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Voluntary Contributions to Property Rights*

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Abstract

This paper reports the results of an experimental test of the Nash equilibrium prediction of voluntary provision of property rights in a contest under anarchy. Specifically, the experiment investigates whether pre-commitment induces positive provision of property rights. As predicted, zero contributions to property rights are observed without pre-commitment. Positive voluntary contributions are observed with pre-commitment, but are less than predicted. Nonetheless, as predicted, stronger property rights with pre-commitment results in less conflict and more production. The experiment also tests predictions for group-size effects. While average contributions to property rights are unaffected by group-size, mean conflict increases and mean production decreases with larger groups.

Keywords: Property Rights; Conflict; Public Goods; Experiments

JEL Classifications: C72; C91; F35; O12; O43; P48

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1 The Introduction

Property rights are essential to the ability of a market economy to allocate resources efficiently. In fact, Coase (1960) postulated that when combined with zero transaction costs, well-defined property rights are all that is necessary for efficient resource allocation. In the absence of property rights, the economy is left in a state of anarchy where agents divert resources away from productive activities in order to secure claims to production (Tullock, 1967; Bush and Mayer, 1974; Tullock, 1972; Hirshleifer, 1978; Tullock, 1985; Hirshleifer, 1991b,a, 1995).[1] Since such conflict simply redistributes what has already been produced, agents have an incentive to minimize this sort of wasteful use of resources from the economy (Demsetz, 1964, 1967; Buchanan, 1975). While property rights serve this purpose, as a public good, property rights provision is likely to suffer from free-riding. It is possible to overcome the free-riding problem, however, if agents can pre-commit to provision of property rights. Allowing agents to contribute to property rights prior to production and conflict creates a strategic incentive that should encourage positive provision. Establishing property rights prior to allocating the remainder of their resources, allows agents to credibly commit to engage in less conflict. This, in turn, increases the amount of resources available for production. Still it remains an empirical question as to whether pre-commitment actually induces people to voluntarily contribute to property rights under anarchy?

To answer this question, a laboratory experiment was designed to test

[1]The problem of appropriation, which represents a transaction cost, is one of the most prominent disincentives to investment discussed in the literature (Alchian and Demsetz, 1973; North, 1987; Murphy et al., 1993; Hall and Jones, 1999; Easterly, 2001; Alesina and Weder, 2002). Recent growth models demonstrate how appropriation through socially costly conflict hinders economic development (Gradstein, 2004; Gonzalez, 2007; Gradstein, 2007; Gonzalez and Neary, 2008). This research is part of a larger literature on economic conflict (Haavelmo, 1954; Garfinkel, 1990; Grossman, 1991, 1994; Grossman and Kim, 1995; Skaperdas, 1992a, 1996). We use the term conflict for the remainder of the paper to be defined as any unproductive rent-seeking activity. Hence, conflict encompasses both appropriation and expropriation.

the predictions of a game-theoretic model of endogenous property rights provision when production occurs under anarchy. Boyce and Bruner (2012) consider a game where identical agents each possess a private endowment which they may allocate between: (*i*) production, which increases potential consumption, but is insecure (*ii*) private conflict, which contests insecure property (*iii*) public property rights, which increases the security of production, or (*iv*) simply consuming one's endowment. Consumption of the endowment earns a zero rate of return, but is secure.[2] While resources allocated to productive activities earn a positive rate of return, production is insecure under anarchy. Hence, agents have an incentive to divert resources away from socially productive activities to appropriate production. There are two means by which appropriation can occur. One one hand, agents can engage in costly conflict, which increases the share of total production an agent receives. On the other hand, agents may contribute to the provision of property rights, which increases the security of all production by making conflict a less effective instrument of redistribution. Hence, contributions to property rights increase the share or their own production an agent receives, while decreasing the share of other agents' production they expropriate for themselves.

The experiment is designed to compare the provision of property rights in two games: (i) with pre-commitment, property rights are chosen prior to production and conflict, and (ii) without pre-commitment, property rights are chosen simultaneously with production and conflict. Theoretically, agents should not voluntarily contribute to the provision of property rights absent the ability to pre-commit, as engaging in conflict strictly dominates contributions to property rights since both increase the proportion of one's own production appropriated, but engaging in conflict increases the proportion of other's production one expropriates, while contributions to property

[2]While both the model and experiment allow for consumption, the data support the equilibrium prediction of zero in all treatments. Hence, discussion of allocations to consumption is suppressed for the remainder of the paper.

rights reduces one's expropriation of other's production. When agents can pre-commit to the provision of property rights, however, a strategic effect arises. Each agent's contribution to property rights in the first stage reduces *all* agents' incentive to engage in conflict in the subsequent stage. Provision of property rights in the first stage, allows an agent to credibly commit to engage in less conflict in the second stage, and in equilibrium all agents respond by engaging in less conflict. Hence, rather than simply substituting one transaction cost for another, property rights can reduce subsequent conflict by more than the cost of provision, which increases the resources available for production. Thus, pre-commitment can theoretically induce voluntary contributions to property rights, which results in an increase in the welfare of all agents relative to the no-pre-commitment equilibrium.

As the number of agents increases, however, the strategic effect of property rights provision diminishes, as the ability to influence other agents' behavior is diluted. Furthermore, as a public good, the incentive to free-ride on other agents' contributions increases as the number of agents increases. Moreover, as the number of agents increases, the incentive to plunder other agents' production through conflict increases, thereby reducing allocations to production. Thus, as the number of agents grows, each expends more resources fighting over their dwindling production. To explore the validity of these theoretical predictions, the experiment implements both 2-player and 4-player groups in games with and without pre-commitment. The result is a 2×2 experimental design where 1-stage and 2-stage games are played in 2-player and 4-player groups.[3]

The positive analysis of the experiment serves to compliment the normative approach of the theoretical literature (Friedman, 1953). Experimental methods can be used to gain insights that are not possible with naturally-occurring data, serving as a compliment to traditional empirical studies. Im-

[3]Technically, a $2 \times 2 \times 2$ design was used to control for possible order-effects associated with variation of group-sizes. A detailed discussion of the experimental design is provided in section 3.

portant contributions include Anderson and Hill (1975), who observed that grazing rights evolved informally in the American west, Umbeck (1977a,b), who noted that miners in the California gold rush devised and enforced their own rules for protecting their mining claims, Libecap and Wiggins (1985a,b), who discuss the use of oil field unitization in the U.S. to mitigate rent-dissipation, Acheson (1988), who described the formation of lobster gangs in Maine to enforce fishery rights, Ostrom (1990), who provides examples in which secure claims to property arose in Swiss alpine meadows, Spanish irrigation canals, and Japanese forests, Ellickson (2009), who observed ranchers in California that voluntarily build and maintain border fencing, and Kaffine (2008), who discusses how surf gangs in California establish property rights over the best waves. While there are valuable insights to be gained from each of these studies, they are primarily anecdotal in nature. Hence, the empirical evidence does not provide a direct test of theoretical predictions from a well-specified model. In general, empirical studies such as these suffer from an inability to observe individuals' endogenous contributions to property rights, conflict, and production, nor are important parameters such as wealth endowments and productivity of investments readily observable. Furthermore, there is considerable uncertainty regarding the effectiveness of property rights and the resulting form of the contest success function. This lack of observability has motivated researchers to employ experimental methods to study the dynamics of property rights, conflict, and production.

The present study extends a growing literature of experimental research on property rights and conflict by exploring endogenous property rights formation through a voluntary contribution mechanism.[4] While it is true that *effective* property rights, or *de facto* property rights, are always endogenously determined by allocations to conflict, the present study examines the endogenous provision of formal property rights. Durham et al. (1998)

[4]A related area of research studies rent-seeking games based on Tullock (1980). See Shogren and Baik (1991) for experimental evidence on these games. Another related strand of literature explores the effect of implicit property rights established through earned income (Fahr and Irlenbusch, 2000; Oxoby and Spraggon, 2008).

were the first to conduct an experimental investigation into the mechanics of conflict, implementing property rights implicitly through an exogenous parameter. Similarly, Carter and Anderton (2001) and Bruner and Oxoby (2012) also incorporate property rights through an exogenous parameter in the contest success function. Duffy and Kim (2005) allow a 'king' to provide property protection in exchange for the right to tax players, eliminating the collective action problem associated with voluntary provision. Recent studies by Kimbrough et al. (2008, 2010); Jaworsk and Wilson (2012); Powell and Wilson (2008); Wilson et al. (2012) investigate whether property rights can evolve endogenously through informal mechanisms, such as non-binding social contracts and norms. Additionally, Smith et al. (2012) investigate how voluntary alliances, which provide property rights and pool resources, influence wasteful conflict. In contrast, the present study considers the case where groups are exogenously imposed but provision of property rights is voluntary.

In general, the present findings support most of the theoretical predictions. Subjects in the experiment are able to establish property rights out of anarchy. Average contributions to property rights, which are statistically equivalent to zero without pre-commitment, increase significantly with pre-commitment. Consequently, average allocations to conflict decrease and average production increases in response to the provision of property rights in these treatments. As is typical in public goods experiments (see the surveys in Ledyard, 1995; Andreoni and Croson, 2008; Laury and Holt, 2008), however, voluntary contributions deteriorate over time. Also consistent with previous experimental results in public goods games (Isaac and Walker, 1988), variation in group-size has essentially no effect on contributions to property rights. Still, average conflict is significantly higher and average production is significantly lower when group-sizes are larger.

The remainder of the paper is organized as follows. Section 2 briefly summarizes a model of conflict from which we motivate our hypotheses.

Section 3 describes the experimental design and procedures. In section 4 we present the results from our analysis of subject choices. Finally, we discuss the results in section 5.

2 The Model

Following Boyce and Bruner (2012), consider a game of conflict in which the security of property is a public good. There are N players, indexed $i = 1, \ldots, N$. Each player has an endowment of ω units. There are four different goods that the endowment may be used to produce. First, the endowment may be consumed directly, yielding one unit of payoff for each unit of consumption. Second, the endowment can be invested to produce a consumable good. An investment of k_i units of endowment into production produces Ak_i units of payoff. The security of property is an issue because production from the investment is easily stolen. Direct consumption of the endowment, however, cannot be stolen. Thus, $A > 1$ is necessary for either conflict or property rights to arise. While conflict begins at this lower bound on A, higher levels of productivity are required for property rights to arise since property rights protection is itself socially costly.

A player may also use his endowment to produce two goods that affect the security of property. The tool of conflict, x_i, is the amount of endowment utilized protecting one's own property and expropriating the property of others. An increase in x_i increases the share of i's own production that i appropriates and it increases the share of the other players' production that i expropriates. Players may also privately provide the public good of property rights protection, y_i.[5] An increase in the public good of property rights increases the share of player i's own production that i appropriates but it reduces the share of other players' production that i expropriates.

[5]We include in property rights protection all aspects of security of property rights including prevention, enforcement, dispute resolution, and sanctions.

Public security is the sum of individual contributions to property rights, $Y \equiv \sum_{i=1}^{N} y_i$.

The 'contest success function' (Skaperdas, 1992b) is based on the rent-seeking model of Tullock (1980). The proportion of player i's production that player i appropriates is given by

$$p_{ii} = \frac{Y + x_i}{Y + X}, \tag{1}$$

where $X \equiv \sum_{i=1}^{N} x_i$, and the proportion of player j's production that player i expropriates is

$$p_{ij} = \frac{x_i}{Y + X}. \tag{2}$$

The proportion of i's production that i appropriates is increasing in x_i and Y, and decreasing in $X_{-i} \equiv X - x_i$. The proportion i expropriates from others is increasing in x_i and decreasing in X_{-i} and Y.[6]

Each player's payoff is the sum of what she appropriates from her own production and what she expropriates from the production of the others, plus her direct consumption:

$$u_i = p_{ii} A k_i + \sum_{j \neq i}^{N} p_{ij} A k_j + c_i. \tag{3}$$

Each player maximizes their payoff by choosing how to allocate their endowment, ω, across the four possible choices: production, property rights, conflict, and consumption:

$$\omega = k_i - y_i - x_i - c_i. \tag{4}$$

[6]Since production is either appropriated or expropriated, the logit condition Dixit (1987) must hold: $p_{ii} + \sum_{j \neq i}^{N} p_{ji} = 1$.

2.1 No Pre-Commitment

If pre-commitment is not possible, each player chooses their allocation to property rights, production, and investment simultaneously. Each unit of the endowment allocated to any of production, conflict, or property rights has an opportunity cost of foregone consumption. The marginal benefit from an increase in production is the *effective* rate of return, or appropriated rate of return Ap_{ii}. The marginal benefit from an increase in conflict is the increase in the share of player i's own production that player i gets to appropriate, p_{ii}, plus the increase in the share of the other players' production that player i gets to expropriate, p_{ij}. The marginal benefit from an increase in security is the increase in the share, p_{ii}, that player i appropriates from his own investment in production. This comes at an additional marginal cost from the reduction in the share of the other players' production that player i gets to expropriate, p_{ij}. Therefore, an increase in player i's expenditures on conflict increases both her appropriation and expropriation shares, while an increase in expenditures on property rights increases her appropriation share, but decreases her expropriation share. This asymmetry implies that provision to property rights is strictly dominated by expenditures on conflict so that in the symmetric Nash equilibrium to the conflict game, each individual contributes zero to the public good of property rights protection. It is shown in the appendix when $A > N$, the symmetric Nash equilibrium (NE) is characterized by:

$$y^{NE} = 0, \qquad x^{NE} = \frac{\omega(N-1)}{N}, \qquad \text{and} \qquad k^{NE} = \frac{\omega}{N}. \tag{5}$$

Thus, players do not voluntarily contribute to the public good of property rights in the symmetric Nash equilibrium. Due to their complimentary nature, equilibrium conflict and production are both positive in the no-pre-commitment Nash equilibrium. Hence, property is less than perfectly secure. As the number of players N rises, each devotes ever increasing amounts of

their endowment to conflict, resulting in less production.

2.2 Pre-Commitment

The possibility to pre-commit to provision of property rights can be modeled as a two-stage game. In the first stage, each player voluntarily contributes an irreversible allocation of y_i from their endowment for the provision of property rights. After the strength of property rights, Y, has been realized, each player allocates her remaining endowment between conflict and production in the second stage. It is shown in the appendix when $A \geq \frac{N+1}{2}$, the subgame perfect Nash equilibrium (SP) satisfies

$$x^{SP} = \frac{\omega(N-2)}{N+1}, \qquad y^{SP} = \frac{\omega}{N+1}, \qquad \text{and} \qquad k^{SP} = \frac{2\omega}{N+1}. \tag{6}$$

Thus, unlike the Nash equilibrium in which no property rights are provided, in the subgame perfect Nash equilibrium, there is positive voluntary provision of property rights. This occurs because there is a strategic effect of reduced subsequent conflict by all players when property rights are strengthened. It is this effect that is absent in the Nash equilibrium. When $N = 2$, conflict is completely eliminated by pre-committing to the provision of property rights. Furthermore, when $N = 2$, total expenditures on property rights are less than the Nash equilibrium expenditures on conflict, which means that production is higher. However, for $N > 2$, conflict is not fully eliminated by pre-commitment. This occurs because as the number of players N grows, the effect any player can have upon influencing the behavior of the balance of the population diminishes.

3 The Experiment

3.1 Design

The primary purpose of the experiment is to investigate whether people will voluntarily contribute to strengthening property rights given the opportunity to pre-commit to provision, as predicted by the theory. Hence, the experiment compares allocation decisions in games where players had to pre-commit to the provision of property rights to those where pre-commitment was not possible. In all games, subjects chose how they would like to allocate an endowment across property rights, conflict and production. Subjects played either a 1-stage game (without pre-commitment) or a 2-stage game (with pre-commitment) throughout an experimental session (i.e., pre-commitment was varied between-subjects). In the 1-stage game, all subjects made all their allocation decisions simultaneously. In the 2-stage game, subjects chose their voluntary contributions to property rights in the first stage and made the remaining allocation decisions in the second stage, after observing the strength of property rights. Since zero provision of property rights is predicted in games without pre-commitment, the 1-stage game serves to establish baseline allocations to property rights, production, and conflict. The main research question is whether the 2-stage game produces significantly greater contributions to property rights, as well as less conflict with more production?

The experiment also explores the theoretically predicted effects group-size has on the strength of property rights, if provided, and the associated allocations to conflict and production. To test the predictions for group-size, the experiment had subjects play in groups of 2-players and 4-players. All subjects were exposed to both group-sizes (i.e., group-size was varied within-subjects). Specifically, each subject participated in 20 decision rounds, 10 consecutive rounds of each group-size.[7] Group members remained anony-

[7]Due to an error in the software, some sessions changed group-sizes after round 9 or

mous throughout an experimental session and were randomly re-assigned after each round to eliminate any association effects, such as reputation and/or reciprocity. Furthermore, the order of group-sizes was varied across sessions to remove any potentially confounding order effects. The purpose is to explore whether larger group-sizes result in lower contributions to property rights, more conflict and lower production?

3.2 Protocol

Upon entering the lab, subjects were seated at individual computer stations. Prior to making any decisions, subjects were presented with instructions on the computer screen which they proceeded through as the moderator read aloud to ensure common knowledge.[8] Subjects were informed that they were being provided with a $10 endowment, which they could allocate across property rights, conflict, and production.[9] Subjects were informed the decision task would be repeated for 20 rounds. In each round, subjects were told they were randomly assigned to anonymous groups of either 2- or 4-players. Group-sizes only changed after 10 rounds from 2- to 4-players or from 4- to 2-players, to control for possible order effects. In a given session, subjects were assigned to either a 1-stage or a 2-stage game, which they played throughout the session. In each decision round of the 2-stage game, subjects first chose how much of their $10 endowment they would like to voluntarily contribute to property rights for their group. After all contributions were chosen and the strength of property rights revealed, subjects then allocated the remainder of their $10 endowment between production and conflict. In the 1-stage game, subjects allocated their $10 endowment across property rights, production, and conflict, simultaneously. In both

11.

[8] Instructions and screen images are available upon request.

[9] In the experiment, property rights were referred to as group 'security', production was called an 'investment', and conflict was referred to as 'appropriation'. Subjects retained any unallocated portion of their endowment as 'savings'.

games, each dollar allocated to production returned \$5, but was insecure. Allocations made to conflict and property rights redistributed production according to equations (1) and (2), which subjects were informed of on the screen where they made their decisions and when presented with the results of the round.[10] Each allocation was restricted to be dollar shares of the \$10 endowment.[11] In order to reduce the cognitive burden of the allocation choice, the decision screen allowed subjects to enter their conjecture of their group members' allocations, in addition to their own allocation. Based on their entries, subjects were shown both their own and their group members' hypothetical earnings for the round. This permitted subjects to explore 'what-if' scenarios before making their final decision. Subjects had three minutes to make their allocation decisions.[12]

Upon completion of the decision round, subjects were shown a summary screen which displayed the allocations and earnings of all group members. In addition to summarizing earnings for the current round, the summary screen provided subjects with their history from previous rounds. In order to reinforce the one-shot nature of the model, subjects were informed that a single round would be randomly selected for payment at the end of the experimental session. Subjects were paid in private for their participation upon the completion of each session, which lasted approximately 90 minutes with average earnings of \$22 (including a \$5 was a show-up fee). The experiment was conducted in the University Laboratory with 56 subjects recruited via the laboratory's Online Recruitment System for Experimental Economics (Greiner, 2004). The experiment was programmed and conducted with the software Z-Tree (Fischbacher, 2007).

[10] The instructions explained how production was distributed according to equations (1) and (2) as well.

[11] The integer shares implementation of the game raised the possibility of multiple equilibria, some of which were asymmetric, but disappear when weakly dominated strategies were eliminated.

[12] In 2-stage games, subjects had ninety seconds in each stage to make a decision.

Table 1: Predicted Allocations by Experimental Treatment

Treatment {Stages , Group-Size}	Property Rights (y)	Conflict (x)	Production (k)
{ 1-Stage , 2-Players }	0	50	50
{ 1-Stage , 4-Players }	0	80	20
{ 2-Stage , 2-Players }	30	0	70
{ 2-Stage , 2-Players }	20	40	40

Notes: Predicted allocations are reported as a percentage of the endowment and are rounded to reflect the discrete nature of the decision space.

3.3 Hypotheses

The equilibrium predictions of allocations to property rights, conflict, and production are summarized in Table 1. There are two instances in which corner solutions are predicted. In 1-stage games, subjects should not allocate any of their endowment to property rights and in 2-player games with 2-stages, subjects should not engage in conflict. All other predictions, however, involve positive allocations. To test these predictions we write the allocation by subject i to account $j = \{k, x, y\}$, playing a game with $G = \{1, 2\}$ stages, in a group with $N = \{2, 4\}$ players, in order $o = \{2/4, 4/2\}$, in decision round $t = \{1, ..., 20\}$ as[13]

$$\text{Allocation}_j = \beta_0^{\text{j}} + \beta_{\text{G}}^{\text{j}}\text{D}_{\text{G}} + \beta_{\text{N}}^{\text{j}}\text{D}_{\text{N}} + \beta_{\text{GN}}^{\text{j}}\text{D}_{\text{G}}\text{D}_{\text{N}} + \beta_{\text{o}}^{\text{j}}\text{D}_{\text{o}} + \beta_{\text{t}}^{\text{j}}\text{T} + \epsilon_i. \quad (7)$$

where $\text{D}_{\text{G}} = 1$ if $G = 2$ and $\text{D}_{\text{G}} = 0$ otherwise; $\text{D}_{\text{N}} = 1$ if $N = 4$ and $\text{D}_{\text{N}} = 0$ otherwise; $\text{D}_{\text{o}} = 1$ if $o = 4/2$ and $\text{D}_{\text{o}} = 0$ otherwise; $\text{T} = t$ is a time trend; and ϵ_i is a robust error term clustered on each subject. The interaction term $\text{D}_{\text{G}}\text{D}_{\text{N}}$ captures any difference in the effect of group-size

[13]The order of group-sizes is indicated as "first/last".

across 1-stage and 2-stage games. Hence, the econometric model captures treatment effects using dummy variables for pre-commitment, group-size, and any interaction between the two with additional controls for the order group-sizes were varied and any time trends.

The qualitative hypotheses about the predicted allocations include the following:

Hypothesis 1.

(a) $\beta_G^y > 0$*: Contributions to property rights are higher in 2-stage games.*

(b) $\beta_N^y = 0$*: Contributions to property rights are unaffected by group-size in 1-stage games.*

(c) $\beta_{GN}^y < 0$ *Contributions to property rights are lower in 4-player group-sizes in 2-stage games.*

Hypothesis 2.

(a) $\beta_G^x < 0$*: Allocations to conflict are lower in 1-stage games.*

(b) $\beta_N^x > 0$*: Allocations to conflict are higher in 4-player group-sizes.*

(c) $\beta_G N^x > 0$*: Allocations to conflict increase more in 2-stage games than in 1-stage games when group-sizes increase.*

Hypothesis 3.

(a) $\beta_G^k > 0$*: Allocations to production are higher in 2-stage games.*

(b) $\beta_N^k < 0$*: Allocations to production are lower in 4-player group-sizes.*

(c) $\beta_G N^k = 0$*: Allocations to production decrease by the same amount in 1-stage and 2-stage games when group-sizes increase.*

Table 2: Mean Allocations as Percentage of Endowment by Treatment

Treatment {Stages , Group-Size}	Property Rights (y)	Conflict (x)	Production (k)
{ 1-Stage , 2-Players }	1.60	54.25	41.04
	(0.25)	(1.11)	(1.20)
{ 1-Stage , 4-Players }	2.05	63.18	28.36
	(0.27)	(1.08)	(1.04)
{ 2-Stage , 2-Players }	9.66	42.09	46.96
	(0.67)	(1.19)	(0.95)
{ 2-Stage , 4-Players }	11.48	47.31	38.90
	(0.67)	(1.11)	(1.09)

Notes: Average allocations are reported as a fraction of the endowment with corresponding standard errors in parentheses. Dividing by 10 yields the mean dollar allocation.

4 The Results

Table 2 reports the mean allocations to property rights, conflict, and production by treatment. The first thing to notice is that the mean contributions to property rights were higher in 2-stage games than 1-stage games, as predicted. Furthermore, average investment in production is higher and mean conflict is lower in the 2-stage games, also consistent with hypotheses. Average contributions to property rights are slightly higher in 4-player groups, however, contrary to the prediction. Average conflict is relatively close to predicted values in 1-stage games, and higher in 4-player than 2-player groups, as predicted. In 2-stage games, however, average conflict is significantly higher than predicted. This resulted in significantly less production than was predicted. Nonetheless, average production is close to predictions for 4-player groups, and decrease compared to 2-player groups, although not as much as predicted. [14]

[14]The remainder constitutes the allocations to consumption, which are all quite small: 3.11, 6.41, 1.29, and 2.31%, respectively.

Table 3: Regression Results for Allocation Decisions

	Property Rights		Conflict		Production	
	(1)	(2)	(3)	(4)	(5)	(6)
Constant	7.19***	2.38	41.18***	41.47***	51.40***	46.93***
	(1.41)	(2.29)	(2.36)	(3.03)	(2.32)	(2.35)
Pre-Commit (2-stage = 1)	12.22***	22.20***	-16.23***	-17.21***	6.61*	10.73***
	(1.57)	(2.74)	(3.62)	(4.40)	(3.82)	(2.84)
Group-Size (4-Player = 1)	0.76	7.76***	4.93	4.84**	-8.08***	-8.50***
	(1.27)	(2.67)	(2.97)	(2.39)	(3.00)	(2.14)
Pre-Commit x Group-Size	1.06	-0.06	-3.45	-3.23*	4.65	5.28***
	(1.44)	(2.24)	(3.47)	(1.90)	(3.35)	(1.71)
Order (4/2-player = 1)	-0.77	-8.19**	0.21	0.07	4.07	9.76***
	(1.39)	(3.50)	(4.44)	(3.83)	(5.05)	(3.02)
Pre-Commit x Order	-7.09***	-3.36	7.09	7.58	-1.37	-7.22**
	(1.59)	(3.69)	(4.69)	(5.14)	(5.69)	(3.27)
Group-Size x Order	-1.87	-7.16*	10.41**	10.51***	-11.09***	-11.78***
	(1.96)	(4.05)	(4.60)	(3.80)	(3.78)	(3.40)
Time Trend	-0.46***	-1.28***	1.15***	1.16***	-1.13***	-1.21***
	(0.09)	(0.18)	(0.21)	(0.16)	(0.18)	(0.15)
R^2	0.37	N/A	0.26	N/A	0.18	N/A

Notes: The data consists of a panel of 56 subjects over 20 decision periods (1120 observations). Models 1, 3, and 5 are estimated using ordinary least squares regression with robust standard errors reported in parentheses which are clustered by subject. Models 2, 4, and 6 report estimates using subject-specific random-effects tobit models to account for the 694, 25, and 60 allocations of zero, respectively. Statistical significance is indicated by asterisks: "*"significant at the 10% level, "**"significant at the 5% level. "***"significant at the 1% level.

Table 3 presents the regression results that investigate the effect of variation in experimental parameters on voluntary contributions to property rights, as well as allocations to conflict and production.[15] Two regressions are reported. Models (1), (3), and (5) are estimated using ordinary least squares with errors clustered by subject, to account for repeated observation of subject decisions, for property rights, conflict, and production, respectively. Column (2), (4), and (6) report estimates using tobit models, to account for the large number of observations at zero, which were estimated with subject-specific random-effects.[16] The results of these regressions are discussed for each account separately in the following sections.

4.1 Property Rights

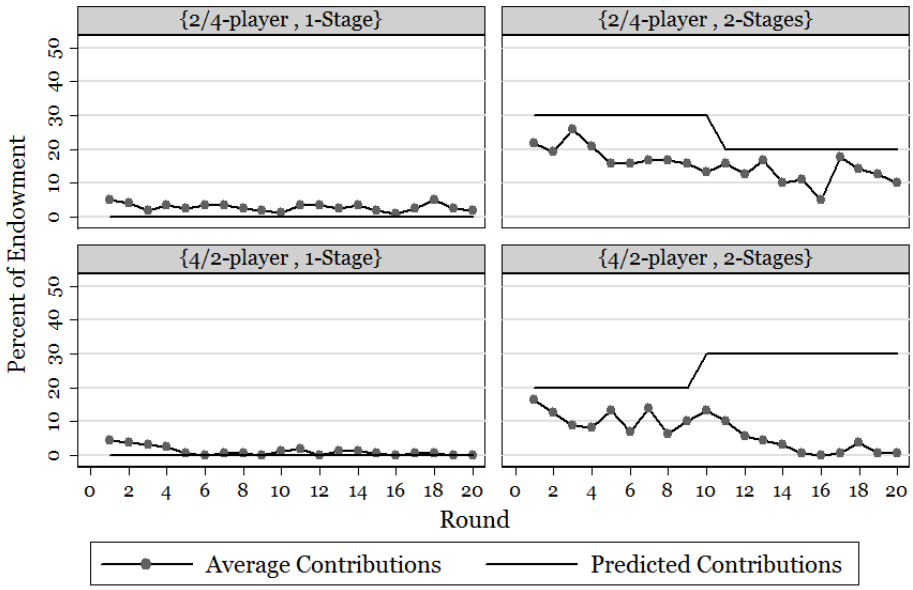
Figure 1 plots time trends of the mean voluntary contributions to property rights by treatment compared to the theoretical predictions.[17] Comparing the trends for 1-stage games with those for 2-stage games, it is apparent that the ability to pre-commit to the provision of property rights induces positive contributions, though less than predicted. There are two effects apparent in Figure 1, however, which are not predicted by theory. First, in 2-stage games, the mean contribution is diminishing as the number of rounds played increases. This trend is observed in many public goods experiments involving the voluntary contributions mechanism (Andreoni and Croson, 2008; Laury and Holt, 2008). Second, in 2-stage games, there is a difference between the average contributions when subjects play 2-player groups first compared to when they are played last; when 2-player groups occur first, contributions are about 50% higher than when 4-player groups occur first. This order effect does not seem to go the other way, however,

[15] The order of group-sizes is indicated as "first/last".

[16] Tobit models with fixed-effects are inconsistent. While tobit models assume these zero observations are censored, which is not the case, these regressions demonstrate the robustness of the results.

[17] The order of group-sizes is indicated as "first/last".

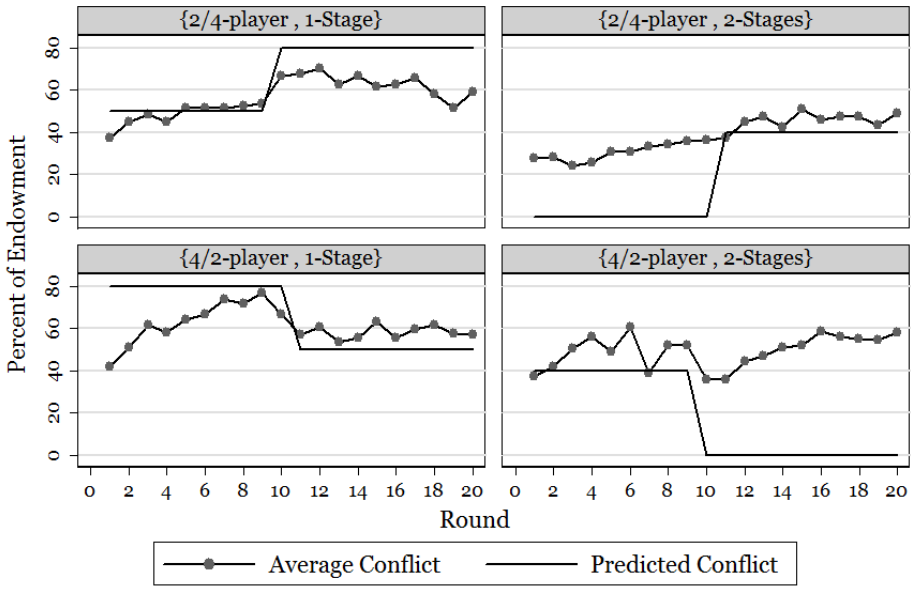
Figure 1: Mean Contribution to Property Rights by Treatment across Rounds



as there is no observable differences in the mean contributions for 4-player groups in 2-stage games.

The results in Table 3 regarding property rights indicate contributions are statistically higher in 2-stage games, when subjects had to pre-commit. The effect of group-size is insignificant. The controls for order effects and any time trend find significant evidence of both. The significant order effect suggests experience plays an important role. Experience with larger group-sizes and the associated higher levels of conflict significantly diminishes contributions to property rights when group-sizes are reduced. This is exacerbated by a persistent negative time trend, as contributions deteriorated over the course of a session, consistent with previous results from public goods experiments. The main results regarding voluntary contributions to property rights are summarized below.

Figure 2: Mean Allocation to Conflict by Treatment across Rounds



Result 1.

(a) *Average contributions to property rights are significantly higher in 2-stage games.*

(b) *There is no significant difference in average contributions to property rights across group-sizes in 1-stage games.*

(c) *There is no significant difference in average contributions to property rights across group-sizes in 2-stage games.*

4.2 Conflict

Figure 2 shows the time-trends of average conflict compared to predictions by treatment.[18] In 2-stage games, the fraction of resources devoted

[18]The order of group-sizes is indicated as "first/last".

to conflict is significantly higher than the prediction of zero for 2-player groups. For 4-player groups, mean conflict was slightly less than predicted in 1-stage games and slightly larger than predicted in 2-stage games. In addition, mean conflict appears to be rising throughout the course of a session. This corresponds to the decline in property rights.

The regression results reported in Table 3 confirm the patterns in the time-series depicted in Figure 2. Conflict is significantly lower in 2-stage games and significantly higher in 4-player groups. Still there are significant order effects; conflict is higher when subjects play in 4-player groups first. Also, mean conflict is rising over the course of a session, as indicated by the positive and significant time trend. The main results regarding production are summarized below.

Result 2.

(a) *Average conflict is significantly lower in 2-stage games.*

(b) *Average conflict is significantly higher in 4-player groups.*

(c) *Average conflict increases less in 2-stage games when group-sizes increase.*

4.3 Production

Figure 3 shows the time trends of average production compared with predictions by treatment.[19] The average fraction of resources devoted to production is fairly close to predicted levels in 1-stage games, as well as 2-stage games with 4-player groups. Mean production is less than predicted, however, for 2-stage games with 2-player groups, corresponding to the underprovision of property rights and excessive conflict observed in these treatments. Unlike property rights and conflict, however, there do not appear to be any obvious order-effects or time trends.

[19]The order of group-sizes is indicated as "first/last".

Figure 3: Mean Production by Treatment across Rounds

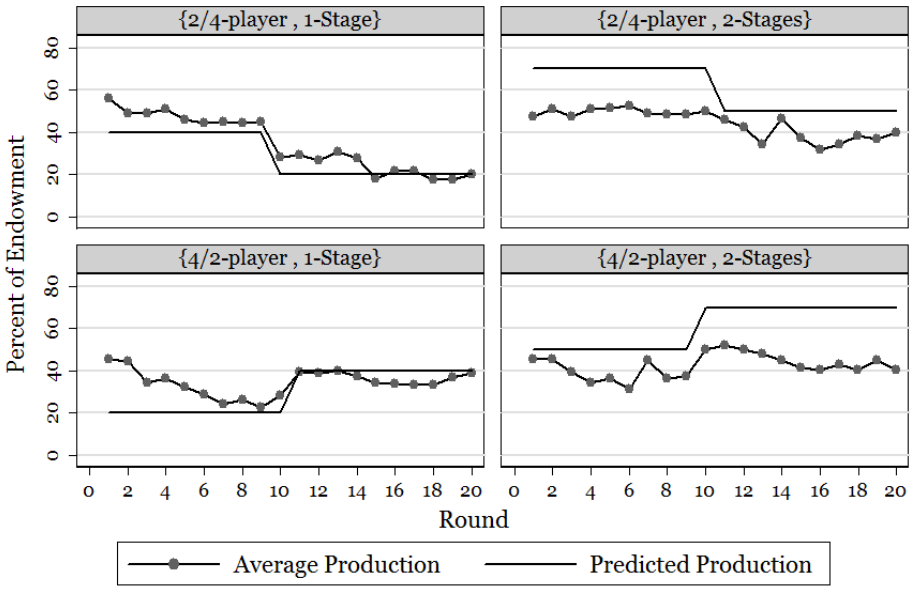


Table 3 reports estimated treatment effects for production, controlling for any order-effects or time trends. The results indicate that production is significantly higher in 2-stage games. This is consistent with the predicted strategic effect associated with property rights provision; the reduction in conflict exceeds the cost of property rights provision, which allows for increased production. The regression results indicate that larger group-sizes allocated significantly less resources to production. Finally, while not obvious from Figure 3, the regression results suggest that production is decreasing slightly over time. The main results regarding production are summarized below.

Result 3.

(a) *Average production is significantly higher in 2-stage games.*

(b) *Average production is significantly lower for 4-player groups.*

(c) *The decrease in average production is significantly less in 2-stage games when group-sizes increase.*

5 Discussion

This paper reports the results of an experiment designed to investigate whether people voluntarily contribute resources to the provision of property rights? The experiment tests the predictions of a game-theoretic model in which property rights assume the form of a public good in a contest under anarchy. The experiment explores whether the ability to pre-commit to the provision of property rights, before allocations to production and conflict are determined, induces people to make voluntary contributions, as predicted by the model. Pre-commitment involves a 2-stage game, where all subjects choose their contributions to property rights in the first stage and allocate the remainder of their endowment to conflict and production in the seconde stage, after observing the strength of property rights. Alternatively, baseline treatments involve a 1-stage game, where all allocation decisions are chosen simultaneously. Absent the ability to pre-commit, no property rights should be provided and none are observed. Average allocations to conflict and production are also quite close to the theoretical predictions in these treatments. In 2-stage games, contributions are positive and significant, albeit less than predicted. Nonetheless, mean allocations to conflict decrease and average production increases in response to the provision of property rights. This is consistent with the predicted strategic effect associated with property rights provision. Specifically, the reduction in conflict exceeds the cost of property rights provision, which allows for increased production.

Property rights contributions deteriorate over time, however, a result that is common in the experimental literature on voluntary provision of public goods (Ledyard, 1995; Andreoni and Croson, 2008; Laury and Holt,

2008). This raises the question of whether there are mechanisms that can facilitate sustained contributions to property rights? An obvious candidate is communication. Combining a channel of communication, which in itself is a means of establishing an informal institution (Kimbrough et al., 2008, 2010), with the formal institution implemented in this experiment seems to be the next logical step. Additionally, the order in which group-sizes were varied has a significant effect upon the way subjects behaved. This suggests embedded preconceptions can have persistent effects when people are exposed to new institutional arrangements. Future research in this vein is likely to provide a more comprehensive understanding of the mechanics of property rights creation.

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A Mathematical Appendix

A.1 Derivation of Nash Equilibrium

Player i's first-order-necessary-conditions defining the Nash equilibrium include (4) and the following:

$$\frac{\partial u_i}{\partial k_i} = Ap_{ii} - 1 \leq 0, \tag{8}$$

$$\frac{\partial u_i}{\partial x_i} = \frac{\partial p_{ii}}{\partial x_i} Ak_i + \sum_{j \neq i}^{N} \frac{\partial p_{ij}}{\partial x_i} Ak_j - 1 \leq 0, \tag{9}$$

$$\frac{\partial u_i}{\partial y_i} = \frac{\partial p_{ii}}{\partial Y} Ak_i + \sum_{j \neq i}^{N} \frac{\partial p_{ij}}{\partial Y} Ak_j - 1 \leq 0, \tag{10}$$

Imposing symmetry implies $\partial p_{ii}/\partial Y = -(N-1)\partial p_{ij}/\partial Y$. Therefore,

$$\frac{\partial u_i}{\partial y_i} = -1 < 0,$$

so each player sets $y_i = 0$ in the symmetric Nash equilibrium. Given that $y^{NE} = 0$, the symmetric Nash equilibrium conditions for the choice of con-

flict, x, and production, k, can be written as

$$\frac{\partial u_i}{\partial k_i} = A\frac{A}{N} - 1 \leq 0, \tag{9'}$$

$$\frac{\partial u_i}{\partial x_i} = A\frac{(N-1)}{N}\frac{k}{x} - 1 \leq 0. \tag{10'}$$

For $A \geq N$, substituting (9′) into (10′) yields the result in (5).

A.2 Derivation of Subgame Perfect Nash Equilibrium

In solving the second stage of the game with pre-commitment, we let all y_i take arbitrary non-negative values. The allocation between x_i and k_i then depends upon the values of y_i from the first stage decisions. The first-order-necessary-conditions for the choice of x_i satisfy

$$\frac{\partial u_i}{\partial x_i} = \frac{A}{(Y+X)^2}\Big[X_{-i}(k_i) + \sum_{j\neq i}(Y+X_{-i})(k_j) - (Y+x_i)(Y+X)\Big] \leq 0. \tag{11}$$

Solving (11) for $x_i(Y, y_i)$ yields

$$x_i^*(Y, y_i) = \frac{(N-1)(N\omega - Y)^2 - N^2 Y(\omega - y_i)}{N^2(N\omega - Y)}. \tag{12}$$

Substituting (12) into the payoff function yields, after some simplification, the value function in terms of y_i and Y:

$$u_i(Y, y_i) = \frac{A}{N^2}\left[\frac{N^2\omega(\omega+\theta) + N(N-2)\omega Y + Y^2 - N^2 y_i(Y+\theta)}{N\omega - Y}\right]. \tag{13}$$

Imposing symmetry on the first-order necessary condition yields

$$\frac{\partial u_i}{\partial y_i} = \frac{A(N-1)[\omega - (N+1)y]}{N^2(\omega - y)} \leq 0.$$

Solving this for y yields the subgame perfect level of private provision to security, and substituting these results back into (1), (2), (8), and (11) yields the results in (6).