Appropriation from a Common Pool Resource: Effects of the Characteristics of the Common Pool Resource, the Appropriators and the Existence of Communication

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Abstract

There is a growing literature that studies the management of common pool resources (CPRs) within the context of controlled laboratory experiments. The seminal work in this area is presented in Ostrom et al. (1994) although some of this work appeared earlier. A major thesis of this work is that non-binding communication (cheap talk) among appropriators of the commons may be sufficient to permit them to manage the commons efficiently without requiring an outside regulator.

Numerous extensions to the work by Gardner, Ostrom and Walker have been completed since these seminal studies. Among them is the environment introduced in Schott et al. (2007) and extended in Buckley et al. (2009, 2013) which use a CPR environment similar to Ostrom et al. (1994) to study output-sharing and non-binding communication among appropriators

The Ostrom et al. (1994) and the Buckley et al. (2013) results, as presented, are not directly comparable. The latter uses system effort as the variable of interest and the former use relative net system rents as the variable of interest. We have generated both the relative system effort and relative net system rent data for the three environments so that we can better compare the three environments with and without non-binding communication. We identify the nature of the differences across the treatments and propose several new treatments that may support a conjecture that cognitive differences induced by the framing of the sessions leads to the differences we find.

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1. Introduction

There is a growing literature that studies the management of common pool resources (CPRs) within the context of controlled laboratory experiments. The seminal work in this area is presented in Ostrom et al. (1994) although some of this work appeared earlier (see Ostrom and Walker (1991) and Ostrom et al. (1992)). A major thesis of this work is that non-binding communication (cheap talk) is a powerful tool for managing the commons. This suggests that the existence of communication among appropriators of the commons may be sufficient to permit them to manage the commons efficiently without requiring an outside regulator.

Numerous extensions to the work by Roy Gardner, Elinor Ostrom and James Walker have been completed since these seminal studies. Many of these extensions augment the controlled laboratory environments with and without non-binding communication by including the role of costly and costless monitoring and sanctioning, direct regulation and voting on management rules. This work includes environments with neutral frames that use subjects recruited from university campuses, environments framed as common pool resources with subjects recruited from communities of people who earn their livings appropriating resources from common pools and some environments which compare the outcomes from the different kinds of subjects (see Hackett et al. (1994), Cardenas et al.

(2000), Schmitt et al. (2000), Walker et al. (2000), Cardenas et al. (2004), Castillo and Saysel (2005), Moir (2008), Ahn et al. (2010), Janssen (2010), Janssen et al. (2010), Moreno-Sánchez and Maldonado (2010), Velez et al. (2010), Cardenas (2011), Velez et al. (2012), Janssen (2013) and Janssen et al. (2013)).

Another extension of this work is found in Schott et al. (2007) and Buckley et al. (2009, 2013) which uses a similar CPR environment to study output-sharing among appropriators from the commons as a management tool as well as the way in which private communication (within-group) and public communication (among all appropriators) can affect the efficiency of system appropriation and the effectiveness of non-binding communication.

The current paper focuses on the effect of non-binding communication on appropriation from a CPR. The results from the two environments first presented in Ostrom et al. (1992) provide contrasting results. The environments have the same yield function for the CPR and the same number of appropriators (8). The environments differ according to the endowment of effort available to allocate between appropriation from the CPR and to an alternative activity that pays a fixed return per unit of effort applied (the different per-subject endowments are 10 and 25 units). Both environments tend to converge to the Nash equilibrium predicted for the one-shot allocation game, although the convergence is faster for the environment with the smaller per-subject endowment. When non-binding communication is permitted prior to each round in which an appropriation decision must be made, the environment with the smaller system endowment of effort converges quickly to the optimal outcome. The environment with the larger endowments shows an increase in net system rent, but not nearly as great as displayed in the

environment with the smaller system net rent (about 60 percent of the optimal net rent versus nearly 100 percent of the optimal net rent). The environment with the smaller system endowment tends to be the environment used in most of the extensions following Ostrom et al. (1992) and Ostrom et al. (1994).

Buckley et al. (2013) present an environment similar to those in Ostrom et al. (1992). There are several differences however. There are twelve subjects in Buckley et al. (2013) who each have effort endowments of 28 units and the non-binding communication is implemented via a computer-mediated chat room rather than face-to-face as in Ostrom et al. (1992). The system effort for the baseline no-communication environment converges to the Nash equilibrium for the one-shot game, as does the system effort for the non-binding communication environment. In many ways the Buckley et al. (2013) environment is similar to the Ostrom et al. (1992) small endowment environment. The outcomes for the no-communication treatments are comparable, yet the outcomes after 15 rounds of decisions in the communication treatments diverge. The Buckley et al. (2013) communication results are, however, close to the results from the Ostrom et al. (1992) large endowment environment.

We are selecting the two Ostrom et al. (1992) environments to compare with the Buckley et al. (2013) environment because of the availability of comparable data and the number of rounds of decision-making included in the laboratory sessions as well as the similarity of their underlying yield functions. Many of the environments summarized in Table 1 have fewer than ten rounds of no-communication and ten rounds of communica-

Table 1. Characteristics of Papers in References

Paper	Number of X rounds (Reps)	Number of C-X rounds (Reps)	Number of subjects	Endow-ment per subject	Nash effort per subject	Opt effort per subject	Data	Comments
Ahn et al. 2010	2 (27)	2 (27)	7	NA	14	9	Summary Tables	Rep Static Game; Graduate
Buckley et al. 2013	15 (4)	15 (4)	12	28	24	13	Figures; Summary Tables	Rep Static Game; Students
Cardenas 2011	10 (?)	10 (?)	5	8*	8	1	Figures	Rep Static Game; Framed; Some Field sessions; Some Student sessions
Cardenas et al. 2004	20 (8) & 10 (13)	10 (13)	5	8*	8	1	Figures	Rep Static Game; Framed; Field
Cardenas et al. 2000	8-11 (14)	9-12 (9)	8	8	6	1	Figures; Summary Tables	Rep Static Game; Framed; Field
Castillo & Saysel 2005	10 (16)	10 (4)	5	8*	8	1	Figures	Rep Static Game Framed; Field
Hackett et al. 1994	10 (4)	10 (4)	8	4 with 8 & 4 with 24	8/8 for sm 16/24 for lrg	56 in total; Diff. allocations possible	Figures; Summary Tables	Heterogeneous Subjects; Random Assignment Only; Rep Static Game; Students
Janssen 2010	1 (22)	3 (22)	4	NA	NA	NA	Figures; Summary Tables	Dynamic Game

Janssen 2013	3 (22)	3 (22)	5	NA	NA	NA	Figures; Summary Tables	Dynamic Game; 11 NC/C & 11 C/NC; 13 IncInfo & 9 CompInfo
Janssen et al. 2010	See Janssen 2013			Includes treatments with and without punishment interacted with communication.				Dynamic Game
Janssen et al. 2013	See Janssen 2013			During C rounds, communication and appropriation occur at the same time rather than sequentially.				Dynamic Game
Moir 2008	15 (5) & 5 (10)	NA	8	20	16	9	Figures; Summary Tables	Rep Static Game; Students
Moreno-Sánchez et al. 2010	10 (56)	10 (8)	5	8*	8 for high 4 for low	1	Figures; Summary Tables	Dynamic Game; Two Levels of Stock (High & Low)
Ostrom et al. 1994	20 (3)	15(4)	8	10	8	4.5	Figures; Summary Tables	Rep Static Game; Students
Ostrom et al. 1994	20 (3)	15 (6)	8	25	8	4.5	Figures; Summary Tables	Rep Static Game; Students
Schmitt et al. 2000	10 (11)	15 (11)	8	25	8	36 in total; diff. allocations possible	Figures; Summary Tables	Forced Stackelberg Coalition; Rep Static Game; 3 Protocols; Students
Velez et al. 2010	10 (60)	10 (12)	5	8*	7	2	No	Similar to Ostrom et al. 1994
Walker et al. 2000	10 (15)	NA	7	80	Design 1: 14 Design 2: 12	Design 1: 9 Design 2: 7	Summary Tables	Voting on Allocation; Two designs varying in game parameters and subject experience

Notes: Ostrom et al. (1994) includes Ostrom and Walker (1991) and Ostrom et al. (1992). Buckley et al. (2013) includes Schott et al. (2007) and Buckley et al. (2009). When an asterisk appears next to an endowment number this indicates that making no appropriation is not possible. Framed experiments are presented as appropriating from a CPR. Subjects in Field experiments are people who as a normal course of their activity appropriate from a CPR. Students indicate subjects are university students. An X rounds is a baseline CPR round with no communication or management treatment. A C-X round is a round that is preceded by communication but with no other management treatment. "Reps" indicates the number of replications of a treatment.

tion sessions. Others have fewer appropriators from the CPR and these appropriators have fewer units of effort to allocate to appropriation than in the three chosen environments. Furthermore, some are dynamic and allow the stock of resources in the common pool to vary over the course of the session as harvest activity changes.

The Ostrom et al. (1992) results and the Buckley et al. (2013) results, as presented, are not directly comparable. The latter uses system effort as the variable of interest and the former use relative net system rents as the variable of interest. Our objective is to generate both the relative system effort and relative net system rent data for the three environments so that we can compare the Ostrom et al. (1992) and Buckley et al. (2013) environments with and without non-binding communication. Furthermore, we want to determine the nature of the differences and similarities and examine the possible sources of differences in results.

2. The Environments

Figures 1, 2 and 3 describe the three common pool resource (CPR) environments we study. The figures reflect differences in yield functions (technical parameters of the CPR), effort available for appropriation by people removing resources from the CPR and the opportunity cost of effort devoted to appropriation from the CPR. The figures are constructed to reflect the mean value of the yield from the CPR, the mean value of the net rent from appropriation from the CPR and the mean value of the profit received by an appropriator from the CPR per period as a function of total system effort devoted to appropriation. These figures provide an abstracted picture of the incentives that are created by the different environments. The figures are presented in two formats. In the first, the vertical axes are denominated in the local currency in which participants were

paid. For two environments this is in 1990 US dollars. In the third environment this is 2009 Canadian dollars. The second format presents the same schedules with their vertical axes denominated in 1990 US dollars. This conversion is done to make the harvest, net rent and profit schedules comparable across environments. The 2009 Canadian dollar values are converted to 1990 Canadian dollar values by adjusting for consumer price index changes between 1990 and 2009 in Canada and then by assuming that adjusting Canadian dollar values by the US/Canadian dollar exchange rate will equalize the purchasing power of the Canadian and US dollar payoffs.

The yield function for the environments presented in Ostrom et al. (1992) that we will identify as O10 and O25 environments is

$$Y = 23\,E - 0.25\,E^2 \qquad (1)$$

where Y is total yield and E is system effort devoted to appropriation from the CPR. Y is measured in laboratory dollars (L$).

The yield function for the environment introduced in Schott et al. (2007) that we will identify as the S28 environment is

$$Y = 32.5\,E - 0.09375\,E^2 \qquad (2)$$

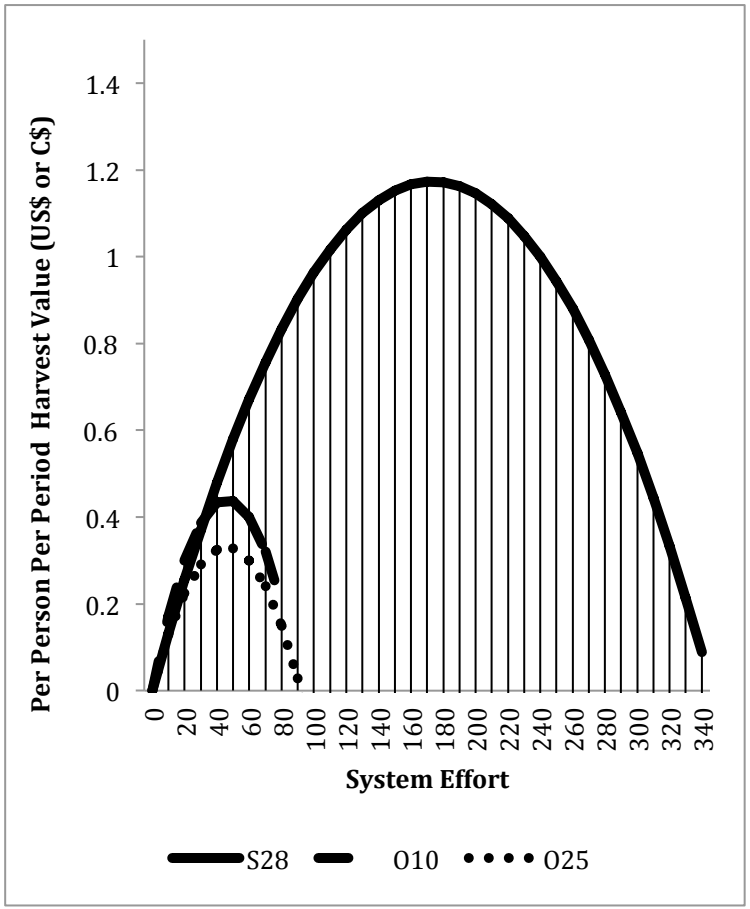
where Y and E are defined as above.

For O10 and O25, each appropriator can apply up to 10 and 25 units of effort, respectively, to appropriation from the CPR. The opportunity cost of applying effort to appropriation is L$5. There are 8 appropriators in the O10 and O25 environments. For S28, each appropriator can apply up to 28 units of effort to appropriation from the CPR. The opportunity cost of applying effort to appropriation is L$3.25. There are 12 appropriators in the S28 environment.

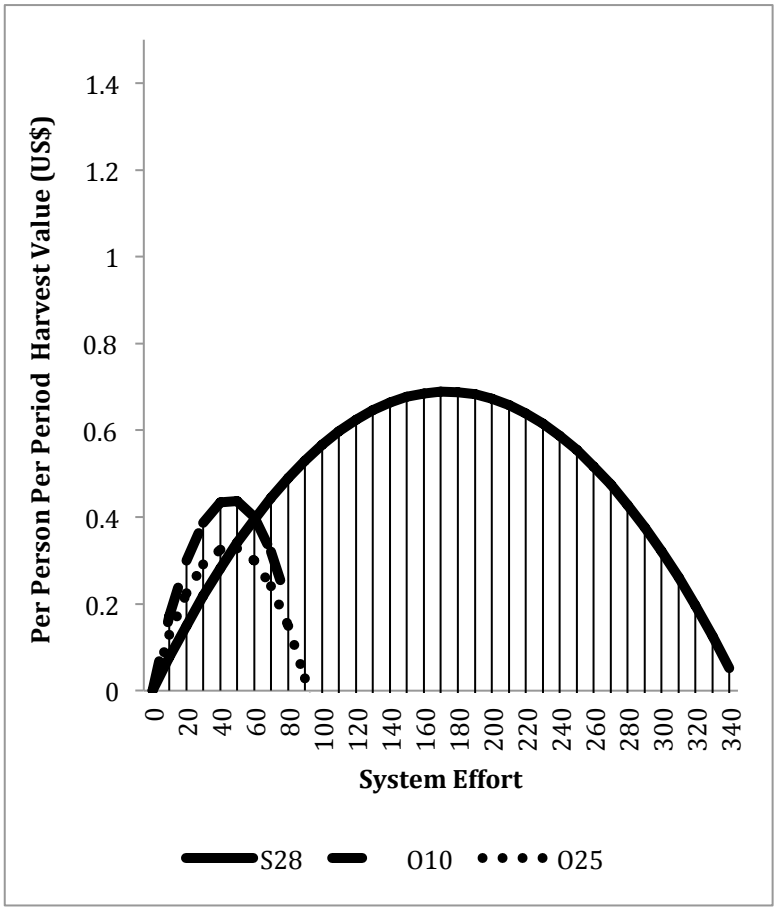
The implementation of these CPR environments did not use the same terminology for the laboratory currency. We are using L$ to "normalize" the name of the laboratory currency. When subjects were paid for their participation, their lab dollar earnings were converted into their respective currencies. For the O10 sessions, L$100 = US$1. For the larger O25 sessions, L$200 = US$1. The S28 sessions converted lab dollar earnings into Canadian dollars at L$200 =C$1.

Figure 1, Panel A presents the mean per-person per-period value of the system harvest (yield) as a function of system effort for the three environments we have presented. Figure 2, Panel A presents the mean per-person per-period net rents. Net rent is the total yield less the opportunity cost of the effort devoted to appropriating the total yield. Figure 3, Panel A presents mean per-person per-period profit. Profit is equal to net rent plus the value of the effort devoted to the activity that is provided as an alternative to appropriating resources from the common pool. Panels B in Figures 1, 2 and 3 present the same data with the 2009 Canadian dollar values converted to 1990 US dollars (the payoff medium for the session reported in Ostrom et al. (1992)) to account for exchange rate and purchasing power differences.

System net rent is maximized at system effort of 36 units for O10 and O25. System net rent is maximized at system effort of 156 units for S28. In the O10 environment this means that 36 of the available 80 units of effort (45%) are devoted to appropriation from the common pool. For the O25 environment only 18% of the available 200 units are devoted to appropriation and for the S28 environment 46% of the available 336 units are devoted to appropriation. Note that system profits are maximized with the same level of effort as system net rent.

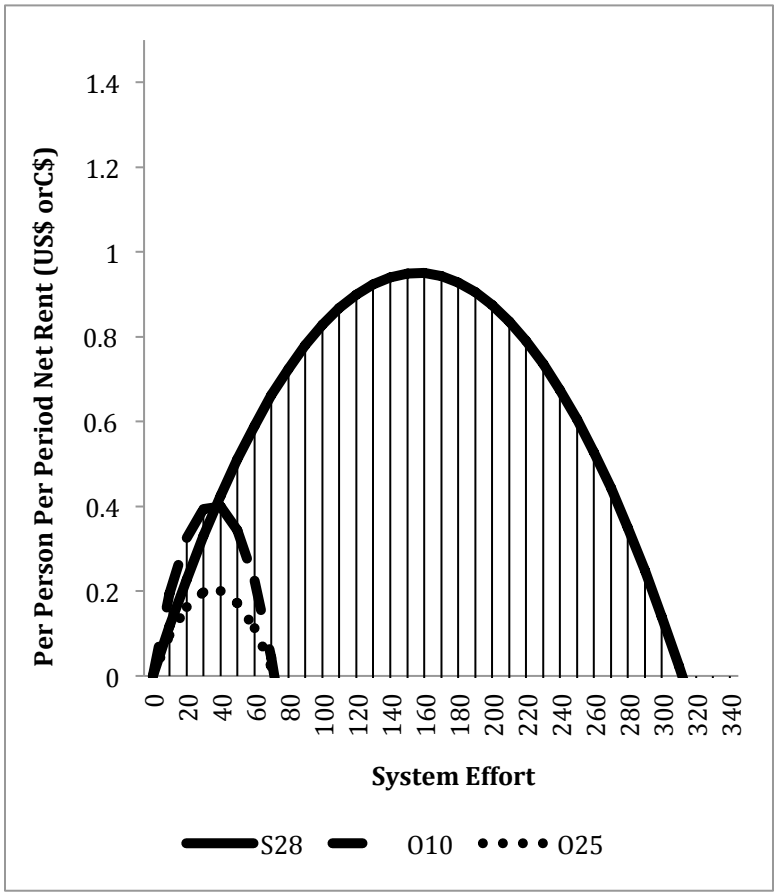


Panel A. O10 & O25 in 1990 US$ and S28 in 2009 Cdn$

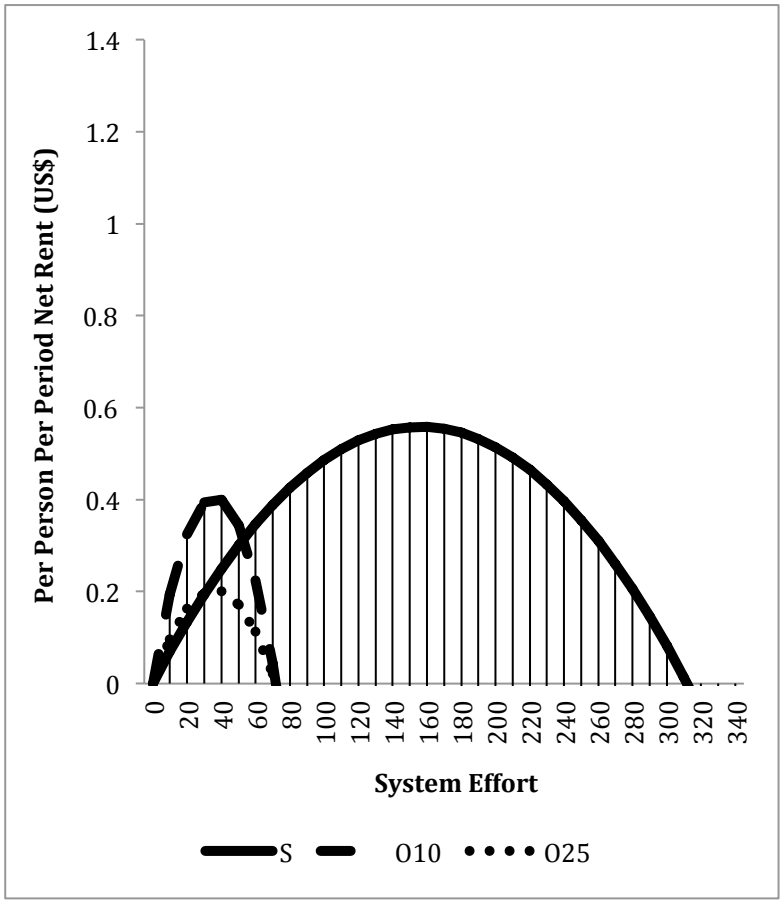


Panel B. O10, O25 & S28 in 1990 US$

Figure 1. Mean Per Person Per Period Harvest Value Given System Effort

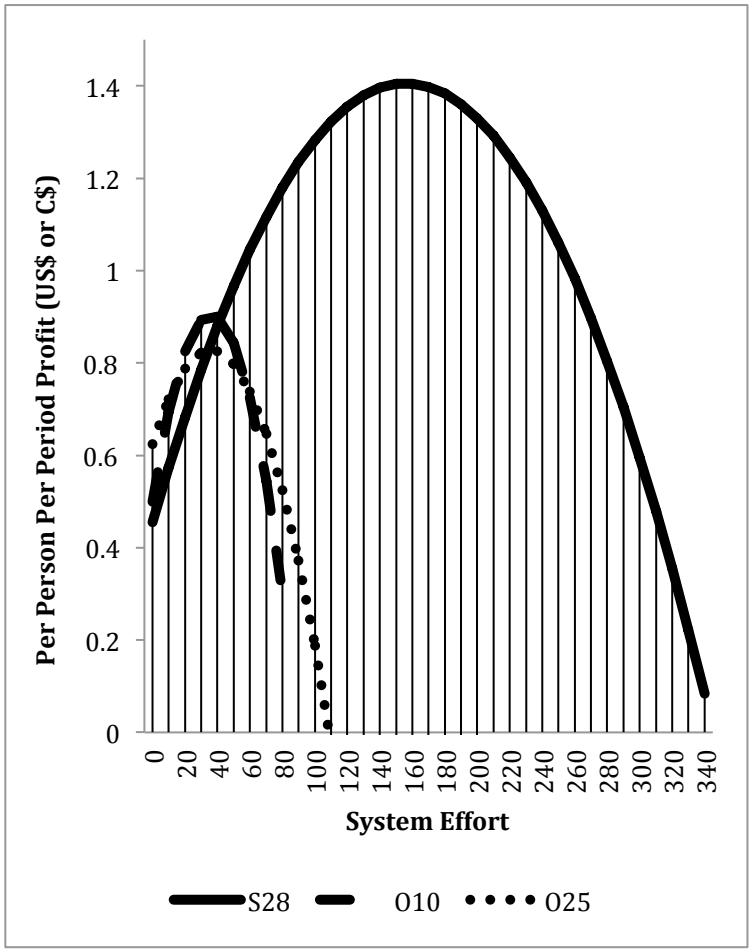


Panel A. O10 & O25 in 1990 US$ and S28 in 2009 Cdn$

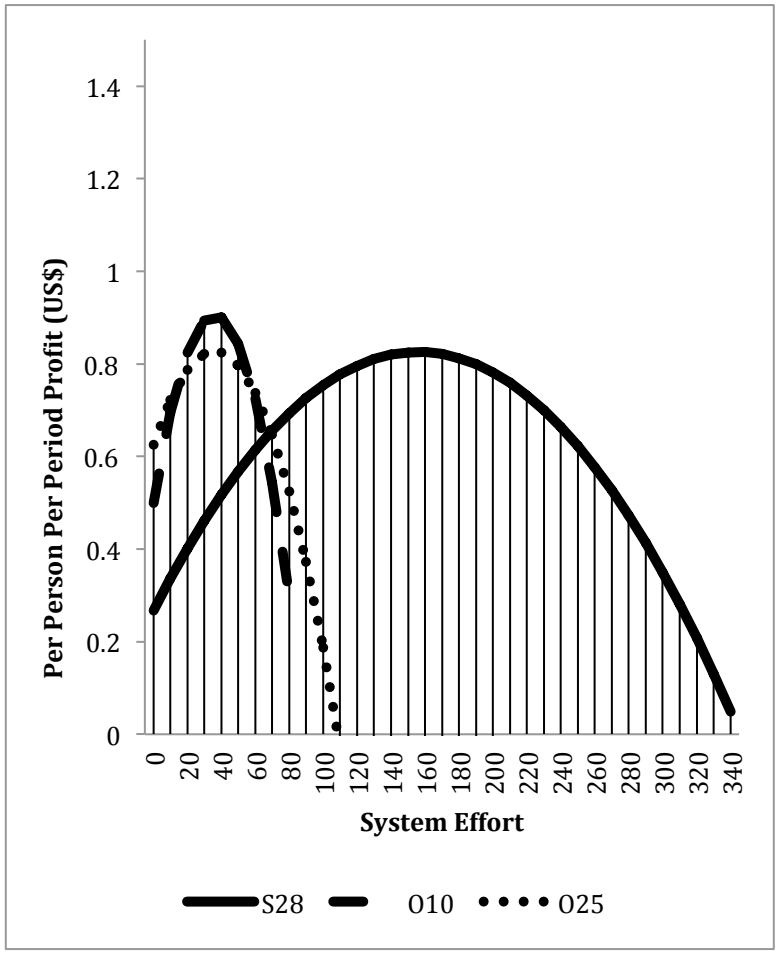


Panel B. O10, O25 & S28 in 1990 US$

Figure 2. Mean Per Person Per Period Net Rent Given System Effort



Panel A. O10 & O25 in 1990 US$ and S28 in 2009 Cdn$



Panel B. O10, O25 & S28 in 1990 US$

Figure 3. Mean Per Person Per Period Profit Given System Effort

A Nash equilibrium exists in these environments at which the individual appropriators over-appropriate from the CPR relative to the profit or net-rent maximizing benchmark. For the O10 and O25 environments the Nash equilibrium has a system effort devoted to appropriation of 64 units (80% and 32% respectively of the total available effort). The Nash equilibrium for the S28 is 288 units of effort devoted to appropriation from the common pool (86% of the available effort).

A Stackelberg-coalition equilibrium exists in these environment in which appropriation from the CPR is less than at the Nash equilibrium but is still greater than at the optimal level of appropriation (see Schott and Wing (2010) for a discussion of Stackelberg-coalition equilibria). For the O10 environment, the Stackelberg-coalition equilibrium will have 6 appropriators in a coalition allocating total effort of 24 units. The other two appropriators will best-respond and each allocate all of their 10-unit endowments (system effort is 44 units). For the O25 environment, the Stackelberg-coalition equilibrium has 5 appropriators allocating together 35 units of effort while the other two appropriators ~~will~~ each allocate 9 units to appropriating from the CPR (system effort is 62 units). The appropriators for the S28 environment can realize a Stackelberg-coalition equilibrium if 8 appropriators form a coalition and together allocate 104 units of effort to appropriation. Each of the remaining 4 appropriators will allocate all of their effort endowment (28 units) to appropriation from the CPR. System effort will be 216 units.

Appropriators in environment O10 will realize 95% of the optimal net rent if a coalition equilibrium can be formed while 48% of the optimal net rent will be realized in

environment O25. For S28, 85% of the optimal rent will be realized with the coalition equilibrium.

System effort, system net rent and system profit are summarized in Table 2 for the three treatments at the three benchmarks: the Nash equilibrium, the Stackelberg-coalition equilibrium and the System Optimum. Also included in Table 2 are the coalition and Nash

Table 2. Per Period System Effort, Net Rent and Profit Benchmarks by Environment in Lab Dollars and Coalition and Nash Values Relative to the Optimum

	O10			O25			S28		
Benchmark	Effort	Net Rent	Profit	Effort	Net Rent	Profit	Effort	Net Rent	Profit
Optimum	36	324	724	36	324	1324	156	2281.5	3373.5
Coalition	44	308	708	62	155	1155	216	1944	3036
Coalition/Opt	*1.22*	*0.95*	*0.98*	*1.72*	*0.48*	*0.79*	*1.38*	*0.85*	*0.90*
Nash	64	128	528	64	128	1128	288	648	1740
Nash/Opt	*1.78*	*0.40*	*0.73*	*1.78*	*0.40*	*0.85*	*1.85*	*0.28*	*0.52*

Note: As system effort varies the difference between Net System Rent and System Profit does not change given the environment. For O10 this is 400, for O25 this is 1000 and for S28 this is 1092.

benchmarks values relative to the values at the optimum. The relative values indicate that there are differences between the three environments.

3. Experimental Designs

The O10 and O25 environments are conducted without communication and with repeated communication. In the repeated communication treatments, non-binding face-to-face communication occurs prior to each decision round for which participants make a decision to devote effort to appropriation from the CPR.

The no-communication O10 sessions are conducted for more than 25 rounds. However, Ostrom et al. (1992) and Ostrom et al. (1994) do not discuss results beyond

those obtained over the first 20 rounds. The no-communication O25 sessions are conducted for 20 rounds. The O10 and O25 sessions with communication are conducted for 25 rounds, with the first 10 rounds being conducted without communication and the final 15 rounds conducted with repeated communication. Ostrom et al. (1992) report that there are 3 sessions for each of the no communication treatments but they do not report the period-by-period or session data. These data are reported in Ostrom et al. (1994 p. 128).[1] The five-period interval data and session data for 4 sessions for the O10 repeated communication treatments and 6 sessions for the O25 repeated communication treatments are reported in Ostrom et al. (1994, pp.154-155).[2] The mean values for system net rent are presented for each communication session in five-period intervals and the system values for effort in each round of each no-communication session is presented in Ostrom et al. (1994).

The S28 environments are conducted without communication and with repeated communication. In the repeated communication treatments non-binding communication via a chat window on the participants' computer screens occurs prior to each decision round for which participants make a decision to devote effort to appropriation from the CPR. The non-communication S28 sessions are conducted for 15 rounds. The communication S28 sessions are conducted for 15. There are 4 sessions for each of the communication and no-communication treatments. The results for the S28 sessions are reported in Buckley et al. (2013).

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[1] The five-period interval relative system net rent derived from these data are not identical to the the values reported in Ostrom et al. (1992, p. 409) and Ostrom et al. (1994, p. 117).
[2] The results reported for O25 with communication are different in Ostrom et al. (1992) and Ostrom et al. (1994) because the former reports the results from three sessions and the latter from six sessions. The result reported here are from the six sessions.

4. Results from O10, O25 and S28

4.1. The Data

The results of the O10, O25 and S28 sessions are summarized in Table 3 by the average relative net rents in five-decision-round intervals. Relative net rent is equal to net rent divided by the maximum net rent that could be realized by appropriators from the CPR. Standard deviations are reported for all of the five-decision-round intervals.

Table 3. Relative Net System Rent (standard deviations are in parentheses)

	Rounds 1-5	Rounds 6-10	Rounds 11-15	Rounds 16-20	Rounds 17-25
Baseline	No Communication				
O10	0.523 (0.174)	0.358 (0.147)	0.358 (0.174)	0.364 (0.127)	
O25	-0.215 (0.303)	-0.030 (0.214)	0.168 (0.276)	0.338 (0.122)	
S28	0.377 (0.072)	0.285 (0.111)	0.268 (0.016)		
Communication	No Communication		Communication		
O10	0.328 (0.048)	0.275 (0.079)	0.973 (0.028)	0.985 (0.013)	1.000 (0.000)
O25	0.103 (0.413)	-0.123 (0.242)	0.710 (0.175)	0.785 (0.103)	0.618 (0.406)
S28			0.653 (0.166)	0.458 (0.177)	0.390 (0.192)

Note: The values for S28 are for rounds 1-5, 6-10 and 11-15 in their 15 round sessions, but are reported here as in rounds 11-15, 16-20 and 21-25 so that they may be more easily compared with the three 5-round phases of the sessions in which communication is used in environments O10 and O25.

Ostrom et al. (1994) do not report data for effort (which they call *tokens*) allocated to CPR appropriation the O10 and O25 environments with communication. Given the reported mean system relative net rents and the net rent function in Ostrom et al. (1994) it is possible to derive the mean system effort that would generate the reported relative net rents in each five-period interval of each communication session. Because session values

for effort were provided for the no communication sessions of environments O10 and O25, we can derive standard deviations for net rent, relative net rent, effort and relative effort in the absence of communication directly from the session system effort data.

The relative system effort is equal to mean system effort for five-round intervals divided by the optimal effort (associated with effort when system net rent or system profit is maximized). Table 4 summarizes the O10, 025 and S28 results with respect to relative system effort allocated to appropriation from the CPR. The mean system effort data and mean system net rent data are presented in Figures A1, A2, A3 and A4 in an Appendix.

Table 4. Relative System Effort (standard deviations are in parentheses)

	Rounds 1-5	Rounds 6-10	Rounds 11-15	Rounds 16-20	Rounds 21-25
Baseline	No Communication				
O10	1.683 (0.122)	1.798 (0.089)	1.796 (0.106)	1.794 (0.082)	
O25	2.097 (0.143)	2.011 (0.106)	1.904 (0.151)	1.811 (0.077)	
S28	1.780 (0.047)	1.836 (0.070)	1.850 (0.008)		
Communication	No Communication		Communication		
O10	1.820 (0.029)	1.851 (0.048)	1.136 (0.109)	1.104 (0.075)	1.000 (0.000)
O25	1.926 (0.220)	2.055 (0.113)	1.521 (0.152)	1.451 (0.120)	1.542 (0.325)
S28			1.560 (0.144)	1.722 (0.127)	1.770 (0.130)

Note: The values for S28 are for rounds 1-5, 6-10 and 11-15 in their 15 round sessions, but are reported here as in rounds 11-15, 16-20 and 21-25 so that they may be more easily compared with the three 5-round phases of the sessions in which communication is used in environments O10 and O25.

4.2. The Analysis: Comparing O10, O25 and S28 to Each Other

The results of the Ostrom et al. (1994) CPR environments identified as O10 and O25 and the Buckley et al. (2013) environment identified as S28 are compared with respect to the

relative system effort and relative system net rent. In particular, the impact of communication on the management of the CPR is the focus of the analysis.

Because of the different yield function parameters, the different endowments and the different number of appropriators in the three environments whose data have been presented above, it is not possible to compare the effects of communication without normalizing the results. Using the relative net system rents and relative system effort permits a comparison of the different environments.

Figures 4 and 5 present a comparison of the baseline (no communication) and communication environments for relative net system rent and relative system effort respectively. Each panel of each figure presents the mean results for the no communication and communication sessions for each of the three environments (O10, O25 and S28). The results are presented for five-period averages. The benchmarks for the relative Optimum outcome (always unity), the relative Coalition outcomes and the relative Nash outcomes are also presented on each panel. The relative benchmark values for the Coalition equilibria (Coalition/Opt) and the Nash equilibria (Nash/Opt) are presented in Table 2.

The controlled laboratory environments provide sufficiently convincing evidence that the O10, O25 and S28 environments in the absence of communication converge to the Nash equilibrium predictions for these environments without generating statistical tests. The visual inspection of the results in Figures 4 and 5 convincingly support the conclusion that convergence to the Nash benchmark characterizes these environments.

The relative net system rent results in Panels A and C of Figure 4 show relative net system rent quickly falling from above the Nash benchmark prediction to values around

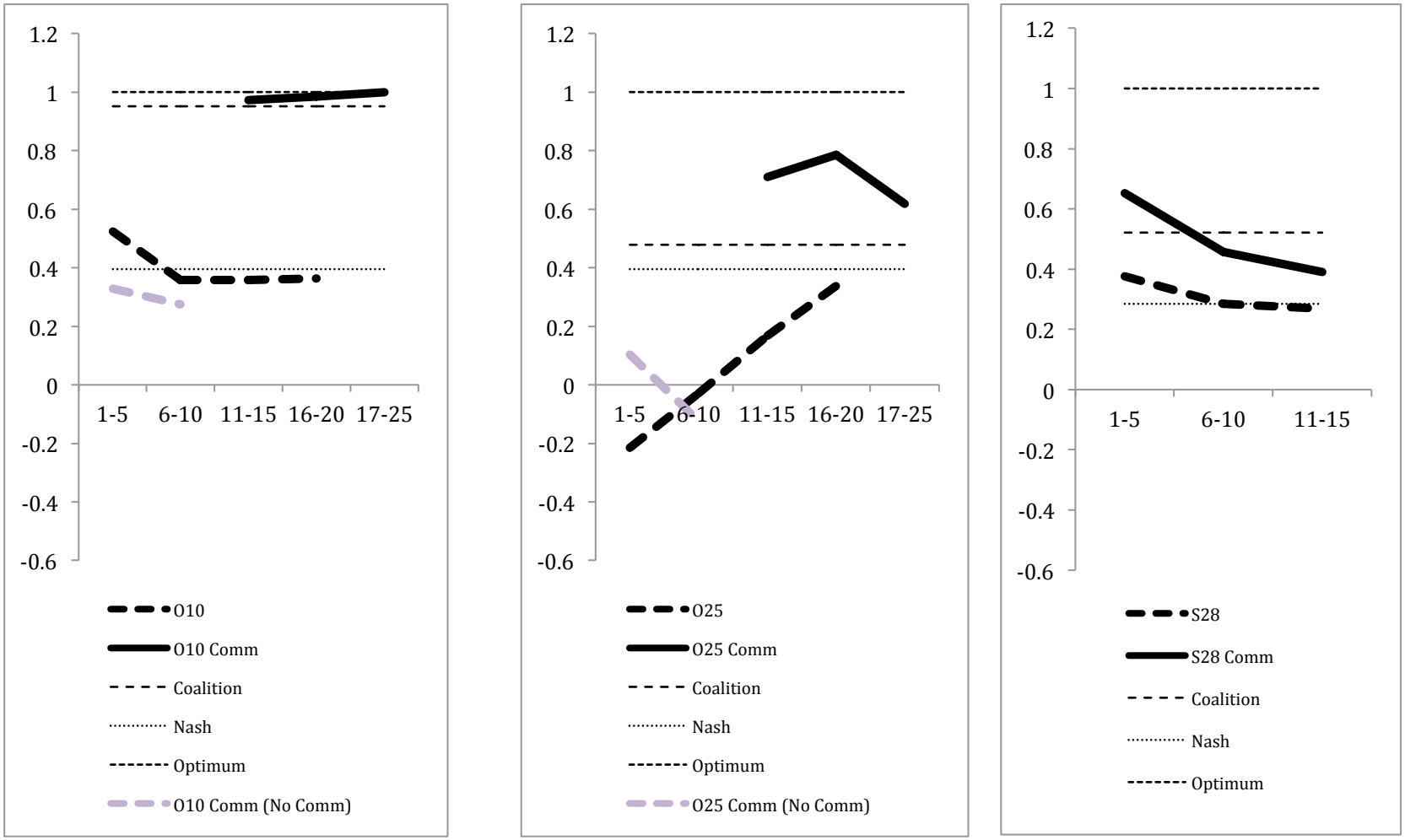
the predicted value for both O10 and S28. Adjustment towards the Nash benchmark is different for O25 with values well below the Nash benchmark (indicating that there was a substantial amount of over-appropriation over the first fifteen decision rounds. Relative system net rent approximates the Nash benchmark over the last five-round interval. A comparable pattern of adjustment to the Nash benchmark is displayed in Figure 5 for the system effort data. In this case the adjustment is from below the benchmark for O10 and S28 and from above the benchmark for O25.

Regardless of whether there are 8 or 12 appropriators, whether they have large or small endowments of effort to allocate to appropriation and whether the Nash equilibria are close to are far from the endowment, these appropriators will over-appropriate from the common pool. The Nash equilibrium is a remarkable organizing principle for the environments without communication. This is an environment in need of some sort of management to control appropriation.

The data in Tables 3 and 4 for the communication treatments are presented in Figures 4 and 5. Tables 5 and 6 present t-statistics for the hypothesis tests that there is no difference between the relative system effort or relative system net rent in the O10 and O25 environments with communication, the O10 and S28 environments with communication and the O25 and S28 environments with communication. The alternative hypotheses are that the pairs of treatments are different (a two-sided test). The tests indicate that over the three five-round intervals of the communication treatments there are differences between the O10 and O25 environments and the O10 and S28 environments ($p < 0.05$ in all intervals for relative system effort and $p \leq 0.05$ for all intervals for relative system net rent).

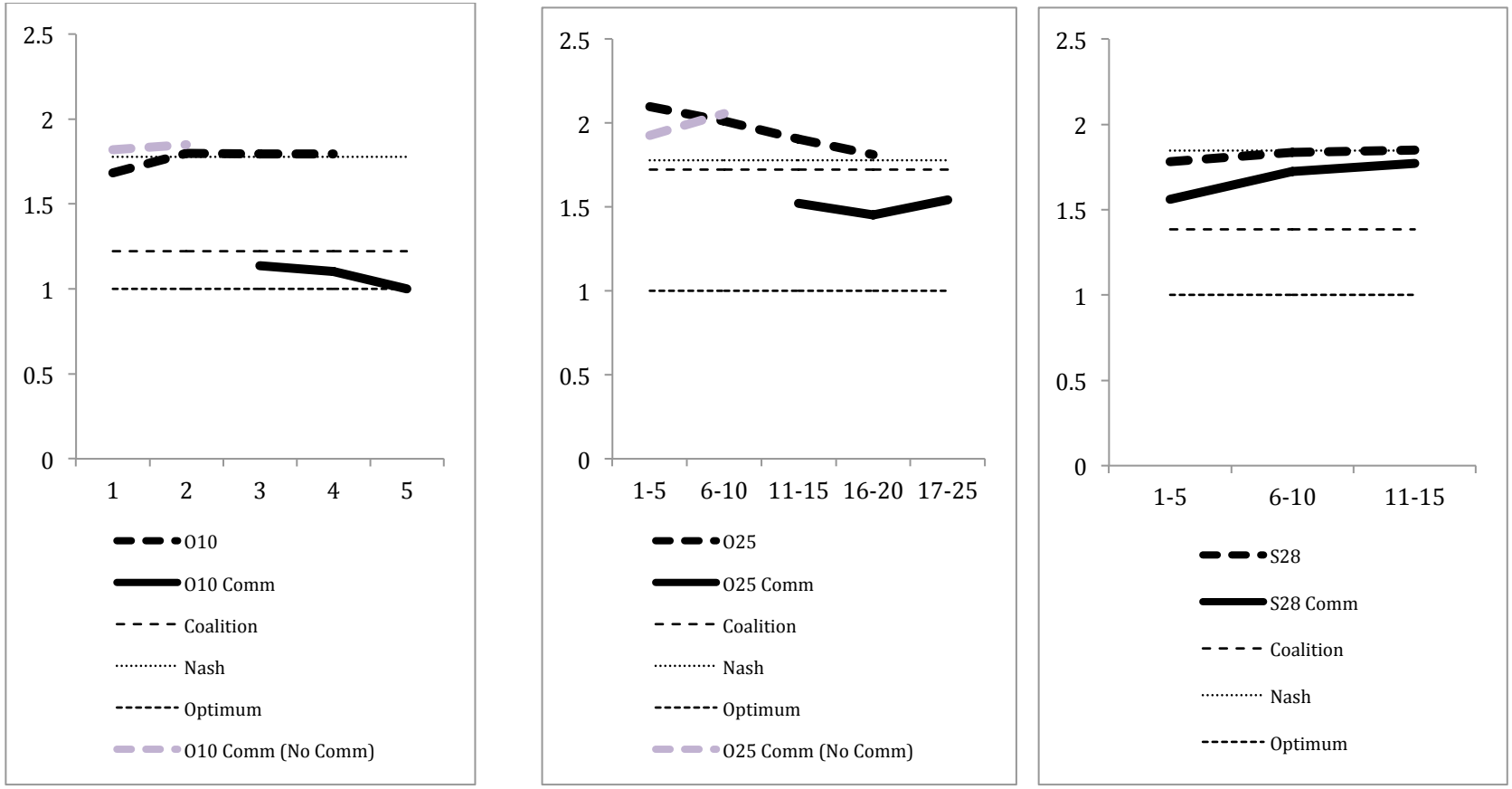
Table 5. Hypothesis Tests for Relative System Effort with Communication						
	O10 versus S28		O10 versus O25		O25 versus S28	
Periods	t-stat	p-value	t-stat	p-value	t-stat	p-value
11-15	4.692	0.003	4.655	0.002	0.407	0.698
16-20	8.403	0.000	5.620	0.000	3.427	0.014
21-25	11.821	0.000	4.079	0.004	1.331	0.232
Note: There are 6 degrees of freedom for the O10 versus S28 tests and 8 for the O10 versus O25 and O25 versus S28 tests. A Mann-Whitney U-test of the difference between average relative system effort for O25 and S28 over the last five periods of their sessions has a p-value of 0.171. This is consistent with the parametric t-test.						

Table 6. Hypothesis Tests for Relative System Net Rent with Communication						
	O10 versus S		O10 versus O25		O25 versus S	
Periods	t-stat	p-value	t-stat	p-value	t-stat	p-value
11-15	3.801	0.009	3.607	0.007	0.514	0.626
16-20	5.936	0.001	4.688	0.002	3.683	0.010
21-25	6.355	0.001	2.301	0.050	1.049	0.335
Note: There are 6 degrees of freedom for the O10 versus S28 tests and 8 for the O10 versus O25 and O25 versus S28 tests. A Mann-Whitney U-test of the difference between average relative system net rent for O25 and S28 over the last five periods of their sessions has a p-value of 0.171. This is consistent with the parametric t-test.						



Panel A. O10 Panel B. O25 Panel C. S28

Figure 4. Relative System Net Rent with and without Communication



Panel A. O10 Panel B. O25 Panel C. S28

Figure 5. Relative System Effort with and without Communication

However, for the O25 and S28 environments there are no significant differences during the first five-round interval and the third five-round interval ($p \geq 0.232$ in both intervals for both relative system effort and relative net system rent). While for these two environments there are no significant differences initially, during the second five-round interval effort falls slightly in the O25 environment but rises in the S28 environment and their differences are significant ($p \leq 0.014$ for both relative system effort and relative system net rent). However, effort rises in both environments in the third five-round interval and the relative system effort and relative system net rents are not statistically significantly different over these last five rounds.

If we focus on environments without communication, O10 and S28 display comparable convergence patterns to the Nash benchmark. O25 converges towards the Nash benchmark from a different direction and more slowly than do O10 and S28. With communication, however, we find no statistical differences between the last five-round intervals for O25 and S28 but we do find that O10 displays a unique convergence pattern.

4.3. The Analysis: Comparing O10, O25 and S28 to the Benchmarks

Tables 3 and 4 and Panels A in Figures 4 and 5 clearly show that with communication there is limited over-appropriation in O10. Both relative system net rent and relative system effort converge to the Optimum benchmark over the three five-round intervals. Because the values for relative system effort and relative system net rent are unity for the last five-round interval they are clearly not significantly different from the Optimum benchmark ($p = 1.000$).

Panels B and C in Figure 5 display relative system effort for O25 and S28. The results of hypothesis tests with regard to the Coalition and Nash benchmarks for O25 and

S28 over the last five-round interval are presented in Table 7. These indicate that the relative system effort for O25 is not significantly different from either benchmark ($p > 0.132$ for both). This is not surprising given that the Nash benchmark is 1.78 and the Coalition benchmark is 1.72 and the relative system effort is about 1.50 across the fifteen decision rounds. For S28, relative system effort is significantly different from the Coalition benchmark ($p = 0.018$), but is not significantly different from the Nash benchmark ($p = 0.306$). This too is not surprising given that the Nash benchmark is 1.85, the Coalition benchmark is 1.38 and the relative system effort is about 1.68 across the fifteen decision rounds. The results are comparable to the results obtained using the relative system net rent data.

Table 7. Hypothesis Tests for Benchmarks over the Last 5-Round Interval

	O25				S28			
Benchmark	Net Rent		Effort		Net Rent		Effort	
	t-stat	p-value	t-stat	p-value	t-stat	p-value	t-stat	p-value
Coalition	0.833	0.443	1.342	0.237	4.792	0.017	4.769	0.018
Nash	1.315	0.246	1.794	0.133	1.146	0.335	1.231	0.306
Note: There are 5 degrees of freedom for O25 and 3 degrees of freedom for S28.								

5. Conclusions

The motivation to compare the O10 and O25 environments presented in Ostrom et al. (1994) and the S28 environment presented in Buckley et al. (2013) was the apparent dramatic difference between the performances of the different environments with communication. In particular, the S28 environment with 12 participants showed little improvement in appropriation from the CPR with the introduction of repeated communication (the amount that effort was below the Nash benchmark was only 9% of the

way to the Optimum benchmark) while even the more poorly performing O25 environment with repeated communication displayed relative system net rent that was 37% of the way from the Nash benchmark to the Optimum benchmark. [Mackenzie thought this was too long]

Was this difference attributed to twelve subjects rather than eight? Was there something crucial about the number of individuals appropriating from a CPR that resulted in substantial congestion externalities that could not be overcome with a small increase in the number of appropriators? Was this difference attributable to the form of communication: computer-mediated chat room communication rather than face-to-face communication? Perhaps it can be attributed to the use of different variables to measure the success of communication as a management tool? The comparisons of the O10, O25 and S28 environments have now been made using both system effort and system net rent.

The first conclusion from the new analysis is that there are not significant differences between the performance of subjects in O25 and S28 with respect to relative system effort and relative system net rent. The two environments perform equally poorly with respect to the role communication plays in reducing appropriation from the CPR.

In explaining the relatively poor performance of the O25 environment relative to the O10 environment, Ostrom et al (1994, p.154) argue that the "high-endowment CPR game is a more challenging decision environment than the low-endowment game." They go on to argue that it takes fewer agents to defect and destroy the coordination to which the others may have agreed. They describe the O25 environment as being "more fragile" and that "in the field, this type of fragility is manifest in fisheries (all small boats versus all trawlers) and in forestry (individuals with chain saws versus bulldozers)." This fragility may be more related to the relationship between the amount of resources that a

participant can devote to CPR appropriation relative to the Optimum, Coalition and Nash benchmarks rather than the nature of the appropriator in a world of homogeneous appropriators. This is something that needs to be explored.

Table 8. Effort Benchmarks Relative to Endowments			
	O10	O25	S28
Nash Benchmark	64	64	288
Coalition Benchmark	44	62	216
Optimum Benchmark	36	36	156
Endowments	80	200	336
Nash/Endowment	0.800	0.320	0.857
Coalition/Endowment	0.550	0.310	0.643
Optimum/Endowment	0.450	0.180	0.464

Table 8 presents effort benchmarks relative to the endowments for each environment. The fragility of O25 relative to O10 is clearly evident when comparing the effort benchmarks relative to endowments. At the Optimum state for O10, 55% of the system endowment should be allocated to the "alternative" activity but for O25 this increases to 82%. With such large amounts of effort not needed to support the Optimum state allocations in the O25 environment relative to the O10 environment it is not difficult to understand the incentives that may exist to drive subjects away from the optimum benchmark when coordination has to be done through non-binding communication. This is a situation that could characterize a CPR fishery regardless of whether the appropriators are operating trawlers or small boats. Within the context of a dynamic externality it is possible that the CPR will be destroyed before the appropriate incentives direct the appropriators to allocate their effort efficiently.

Within the context of the CPR game in a controlled laboratory setting a relevant question is why do two environments with effort benchmarks relative to endowments so similar as O10 and S28, as displayed in Table 8, have such different outcomes? While the mode of communication or the number of appropriators are obvious differences between the environments, there may be a cognitive difference between the two environments that will provide an explanation.

In S28 appropriators are making decisions to pick one of 29 values for their appropriation effort in each decision round. In O10 appropriators are making decisions to pick one of 11 values for their appropriation effort in each decision round. A small change from round to round in O10 brings a substantial change in reward. In S28 a small change from round to round does not bring a substantial change in reward. What if appropriators in O10 were given 10 units of effort and asked to select from the set of effort {0, 0.33, 0.67, 1, 1.33, 1.67, … , 30}? This makes the decision space of the O10 participants comparable to that of the S28 participants. An alternative is to give the appropriators in S28 9.33 units of effort and ask them to select from the set of effort {0, 1, 2, 3, … , 9). This makes their decision space comparable to the decision space that the O10 appropriators with endowments of 10 face. Will the modified O10 environment converge to the Nash benchmark as does the unmodified S28? Will the modified S28 converge to the optimum benchmark as does the unmodified O10? These are relatively easy environments to implement in the laboratory and should provide insight into the value of results from laboratory environments that provide participants very small decision spaces when decisions in the field may be from a substantially different domain.

There are many different ways to present a CPR environment. In some, communication works extremely well. In other environments communication does not work as well in offsetting the over-appropriation found in environments in which appropriators are unable to communicate. We have to be careful when we try to draw policy prescriptions based on experiences whether they are in the laboratory or in the field. One thing is clear, experimentation may help sort out whether a policy instrument (such as promoting communication as a management mechanism) will work or fall short.

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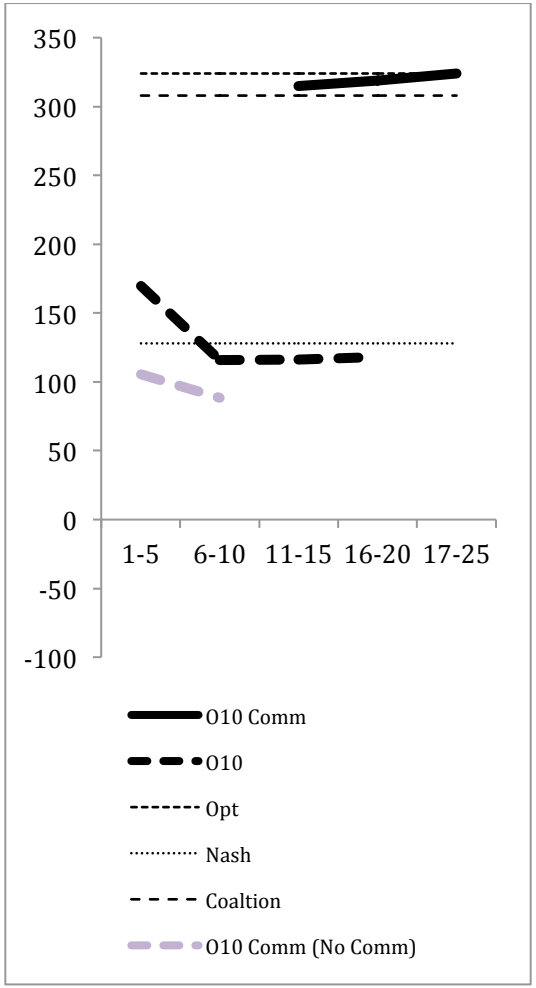
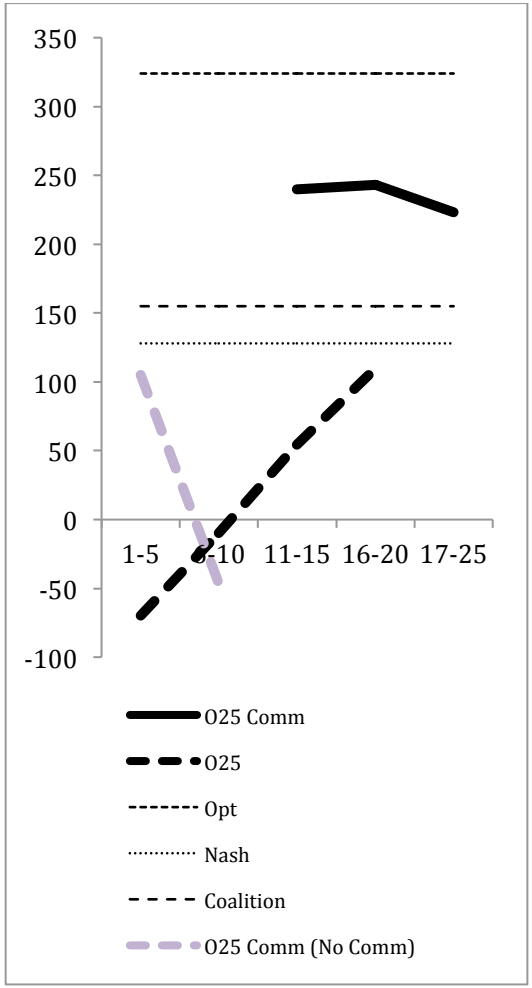
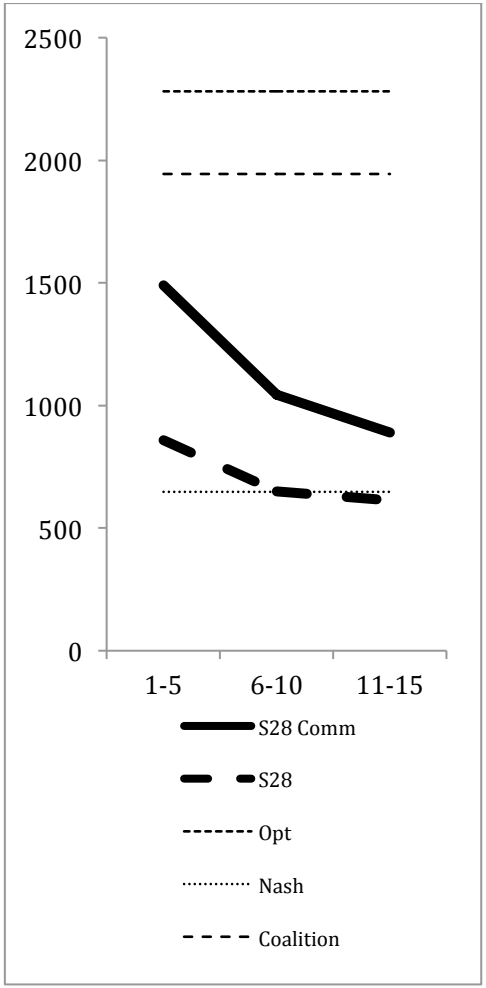
Appendix: Summary Figures Comparing O10, O25 and S28 Environments with Respect to System Effort and Net System Rent



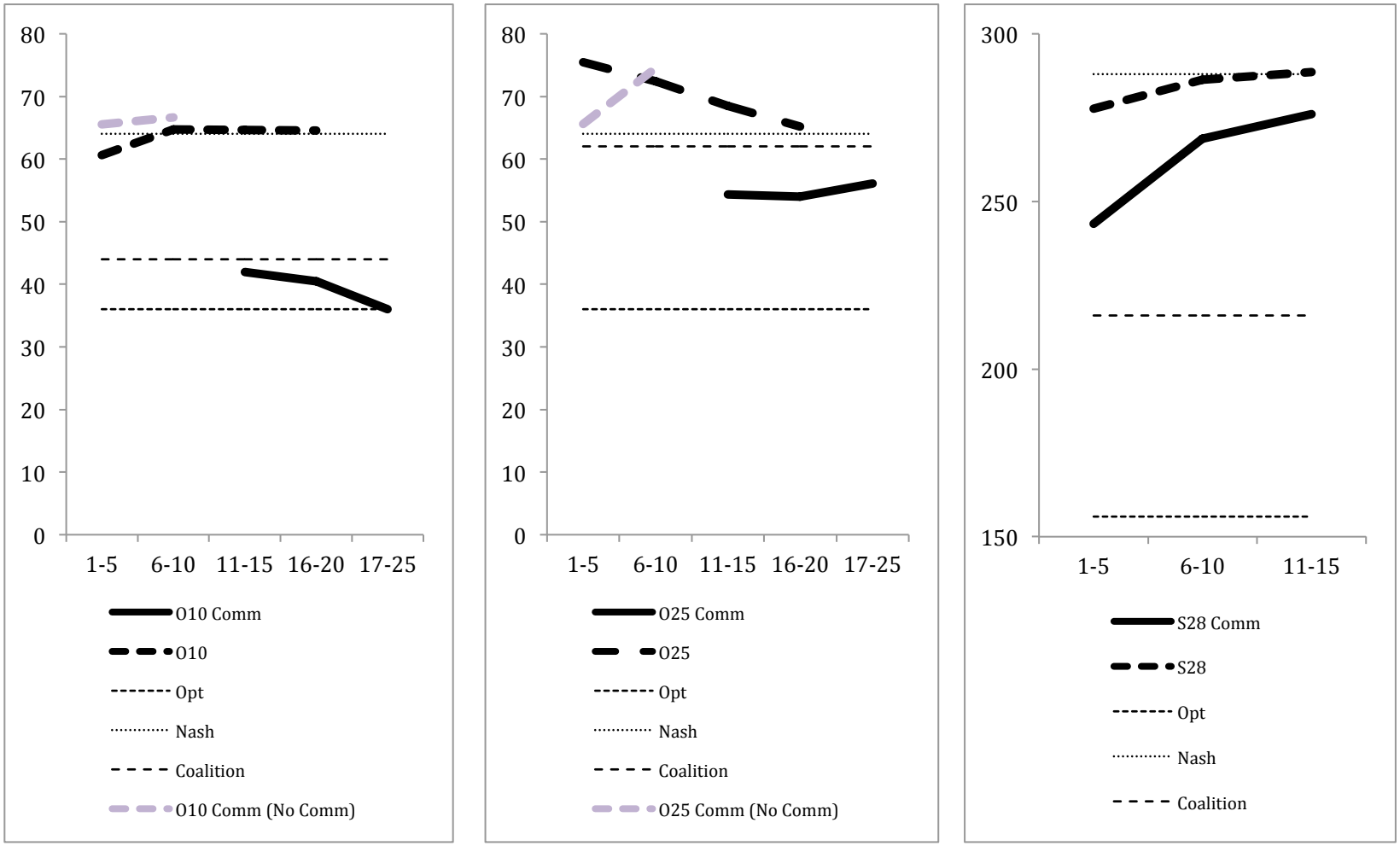
Panel A. O10



Panel B. O25



Panel C. S28



Panel A. O10 Panel B. O25 Panel C. S28

Figure A2. Mean System Effort with and without Communication