choose to voluntarily cooperate at the first level, the amount of collective good generated by second level cooperation decreases, because there are fewer actors susceptible to control. Second level cooperation produces collective goods only if first level defectors are present. Thus, as the number of actors complying at the first level increases, second level compliance becomes less advantageous, and at some point becomes uneconomic.

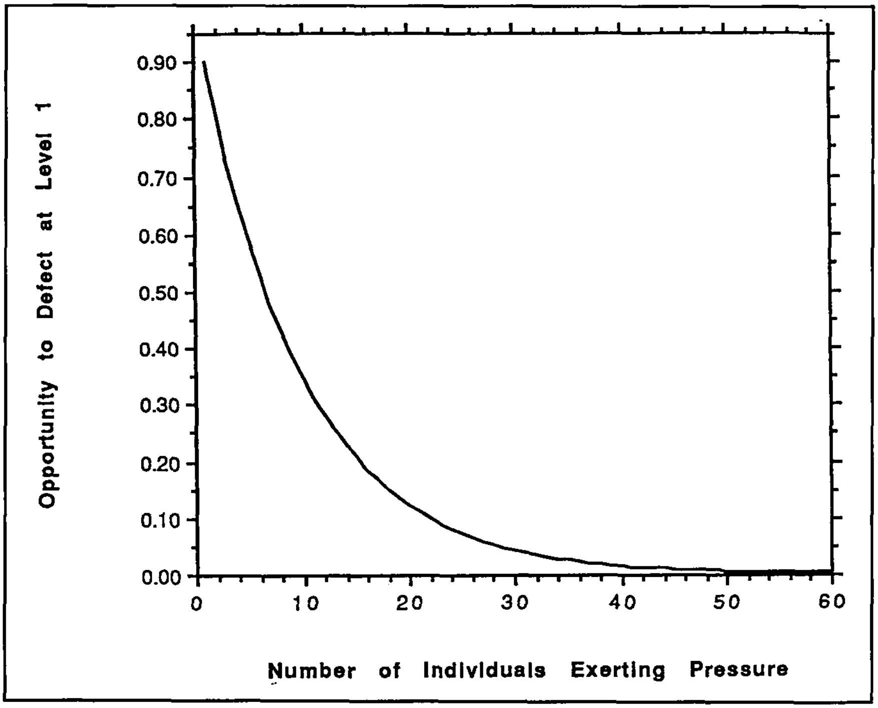

Figure 7. Opportunity to defect as a function of the number of individuals exerting pressure.
(Note: E2 = .1 and E = 1.)

The consequences of these two characteristics for the group shown in Figure 6 is that, after actors one through eight choose full cooperation, actors nine through fifteen choose private cooperation. When actors one through eight get the opportunity to change their earlier decisions, each one chooses private cooperation. This results in the equilibrium condition of 100 percent private cooperation, and, of course, 100 percent group compliance at level 1. Figure 6 indicates that inter-member influence may be used temporarily in groups consisting of privileged individuals, in order to "speed up" first level compliance.

Mimicking the Spaccarelli Effect

It will be interesting to determine whether the model can produce results similar to those observed in the field. It has already been demonstrated that the model can be used to mimic the Salimando effect. In this section, the model is used to mimic the *Spaccarelli effect.* Spaccarelli et al. examined the effect of written and verbal prompts on participation, at the block level, in a weekly newspaper only curbside collection program [59]. They observed blocks which differed by income level, the presence or absence of a block club for the purpose of block maintenance and safety, and the presence or absence on a block of a few (1-3) pre-intervention recyclers. The prompt only treatment consisted of two handbills handed to the resident or left in the door or mailbox. The handbills emphasized the ease and importance of newspaper recycling. In the prompt and verbal exchange treatment, a handbill was accompanied by a verbal prompt to begin recycling or to continue to do so. Treatments were applied so that comparisons could be made concerning income levels, block clubs, and pre-intervention recyclers.

The prompt alone was ineffective, only 2.4 percent of the non-recyclers began to recycle after receiving the prompt. The prompt and verbal exchange was more successful, and 22.1 percent of the non-recyclers began to recycle after receiving the prompt and verbal exchange. It was concluded that the personal nature of the prompt with verbal exchange led to its greater effectiveness. Effects did not appear to vary by income. There was, however, a very interesting interaction between block clubs and pre-intervention recyclers. As expected, interventions were most effective on blocks with block clubs and pre-intervention recyclers. However, interventions were least effective on blocks with block clubs and without pre-recyclers. They suggest that

> persons confronted by social pressure tend to determine whether or not the behavior being promoted is approved of as endorsed by an appropriate group of peers, and that for visible behavior such as curbside recycling, one's neighbors would be an appropriate peer group to examine [59, p. 55].

Thus block clubs may have facilitated observation of or conversational interaction with neighbors. On blocks with pre-intervention recyclers this may have promoted the view that recycling was normal, acceptable, or worthwhile. On block without pre-intervention recyclers, this may have promoted the view that recycling was not normal, acceptable, or worthwhile.

An explanation in accordance with the model presented here involves the assumption that E2 and E3, measures of the ability of group members to control level 1 and 2 behavior, respectively, are higher for groups with block clubs, compared to groups without block clubs. Furthermore, in groups with block clubs, the presence of a recycler results in level 2 compliance, while the absence of a recycler results in level 3 compliance. In order to explore this possible explanation, equilibrium conditions over a range of E2 and E3 values are shown in Figures 8 and 9, for two similar groups different only in the cost of level 1 compliance.

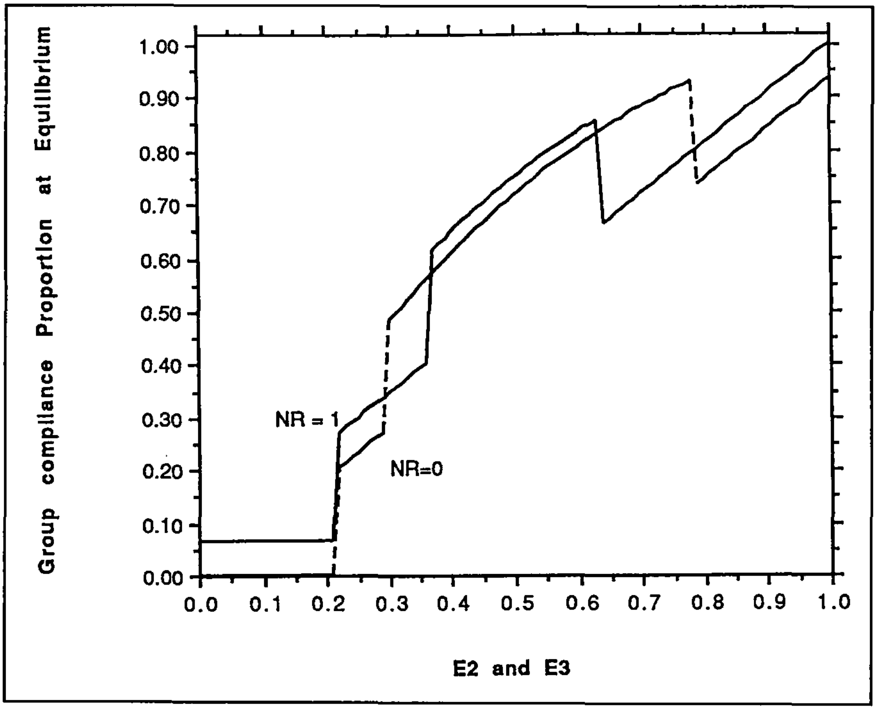

Figure 8. Effect of voluntary level 1 compliers when cost of level 1 compliance is 100 units.
(Note: CG_j = 100, CG_{nj} = 0, PB = 20 for recyclers and 0 for non-recyclers, K1 = 20 for recyclers and 100 for non-recyclers, K2 = 20, K3 = 10, E = 1, and N = 15. NR = number of privileged individuals in group.)

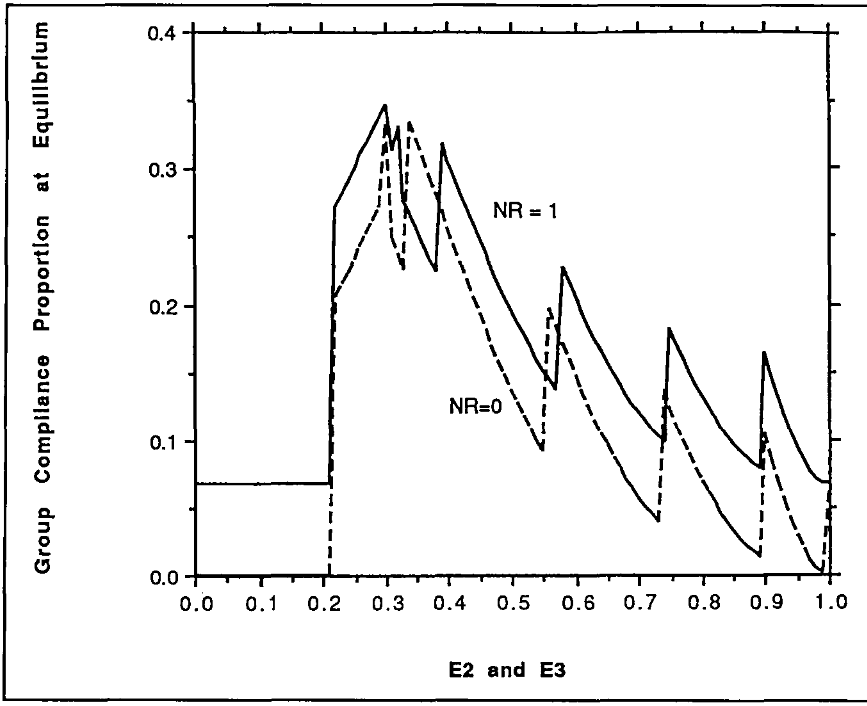

Figure 9. Effect of voluntary level 1 compliers when cost of level 1 compliance is 200 units.
(**Note:** $CG_j = 100$, $CG_{nj} = 0$, PB = 20 for recyclers and 0 for non-recyclers, K1 = 20 for recyclers and 200 for non-recyclers, K2 = 20, K3 = 10, E = 1, and N = 15.
NR = number of privileged individuals in group.)

In each Figure two lines are shown, a dashed line representing the theoretical behavior of a group with no privileged individuals, and a solid line representing the theoretical behavior of a group with one privileged individual. Privileged individuals are used to represent pre-recyclers. These individuals will recycle whether or not any group interaction occurs. In each Figure, higher values of E2 and E3 can be interpreted to represent groups with block clubs, while lower values represent groups without block clubs. The values of E2 and E3 are assumed identical in the Figures; however, this has been done only to simplify the analysis, and is not meant to imply that E2 and E3 are expected to be the same.

The members of the group used to create Figure 8 perceive the cost of level 1 compliance to be 100 units. This is identical to the total collective good with jointness of supply, CG_j, produced when the entire group participates at the first level. Thus, even if the entire group participates, no individual will receive a positive benefit. However, the relationships presented in the Figure indicate that for each group level one compliance generally increases as E2 and E3 increase. Not shown in the Figure is compliance at levels 2 and 3. Regardless of the presence or absence of recyclers, no level 3 compliance is observed. However, between zero and two members participate at the second level, depending on the value of E2 and E3, resulting in the levels of level 1 compliance observed in the Figure.

The lack of level 3 compliance indicates that the cost of such compliance exceeds the saving that would result from reducing the opportunity of others to comply at the second level. This indicates that for values of K1 less than 100, level 3 compliance will not be chosen. In fact, this will also be true for some values higher than 100 units. For example, if E2 and E3 equal 0.4, there will be no level 3 compliance at equilibrium until K1 reaches 143 units or higher, in groups without pre-recyclers. For any values of K1 that do not result in level 3 compliance, the shape of the relationship between group compliance and the value of E2 and E3 will be similar to that indicated in Figure 8.

Discontinuities in the Figure are the natural result of the discontinuous nature of the model system, where egos make discrete binary decisions to comply or defect at any of three levels. Each discontinuity represents a point at which ego changed behavior.

At least two important points are demonstrated by Figure 8. First, it does not match the Spaccarelli effect, i.e., the presence or absence of privileged individuals has little effect on group compliance. Second, the group compliance level tends to increase with E2 and E3. However, small changes in E2 and E3 can result in a change in one actor's level 2 behavior, which can cause relatively large changes in group compliance.

The members of the group used to create Figure 9 perceive the cost of level 1 compliance to be 200 units. This is twice the total collective good with jointness of supply, CG_j, produced when the entire group participates at the first level. Examination of the Figure indicates that the group compliance proportion tends to decrease as the value of E2 and E3 increases. Not shown in the Figure is the significant proportion of group members complying at the second and third levels over a wide range of E2 and E3 values.

A CG_j value of 200 ensures that no group member will ever receive positive personal benefit from participation. However, the cost of level 2 compliance is low enough that group members can receive benefit from forcing other members to comply at level 1. The cost of level 3 compliance is low enough that these members, responding to the reduction of their opportunity to defect at level 1, comply at the third level. As both E2 and E3 increase, level 3 compliance reduces the opportunity to comply at level 2 enough that the opportunity to defect at level 1 is increased. However, just as with Figure 8, the presence or absence of privileged individuals has little effect of the general trend of the relationship.

The results presented in Figures 8 and 9 indicate that the model as presented cannot reproduce the Spaccarelli effect. However, inspection of the model and Figures suggests a simple modification that will allow this to take place. If it is assumed that members who have actually recycled, i.e., voluntarily complied at the first level, have the ability to change the perceptions of non-recyclers, then it is reasonable to modify the model so that whenever a recycler complies at level 2 the perception of non-recyclers concerning level 1 compliance cost is reduced. In Figures 10, 11, and 12, various relationships are presented for a group where K1 drops from 200 to 100 when a recycler complies at the second level.

The Spaccarelli effect is demonstrated in Figure 10. Groups without block clubs are represented by a range of E2 and E3 values from about 0.2 to 0.35 and

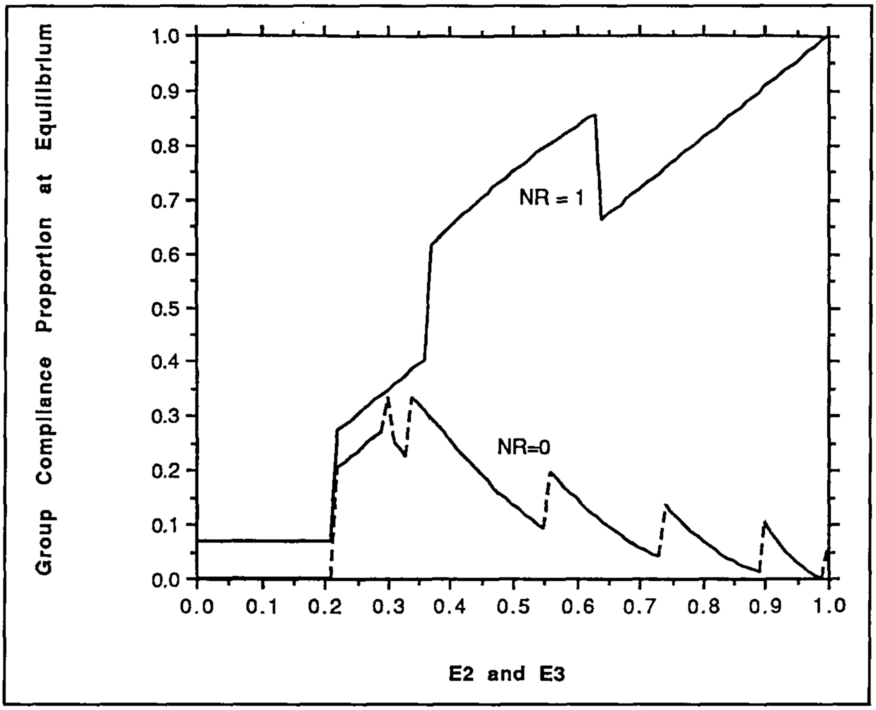

Figure 10. Effect of voluntary level 1 compliers when cost of level 1 compliance depends on influence by a level 1 voluntary complier. (**Note:** $CG_j = 100$, $CG_{nj} = 0$, PB = 20 for recyclers and 0 for non-recyclers, K1 = 20 for recyclers and 200 and 100 units for non-recyclers not influence or influenced by a recycler, respectively, K2 = 20, K3 = 10, E = 1, and N = 15. NR = number of privileged individuals in group.)

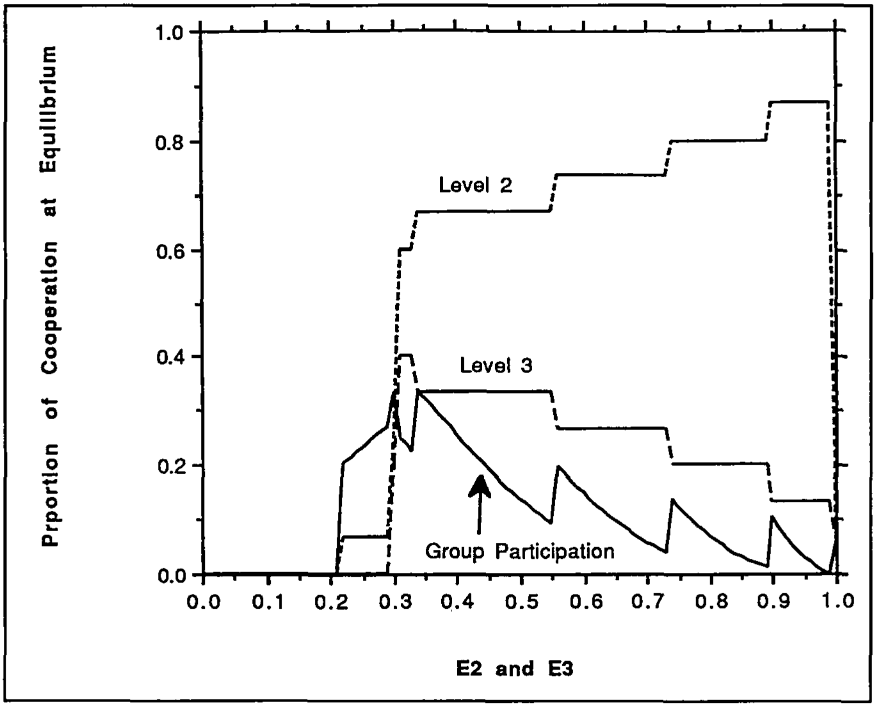

Figure 11. Levels 1, 2, and 3 compliance when cost of level 1 compliance depends on influence by a level 1 voluntary complier: no pre-recyclers. (**Note:** $CG_j = 100$, $CG_{nj} = 0$, PB = 20 for recyclers and 0 for non-recyclers, K1 = 20 for recyclers and 200 and 100 units for non-recyclers not influence or influenced by a recycler, respectively, K2 = 20, K3 = 10, E = 1, and N = 15.)

groups with block clubs are represented by values above 0.35. Group compliance increases the most for groups with privileged individuals and block clubs. Group compliance increases the least for groups without privileged individuals, but with block clubs. Intermediate increases are shown for the other two possible combinations.

Figures 11 and 12 are presented in order to show how level 2 and 3 compliance produce the Spaccarelli effect. In Figure 11, results for a group without privileged individuals are presented. No member of the group voluntarily recycles. Between E2 and E3 values from 0.22 to 0.29, one member complies at level two, producing corresponding compliance levels. At 0.31, level 2 compliance is 60 percent and level 3 compliance 40 percent. Thus the equilibrium condition at E2 and E3

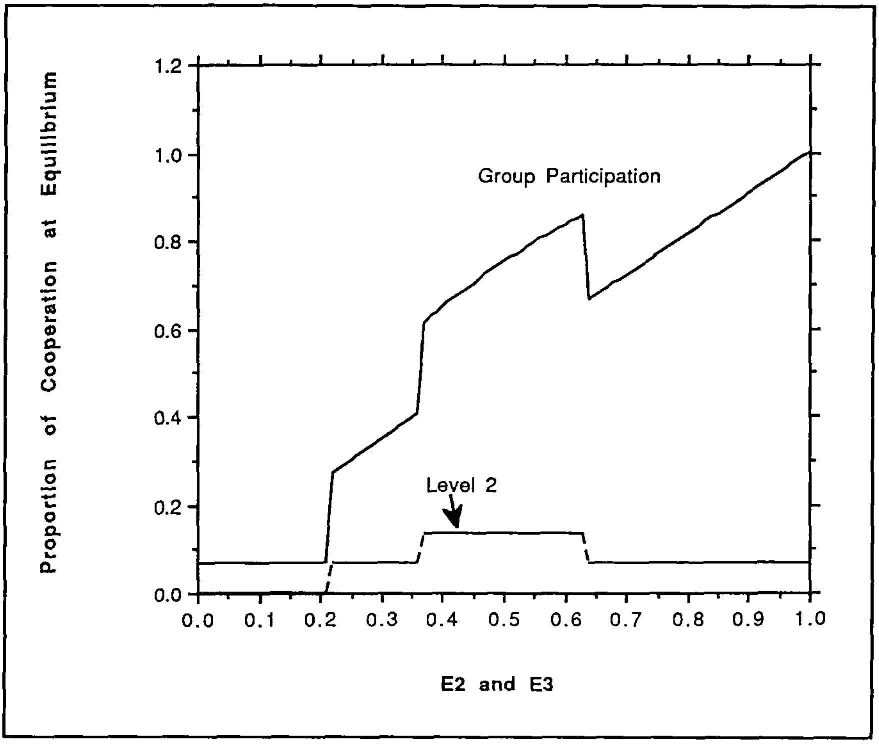

Figure 12. Levels 1, 2, and 3 compliance when cost of level 1 compliance depends on influence by a level 1 voluntary complier: pre-recyclers. (**Note:** $CG_j = 100$, $CG_{nj} = 0$, PB = 20 for recyclers and 0 for non-recyclers, K1 = 20 for recyclers and 200 and 100 units for non-recyclers not influence or influenced by a recycler, respectively, K2 = 20, K3 = 10, E = 1, and N = 15.)

equal to 0.31 is 60 percent hypocritical cooperation and 40 percent full opposition, where full opposition is defined as defect at levels 1 and 2 and compliance at level 3. As E2 and E3 increase to 0.99, level 2 compliance increases and level 3 compliance decrease, both in stages. However, from 0.31 to 0.99, each member of the group is involved in either hypocritical cooperation or full opposition. The reduction in opportunity to comply at the second level, caused by third level compliance, results in reduced group compliance. Given a constant distribution of hypocritical cooperators and full defectors, increasing E2 and E3 equal amounts will result in a decrease in group compliance. When E2 and E3 are 1.0, one member of the group chooses hypocritical cooperation, another chooses full opposition, while the rest choose full defection.

In Figure 12, results for a group with privileged individuals are presented. No member complies at the first or third level. Over a range of E2 and E3 values from 0.22 to 1.0 the privileged individual complies at the second level, which amounts to full cooperation. From 0.37 and 0.63 one member of the group is a hypocritical cooperator. This level of activity is sufficient to produce relatively high levels of group compliance. Because the pre-recycler choose to comply at the second level, the perception of other members of the group drops from 200 to 100 units. At 100 units, it is not personally beneficial for any member to comply at the third level.

The simple modification of the model presented above provides privileged individuals the ability to influence the cost perceptions of non-privileged individuals, and allows the model to produce results that are in agreement with the Spaccarelli effect. However, this does not mean that other modifications cannot produce the same effect. For example, it might be possible to produce similar results by giving recyclers the ability to change the benefit perceptions of non-recyclers, or to assign recyclers higher values of E2.

CONCLUSIONS

In this article, literature concerning residential recycling programs was presented, resulting in the identification of five factors which appear to effect participation behavior. These factors are market, coercive, convenience, and promotion strategies, and attitudes, beliefs, and demographics. The first four factors can be directly controlled by residential recycling programs. The latter factor, though amenable to some influence, is largely a function of the specific population served by a given program. Information gathered from the literature indicates that each of these factors influences participation behavior.

A group-mediated social control model, similar to models introduced by Heckathorn [1-3] was developed and presented. The model simulates the iterative decision choices of individuals in a group with an opportunity to participate in an action. In turn, each actor becomes ego and chooses his or her behavior at three different levels, based on the payoffs resulting from these choices and the current behavior of the other actors. Ego chooses the combination of behaviors that generates the largest personal gain. After the model has iterated through the entire group several times, an equilibrium is reached, after which no actor changes behavior upon becoming ego.

At the first level, ego can choose to participate or not participate in a collection action. *First level compliance* produces individual and group benefit, but also involves costs to ego. *Second level compliance* involves ego exerting control in order to reduce the opportunity of other actors to defect at the first level. By doing this, ego ensures that more of the collective benefit is produced. However, second level compliance also entails personal cost. Finally, *third level compliance* involves ego exerting control to reduce the opportunity of other actors to comply at the second level. By doing this, ego increases his or her opportunity to defect at level 1 and thus avoid level 1 costs. However, level three compliance also involves personal cost.

The model was used to simulate a number of scenarios, including: groups that produce only personal benefits, groups that produce collective goods but with no social interaction, and groups that produce collective goods with social interaction. Group heterogeneity is found to be necessary in most cases to obtain reasonable results. For example, this was shown to be true for groups that produce only personal benefits. Heterogeneity is produced by assigning group members different characteristics, which in turn can be accomplished using constant or random variables.

The model was used to simulate the behavior of individuals in groups that produce collective goods without social interaction. Important factors for such groups include: the number of privileged individuals, the way the collective goods are produced, the types of collective good (with or without jointness of supply), and the way individuals assess their payoff (individual or group assessment rationale). The model was used to simulate the Salimando effect. Salimando observed that, in residential neighborhoods where residents were given official recycling containers, as soon as a significant percentage of households started setting out material in these containers, a large percentage of the remaining houses suddenly joined in setting out material [66]. The model simulated this effect using a heterogeneous group with individuals following a group assessment rationale. Non-privileged individuals following a group assessment rationale were obtained to begin recycling once a sufficient number of privileged group members began recycling.

The model was also used to simulate groups producing collective goods with group interaction. It was demonstrated that level 2 compliance can be used to create level 1 compliance in groups without privileged members, or to encourage early level 1 compliance in groups composed of privileged individuals. The model was also used to simulate the Spaccarelli effect.

Spaccarelli et al., studying a curbside recycling program, found that on residential blocks with block clubs but no recyclers, a personal prompt to recycle resulted in a smaller increase in recycling than the same prompt administered in blocks with no block club but a few recyclers [59]. The largest increase occurred on blocks with clubs and recyclers. The results from the Spaccarelli study indicate that social pressure can work for or against activities such as recycling. By introducing heterogeneity (privileged and non-privileged members) and by allowing recyclers to reduce the level 1 cost perceptions of non-recyclers, the model was able to simulate the Spaccarelli effect.

Future research can involve further modifications of the model, to create a model able to simulate participation in specific residential recycling programs. The participation behavior of a large number of individuals in a newly instigated residential recycling program could be observed. The individuals could also be questioned regarding their social networks, and attitudes and beliefs concerning recycling. A model could be developed that describes the observed behavior, based on questionnaire results. Such a model would most likely involve very heterogeneous groups, much more heterogeneous than the groups used in this article.

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