

Renewable Resource Extraction:

Experimental Analysis of Resource Management Policies

Under Assumptions of Resource Migration

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Abstract:

This paper presents research using a spatially explicit and dynamic common pool resource experiment to compare renewable resource extraction behavior between four treatments combining (1) open access and sole ownership institutions with (2) mobility and non-mobility of the renewable resource. The primary purpose of this research is to test the theory that introducing resource mobility into a sole ownership regime will remove the incentive for subjects to maximize the resource, instead causing them to revert to the myopic strategy predicted for the open access regime. I also test the hypothesis that open access firms are indifferent to resource dispersal. The results show that efficiency is unaffected by dispersal but the behavior of sole owners differs between dispersal conditions. Extraction requests increase at a faster rate under dispersal, fewer tokens remain unextracted in the final period, and some subjects show strategic behavior resulting in greater than 100% efficiency. This is a pilot study that presents preliminary evidence of a behavioral change. The results are subject to experimental factors such as subject misperceptions of linearity and statistical significance suffers from a small subject pool.

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1. Introduction

With population growth and economic development continually increasing world demand for natural resources, policy makers must have a robust understanding of the physical and economic factors affecting resource extraction. In 1987 the World Commission on Environment and Development, also known as the Brundtland Commission, published *Our Common Future*. This report introduced the concept of sustainable development and elevated natural resource extraction to a prominent place in policy discussions. Among the many natural resources, renewable resources are of particular interest. These resources are extremely important and include resources like fish and timber, cornerstones of major commercial industries, as well as surface water and aquifers, essential inputs for agriculture and human consumption.

Many renewable resources can be described as common-pool resources (CPRs) because (1) extraction produces an externality, reducing the resource stock and increasing the extraction cost of other firms and (2) restricting access, while not impossible, is difficult and costly. Over 40 years ago Garret Hardin (1968) presented a pasture shared by a number of herdsman as a classical example of a CPR. According to Hardin, the profit-maximizing herdsman decides whether or not to add an additional herd based on a simple cost-benefit analysis. Because the marginal benefit of the additional herd accrues exclusively to the herdsman but the marginal cost is an externality divided between every herdsman, he chooses to add another herd.

Unfortunately, when every herdsman pursues “his own best interest in a society that believes in the freedom of the commons,” the outcome is “ruin [for] all.” This is the tragedy of the commons. More generally, Mancur Olson argued in *The Logic of Collective Action* that rational actors seeking their own self-interest will not act in the common good without a separate incentive (1965). Works such as these have played a pivotal role in developing policy interventions meant to modify economic incentives.

One such intervention is property rights. In the absence of property rights, CPRs operate under an open access regime where there is unrestricted entrance to the market and therefore potential for the tragedy of the commons. In his 1960 article “The Problem of Social Cost,” Ronald Coase presented transferable property rights as an efficient solution to externalities under a specific set of conditions. Assigning sole ownership is one extension of this principle and has proven a solution to a number of CPR problems (Hilborn et al, 1995; Johannes, 1978). For natural resources sole ownership is often established by granting a single firm sole extraction rights within a given geographic area. To assume that the benefits of sole ownership applies to this type of allocation regime is to implicitly assume that the sole owner controls every aspect of that resource. This paper examines the effects of relaxing this assumption by considering the case of a mobile renewable resource.

Imagine an island nation that is physically isolated from other countries by a large expanse of sea and that has access to a fishery resource within its exclusive economic zone (EEZ)². Assume the fish in this zone are incapable of crossing the physical barriers separating the island from other nations. In this situation the country is not only the sole owner of extraction rights, but also the sole owner of the resource. On the other hand, consider countries bordering the Mediterranean Sea. While these countries also have their own EEZs, the geography allows fish to travel across EEZ borders. The countries in this situation have sole ownership of the extraction rights within their respective EEZ. However, the ability of the resource to move between EEZs prevents any one country from having sole ownership of the resource itself. In this example Mediterranean countries continue to face a common-pool resource and the associated tragedy of the commons.

² An exclusive economic zone (EEZ) is an area consisting of all waters within 200 nautical miles of a country’s coastline. A country has exclusive fishing rights within this EEZ.

Resource mobility and spatial attributes are the key factors that create this scenario. Economic research on renewable resources has only recently begun to consider spatial dynamics and resource mobility, and there is a significant lack of experimental work on the subject. This paper presents an experimental methodology that examines the effect of spatial dynamics and resource dispersal on the outcomes of open access and sole ownership regimes. This is, to the best of my knowledge, the first study to do so. To examine this effect I recruit undergraduate students to participate in a dynamic CPR experiment modified to include spatial dynamics and resource mobility.

Subjects are placed into groups of three and tasked with making token extraction decisions from either three common zones (in the open access treatments) or one private zone (in the sole ownership treatments). At the end of each period a logistic growth function is applied to remaining tokens to simulate natural resource growth, and this growth is added to the zone's previous token stock. I introduce resource mobility in the form of simplified, density-dependent dispersal that equalizes the token endowment across zones prior to the start of each period. I examine the open access regime and the sole ownership regime both with and without resource dispersal, for a total of four treatments. Payoffs are directly proportional to the total number of tokens extracted by each subject.

The primary purpose of this research is to test the theory that introducing resource mobility into a sole ownership regime will remove the incentive for subjects to maximize the resource, instead causing them to revert to the myopic strategy predicted for the open access regime. I also test the theory that open access firms are indifferent to resource dispersal because the myopic strategy exhausts tokens in the first period, making resource dispersal irrelevant. The main findings are that:

1. Average efficiencies are unaffected by resource dispersal.
2. The behavior of sole owners differs when dispersal is introduced.
 - 2.1. Dispersal causes requests to consistently increase every period, whereas without dispersal requests appear to follow a cyclical pattern.
 - 2.2. Under dispersal, increasing requests cause fewer tokens to remain in the final period.
 - 2.3. Dispersal allows many subjects to achieve greater than 100% efficiency, suggesting that some subjects capitalized on opportunities to harvest tokens dispersed from other zones.
3. Open access behavior is not significantly affected by dispersal

The results show that the research design could be improved by respecifying parameters and extending the experiment length in order to capture long-term behavioral adaptation to dispersal. In this sense the results also highlight some shortcomings of the experimental methodology which will be discussed in detail later.³ However, as a pilot study of mobile renewable resource policies, this research shows that sole owners facing dispersal do not immediately follow the dominant strategy of myopic extraction.

The paper is organized as follows. Section 2 provides a literature review of renewable resource policy, experimental findings from CPR experiments, and justification for the experimental methodology. Section 3 develops the CPR model and explains the experimental design. Section 4 presents the hypotheses. Section 5 presents the results. Section 6 discusses the findings and section 7 briefly concludes and makes recommendations for future research.

³ ³ This was a pilot study with limited resources, time, and funding. A number of parameters showed differences across treatments but were not significant at the 5% level. See the results and discussion for details.

2. Literature Review

2.1 Renewable Resource Policies

There is substantial literature on renewable resource extraction in the both economics and the physical sciences. Fisheries have been studied extensively in the last century and have probably generated the most policy-related research. Modern fishery management policies began after WWII with open access regulations that dictated the number and species of fish that could be caught as well as how, when, and where fishing could occur (Wilens, 1999). During this time new research began connecting biological understandings of fishery stock dynamics to economic behavior and suggested that economic incentives could be manipulated to achieve targeted policy outcomes (Beverton and Holt, 1957; Gordon, 1954; Schaefer, 1957; Scott, 1955). Now commonplace, the concept of maximum sustainable yield (MSY) was developed as a policy goal to maximize both economic yield and biological growth (Schaefer, 1957).

The exclusive economic zones created in 1982 by the United Nations Convention on the Law of the Sea introduced limited entry techniques to fishery management by excluding foreign fishers from very large domestic fishing markets (Wilens, 1999).⁴ In contrast to the open access regulations already in place, limited entry techniques attempt to constrain overexploitation by limiting the number of firms that participate in an industry. At the most extreme, a limited entry technique might establish a government agency, nonprofit, or private firm as the sole owner of a renewable resource. Economic theory of the fishery suggests that sole ownership will result in a more socially optimal outcome than an open access regime. In open access an individual firm receives the market's average revenue rather than its own individual marginal revenue, thus incentivizing an over-allocation of effort (Gordon, 1954; Schaefer, 1957). In contrast, sole

⁴ Prior to this convention, countries' exclusive rights consisted of only their territorial waters within 12 nautical miles from their coastline. Through this act exclusive rights were extended to 200 nautical miles

owners maximize profit by producing where marginal cost is equal to marginal revenue. This corresponds to the optimal level of extraction that lowers effort allocation and maximizes net economic yield (Gordon, 1954) (Figure 1).

When a sole owner is the only producer in a market it can increase its profit by charging a monopoly price higher than the competitive equilibrium. However, many renewable resources exist over a wide geographical area, making it possible to establish many sole owners of distinct resource patches. This prevents any one firm from establishing monopoly power and increasing the market price. Under this assumption, a sole owner who maximizes the present value of a fishery would find equilibrium closer to the social optimum than would firms in competitive equilibrium (Scott, 1955). Sole ownership has proven one of the most effective institutions in promoting sustainable extraction of some renewable resources (Hilborn et al, 1995). In Palau, Micronesia, control of fishing rights by chiefs helped maintain fishing stocks and allowed mutually beneficial fishing transactions in the vein of the Coase theorem (Johannes, 1978). Experimental evidence has shown that sole owners are able to achieve high levels of efficiency in resource extraction decisions when given adequate information (Hey et al, 2008).

2.2 Common Pool Resource Experiments

CPR experiments typically find that self-interested behavior prevents collective action from following an optimal path. Walker, Gardner, and Ostrom (1990) run an experiment where subjects repeatedly choose to invest tokens in either a fixed-return investment or a CPR with decreasing marginal returns. Subjects consistently overinvest in the CPR and even create negative returns when given a large enough endowment. A further study with probabilistic destruction finds that while most subjects appear to play “safe” strategies, a few myopic subjects overinvest and create early termination and low efficiency for the group (Ostrom et al, 1992).

Herr, Walker, and Gardner (1997) use the same basic design to compare performance between time independent and time-dependent treatments. They find that time dependency increases myopic behavior and exasperates the tragedy of the commons. High availability and low marginal extraction costs during initial periods cause subjects to over-extract early on, thus reducing future profits. This coincides with the “fall down” seen in emerging forestry and fishery industries where extractors face a dramatic drop in yield once they harvest all the original and unsustainable stock (Hilborn et al, 1995). The consequences of overcapitalization based on initial harvests are discussed elsewhere in the literature (Johannes, 1978; Moxnes 1998, 2000; Rouwette et al, 2004; Walker et al, 1990; Wilen, 1999).

Economics research has largely ignored spatial distributions until the 1960s and 1970s when biologists began examining discrete spatial distributions (Wiens, 1976). Levin (1976) develops a general mathematical model of populations in patchy environments and discusses density-dependent dispersal and the creation of uniformity across patches. Sanchirico and Wilen (1999) develop a differential equations model of a patchy fishery system that includes spatially distributed effort allocation that adjusts according to resource dispersal patterns. Schnier (2009) adapts the CPR design used by Walker, Gardner, and Ostrom (1990) to examine the sink-source spatial dispersal model discussed in Sanchirico & Wilen (1999). He finds that the spatial component decreases average net returns because subjects consistently over-extract in the more plentiful source CPR. On the other hand, a study of groundwater extraction with a spatial component that increases private costs relative to external costs found that subjects were less likely to behave myopically with the spatial component (Suter et al, 2012).

2.3 Why Use an Experimental Methodology

The experimental methodology lends itself well to research on renewable CPRs for several reasons, one being the challenges facing empirical studies. Data on renewable resources are often limited and rarely accurate due to the inherent difficulty of measurement (i.e. fish stocks are impossible to observe directly and many fisheries rely on informal logbooks for economic data). Estimating economic parameters that rely on biological data is therefore extremely difficult to do with confidence. Most Schaefer production functions of fisheries typically overestimate carrying capacities and maximum sustainable yields which can lead to potential fishery collapse (Zhang & Smith, 2011). Research directly analyzing policy must use extra caution because management policies are sensitive to measurement error and increasing levels of measurement error increase sensitivity to stochastic variation (Moxnes, 2003). Poor estimation has overinflated our perception of the health of resources and has played a major role in the collapse of some potentially sustainable resources (Hilborn et al, 1995).

Experimental methods can solve some of these problems. Researchers can design a system with known biological parameters to mimic any type of resource environment. If desired, information about the resource can be withheld and stock signals to subjects can be intentionally blurred to simulate real-world uncertainty. Renewable resource extraction is extremely complex because it relies on economic and biological variables that are not only endogenously determined, but also impacted by innumerable exogenous effects such as weather and macroeconomic variables. Experiments use random assignment to control for these confounding variables that are difficult to control and, in some cases, impossible to observe (Angrist & Pischke, 2010; Leamer, 2010). By isolating the institutional and environmental changes from

these confounding factors, this research attempts to discover the causal effects of dispersal on outcomes and behavior within open access and sole ownership policies.

3. Model & Experimental Design

3.1 The Model

This research uses a standard Gordon-Schaefer model of fishery extraction (Gordon 1954; Schaefer 1957). This model defines stock, extraction cost, and resource harvest as functions of effort. The resource is modeled as having logistic growth where growth is dependent on the resource's intrinsic growth rate and stock density relative to the carrying capacity of the environment (Figure 2).⁵ N represents stock, K carrying capacity, and r intrinsic growth rate. Maximum sustainable yield (MSY) occurs where growth and catch are maximized; in a standard logistic growth function this happens at one half the carrying capacity (Schaefer, 1957).

The current research investigates a resource inhabiting three distinct patches referred to as “zones.” I use a standard logistic growth function to model resource growth within each zone and I use a simple density-dependent dispersal that equalizes population densities across zones to model resource mobility (Figure 3). Growth & stock are modeled as:

$$\text{Growth:} \quad F(N_{it}) = rN_{it}\left(1 - \left(\frac{N_{it}}{K_i}\right)\right) \quad (1)$$

$$\text{New Stock(no dispersal):} \quad N_{i(t+1)} = N_{it} + F(N_{it}) \quad (2)$$

$$\text{New Stock (dispersal):} \quad N_{i(t+1)} = \frac{\sum_{i=1}^I [N_{it} + F(N_{it})]}{I} \quad (3)$$

⁵ Carrying capacity is determined by factors such as food, competition, predation, etc. Intrinsic growth rate represents the per-capita growth rate of a population.

In this design the total number of periods (T) is set equal to 5 while the number of zones (I) is set equal to 3. The carrying capacity (K) is 100 tokens and the intrinsic growth rate (r) is set to 1. N_{it} represents stock in zone I at time t, and the experiment begins as a virgin resource meaning $N_0=K=100$. There is no harvesting cost and the discount rate is assumed to be zero. Token harvests (x) are positively and directly proportional to cash payments by σ . Thus payoffs to subject n can be represented by π_n :

$$\text{Payout:} \quad \pi_n = \sigma \sum_{t=1}^T \left(\sum_{i=1}^I x_i \right) \quad (4)$$

I develop two benchmark strategies for evaluating the results of the experiment. Substituting $K = 100$ and $r = 1$ into equation (1) and solving for $F(N_{it})$ gives a growth maximizing stock level of 50 tokens. In this environment a rational agent thinking dynamically would maximize profit π_n by reducing the stock in all available zones to the optimal level of 50 tokens in the first period. The agent would then harvest only the new growth in periods 2-4 to return the stock to the growth-maximizing level. In the final period the agent would extract all remaining tokens. Thus the maximization strategy (MAX) is to request (50, 25, 25, 25, 75) tokens which achieves 100% efficiency (Figure 4). The second benchmark is extremely simple and considers a rational agent who thinks only in terms of present conditions. Such an agent would request all the tokens from each zone in the first period, leaving no tokens for future consumption. The MYOPIC strategy is thus (100, 0, 0, 0, 0) with an efficiency of 50%. The logic behind this benchmark is explained in the next section.

3.2 Experimental Design

A total of 113 subjects were recruited to participate in this experiment.⁶ Subjects were undergraduate students of Gettysburg College randomly recruited through email. They were told they would receive \$5 for participating in the experiment and would be able to earn an additional cash payment based on their performance in the experiment. Payoffs are designed such that the average subject was projected to receive approximately \$10 for 20 to 40 minutes of participation.

The experiment uses the z-Tree experimental software.⁷ The basic design follows a standard CPR experiment wherein subjects are placed into groups of three and must make individual token extraction decisions for five periods. After each period any remaining tokens within a zone grow according to the logistic growth function described in equation (1). The tokens available in the next period are calculated using equation (2) if the treatment does not include dispersal or equation (3) if dispersal is present. After each period subjects see a summary of the results from that period as well as the tokens available in the next period. Each stage of the periods is set to a nonbinding timer to encourage timely action.

There is one zone per subject. Extraction requests need not be whole numbers but may never exceed the endowment available in the zone. Tokens extracted by a subject are credited to her account and, at the end of the experiment, are exchanged for dollars at a known rate of \$0.05 per token. There are a total of four treatments: (1) open access with no dispersal (OAND); (2) open access with dispersal (OAD); (3) sole ownership with no dispersal (SOND); and (4) sole ownership with dispersal (SOD).

⁶ See Appendix B for details on recruitment.

⁷ Fischbacher, Urs. "z-Tree: Zurich Toolbox for Ready-made Economic Experiments." *Experimental Economics* 10, no. 2 (2007): 171–178.

In the open access treatments subjects are free to request tokens from all of the three common zones. If the group request from a zone is less than the zone's endowment, each subject receives a number of tokens equal to her request. If the group request from a zone is greater than the zone's endowment, each subject receives a number of tokens equal to her proportion of the group request. Period summaries display the group withdraw, the number of tokens received by the subject, and the number of tokens available in the next period for each zone. In the sole ownership treatment each subject may only request tokens from her own private zone. Likewise, period summaries only display the number of tokens received and the number of tokens available in the next period for the subject's own zone.

An important component of the design is that subjects are given both the exact growth function as well as a table of growth possibilities.⁸ The experimenter reads the description of growth and dispersal aloud and gives subjects time to review the instructions before beginning the experiment. This availability of information is not representative of real-world renewable resources. However, giving subjects this information removes the confounding affect of adaptive management strategies subjects would need to use to determine the optimal stock level and extraction pattern.⁹

4. Hypotheses

The current research tests three hypotheses concerning the effects of dispersal on outcomes: (1) subjects in sole ownership without dispersal follow the MAX strategy; (2) subjects in open access follow the MYOPIC strategy, regardless of dispersal condition, and (3) introducing resource dispersal to sole ownership causes subjects to follow the MYOPIC strategy

⁸ See Appendix C for experimental materials

⁹ See Hey et al (2008) for a discussion of a "reasonable" benchmark strategy when stock is known but the growth function is unknown.

rather than the MAX strategy. These hypotheses rest on the assumption that individual subjects are rational, self-interested, profit-maximizing actors.

Economic theory suggests that the equilibrium extraction level of a sole owner of a renewable resource maximizes the present value of the resource in the absence of price factors (Gordon, 1954; Scott 1955). Past studies have shown that sole owners without full information achieve poor outcomes (Moxnes 1998, 2000, 2004) while subjects not directly given full information but with access to it fall somewhat short of complete maximization (Hey et al, 2008). Subjects in this study are directly given both the growth function as well as a table of every possible integer stock level and its corresponding growth. Thus subjects in SOND are expected to follow the MAX strategy and obtain 100% efficiency.

Rational choice theory, collective action theory, and theory of the commons predict that subjects in the open access treatments will act in their own best interest and not achieve the goals common to each subject. The theory of myopic loss aversion suggests that subjects emphasize present conditions over future conditions and will assign more weight to potential losses than potential gains when making extraction decisions (Benzarti & Thaler, 1993). Results from CPR experiments show that subjects consistently tend to act myopically (Ostrom et al, 1992; Herr et al, 1997; Walker et al, 1990; Walker & Gardner, 1992). From a game-theory perspective, if each subject knows that the other subjects will request all tokens in the final period, it is then strategic to request all tokens in the penultimate period. Using backwards induction it becomes clear that the dominant strategy of each subject is to extract all tokens in the first period. Because dispersal only affects next period endowments, dispersal should have no effect on open access outcomes. Thus, subjects in OAND and OAD are expected to follow the MYOPIC strategy and achieve 50% efficiency.

It is easy to see how the same concept applies to sole ownership when resource dispersal is present. The benefits of sole ownership imply the owner is in control of not only the resource environment but also the resource itself. While a subject cannot request tokens from another subjects' zone, she can "steal" tokens through the dispersal mechanism. Imagine a game in which subjects A and B play MYOPIC and subject C plays MAX. Subjects A and B each receive 100 tokens in the first period while subject C receives only 50 tokens. In the second period subjects A and B are each endowed with 25 tokens that have dispersed from subjects C's zone, leaving subject C with 25 tokens. All three subjects now play MYOPIC, as subject C can no longer play MAX and realizes her endowment may continue to drop even if she does not extract. All subjects receive 25 tokens and the game ends. Subject C receives a total of 75 tokens compared to the 100 tokens she would have received if she had played MYOPIC from the start. Thus, subjects in SOD are expected to follow the MYOPIC strategy and achieve 50% efficiency.

5. Results

The experimental results are summarized in Table 1. Unless explicitly stated, all reference to statistical significance considers significance at the 5% level. The experiment can generate at most 600 tokens, so individual efficiency is compared to one third of this, or 200 tokens. Individual efficiencies greater than 100% are thus possible in all but the SOND treatment.¹⁰ Subjects in open access make extraction decisions from three zones per period while subjects in sole ownership only make extraction decisions from one zone. Because the three zones cannot be treated as statistically different, I test that the percentage extractions do not differ between zones, and find that only the difference between zones B and C is statistically

¹⁰ In open access this is easy to understand: a subject could obtain up to 600 tokens if the other subjects in her group made no extraction requests. Similarly, subjects in MD can harvest tokens dispersed from other zones, up to a maximum of 335 tokens.

significant ($p=0.0431$). With this in mind I construct a single period request that is the individual's average request from the three zones in order to make open access requests comparable to sole ownership requests.

5.1. Open access

Efficiency in open access is negligibly higher without dispersal but this difference was not statistically significant using a two-sided Mann-Whitney test ($p=0.6591$) (Figure 5). Neither treatment was statistically different from the MYOPIC result of 50% efficiency using a Wilcoxon signed-rank test (OAND $p=0.0679$; OAD $p=0.4004$). Three subjects in OAD exceeded the MAX benchmark with a high of 105.2% and one subject in OAND exceeded the benchmark with 101.19%. Open access treatments exceeded the expected experiment length of one period (Figure 6). Still, 11% of groups with dispersal and 44% of groups without dispersal fully exhausted the resource in the first period. Dispersal increased average length by 0.55 periods but this result is not statistically significant ($p=0.3091$). Only one group in each treatment played the full five periods.

First period extractions are skewed heavily to the left, with the most prominent skew of the four treatments being in OAND (Figure 7). The average per zone request is higher without dispersal but the difference is not statistically significant ($p=0.9035$) (Figure 8). Between all three zones, the total individual requests in the first period exceed the initial endowment of 100 tokens. Extraction patterns in the open access treatments clearly reflect the fall-down in resource stock predicted by overharvesting in the first period (Figure 9). First period percentage requests are lower under dispersal but quickly increase to exceed requests in the absence of dispersal (Figure 10). Despite the fact that each of the two groups reaching the final period had an endowment of less than one token, neither group failed to achieve full exhaustion.

5.2. Sole Ownership

Sole ownership efficiency is identical across treatments and far exceeds open access efficiency, but falls short of the MAX prediction of 100% efficiency. Nine subjects in SOD exceeded 100% efficiency with a maximum of 112.43%, the largest of all treatments. Exceeding 100% was not possible in the SOND treatment. All groups in SOD played the full five periods while one subject in SOND exhausted the resource in the second period.

Like in open access treatments, first period requests were right skewed. Sole ownership reduced first period per-zone percentage requests by 6.68 points with dispersal and 5.61 points without dispersal, but this effect was not statistically significant ($p=0.0839$ and $p=0.5757$, respectively). Moreover, total individual requests were significantly lower than in open access where subjects withdraw from all three zones. Within sole ownership, dispersal reduced initial requests by 4.75 but was not statistically significant ($p=0.1525$).

The extraction pattern for SOND pulses around 30 tokens while the pattern for SOD follows a flattened quadratic form. The treatments have an identical final period request that is achieved by a sharp increase in final period requests in SOND. As a percentage of endowment, both treatments maintain their basic form but SOND is now increasing and SOD is increasing at a much faster rate. First period extraction percentages in SOD are the lowest of all four treatments but steadily increase and triple over the course of the experiment, ending as the highest of the four treatments. Despite the increasing percentage requests, failure to exhaust tokens in the final period was a major problem in both treatments (Figure 11). Only 46.43% of SOND subjects and 36.67% of SOD subjects fully exhausted the resource.¹¹ The maximum

¹¹ In making this calculation, remaining token values of less than one were treated as exhausted. See the next section for a discussion of this and its impact on behavior. The subject in MND who had previously exhausted his resource was not considered.

number of tokens remaining was 63.7 tokens with dispersal and 79.6 without. This reduced efficiency by 10.8% in SOND and 6.4% in SOD.

6. Discussion

6.1 Sole Ownership: Extraction Patterns

The results did not support my primary hypothesis that sole ownership efficiency gains would erode when subjects faced resource dispersal. Rather than follow MYOPIC behavior, subjects in the SOD treatment appeared to have the most cautious behavior in the first period. Considering low first period requests as well as efficiency and game length on par with, and even slightly better than SOND, it would at first seem that adding dispersal did not cause sole ownership subjects to behave more like open access subjects.

On the other hand, a few subjects in SOD appeared to behave according to the MYOPIC strategy. In every period at least one subject requested the full endowment and 30% of subjects achieved over 100% efficiency, an outcome that could only occur if the subject was harvesting tokens that had migrated from other zones. Mean percentage requests also increased over time at an increasing rate. This suggests the possibility that subjects initially playing cautious strategies began to become more aggressive as the experiment progressed. It is impossible to predict what would have happened given a longer experiment, but the linear decline in stock hints that early exhaustion may have occurred (Figure 12).

Given that two thirds of SOD subjects failed to exhaust the stock in the final period, it is possible that these subjects were playing as if the game would continue. Extraction in SOND appears to slow in the fourth period after stock finally drops below the optimal level. If the game were longer, this might reflect an adjustment that would bring the stock back towards the optimal level. On the other hand, SOD extraction in the fourth period increases stock deviation from the

optimal level at an increasing rate. If this trend continued resource extinction would occur in only a few additional periods. These findings highlight the limitations presented by the length of the experimental design and suggest the effects of dispersal may be witnessed in long-term behavioral adjustment rather than immediate strategy change.

6.2 Sole Ownership No Dispersal: Failure to Maximize

Although these findings show that sole ownership subjects not facing dispersal did not follow the predicted MAX strategy, they still performed better than open access subjects. Subjects in SOND did extend the life of the resource throughout the game despite failing to maximize growth. Only 8 first period requests hit the optimal 50 tokens and 62.07% of requests were at or below 35 tokens. Subjects did not bring tokens to the optimal stock in the second period either, with more than half of subjects having a stock level above the optimal. Clearly, subjects are choosing cautious extraction patterns. Furthermore, the 8 subjects with optimal post-extraction stock in the first period shrank to 3 subjects in the second period and 2 subjects in the third and fourth periods.

The fact that most sole ownership subjects do not reach or even approximate the MAX strategy suggests that subjects do not fully understand the game. This is surprising because subjects are directly given growth information in both equation and table format. Similar results have been found in another study of sole ownership extraction where subjects were given indirect access to full information (Hey et al (2008)). This study found a SOND efficiency of 87.4% compared to 76.4% in the current study. This difference is probably in large part due to three factors. First, subjects in that study tended to over-extract in the first period compared to my research where severe under-extraction was common. Second, failure to extract all tokens in the final period was about 50% more common in my study. Finally, the shorter length of my experiments put greater weight on the first few periods where deviation from optimal behavior

was more common. For this reason I expect that SOND efficiency would increase in a longer experiment and more closely resemble the results found in Hey et al (2008).

6.3 Open access: Expected Outcomes, Unexpected Behavior

MYOPIC behavior was expected in both of the open access treatments in addition to SOD. There is evidence to suggest that a small number of subjects followed self-interested strategies although only two subjects in OAND and no subjects in OAD followed the MYOPIC strategy. In both treatments one subject closely approximated this strategy, requesting all but one token. Likewise, one subject in OAND and three subjects in OAD achieved efficiencies greater than 100%. However, most subjects in the open access treatments did not behave aggressively. Over two-thirds of OAND subjects chose to request less than the 'fair' value, which I consider to be one third of the tokens available to the group. In the second and third periods this jumped to 80% and 85%, respectively. The same is true for OAD where half of subjects requested less than the fair value in the first period. This remained true for the second and third periods, but increasing cumulative requests exhausted most of the resource before the fourth period.

Clearly, most subjects were not following the self-interested strategy predicted by rational choice theory. On one hand, the two MYOPIC extraction requests and the handful of other aggressive requests mixed with many more conservative requests suggests that only a handful. On the other hand, this evidence also supports criticism of the belief that subjects conform to self-interested interpretations of rational choice theory. Regardless of interpretation, the results clearly show that the few subjects acting in self-interest succeeded in ensuring the tragedy of the commons occurred for all members of their groups. Thus, overall efficiency was nearly identical in both treatments and very close to the MYOPIC benchmark. No outcome variables were significantly different at the 5% level and extraction patterns were very similar.

The evidence appears to support the hypothesis that dispersal has little effect on behavior and outcomes in open access.

6.4 Experimental Design

When experimental research reveals surprising results, it is necessary to consider whether the results are a consequence of the experimental design. In this experiment the lack of different outcomes between sole ownership treatments, as well as the lack of MYOPIC and MAX strategies in open access and SOND, respectively, are all surprising results. I will examine two factors that could have affected the results: (1) subject understanding (2) parameter values, incentives, & payoff structures.

Because subjects in SOND face no competition, any deviation from the predicted MAX strategy is a result of individual conceptualization and understanding of the experiment. A number of subjects in all treatments asked questions and made statements indicating that they did not fully understand the experiment. The wide range of efficiencies in SOND and the mixed strategies within each treatment backup the anecdotal evidence of misunderstanding (Figure 13). The model of resource growth used is nonlinear in the growth equation, and there is evidence that subjects in experiments consistently misperceive linearity in non-linear environments. Psychological studies have found that subjects tend to default to linear mental models and struggle to develop a non-linear understanding based upon feedback (Brehmer, 1980, 1992; Sterman, 1994). Even when using perfect property rights to remove the commons problem from resource management, subjects consistently mismanage the resource and achieve sub-optimal outcomes (Hey et al, 2008; Moxnes 1998, 2000, 2004; Sterman, 1994). These studies suggest that mismanagement is worse in experiments with higher degrees of complexity and lower information availability.

Misperceptions of linearity are one optimistic explanation of the mismanagement scene. However, there is evidence that linearity is not the cause. In the study by Hey et al (2008) subjects fell short of maximization despite being given a calculator that they could use to explore post-extraction stock, growth, next period stock, and savings based on possible extraction amounts (Figure 14). Furthermore, subjects in the current study were given a growth table including all integer stock values. Subjects in these experiments can use the resources provided to find the optimal strategy without understanding the non-linear growth function. It was highly unexpected that subjects in the SOND would fail to maximize the resource given the ease of identifying the growth-maximizing stock. The reason for this failure is unknown.

Based on the results and findings by other experimental studies, subject understanding is likely the most serious problem that could be addressed by the experimental design. However, parameter specification also impacts results, specifically experiment length. A length of only five periods highlights initial mismanagement by weighting each period so heavily in overall outcomes. This brevity also may have hidden differences between sole ownership treatments that would have become apparent in a longer experiment. The initial endowment and intrinsic growth rate likely influenced results by limiting absolute change in marginal token growth to less than 1 token. This specification also created situations where subjects faced fractional endowments. With a payoff ratio of \$0.05 per token and a difference between MYOPIC and MAX payouts of \$5, subjects had very small real-world incentive to search for the optimal extraction path.¹²

¹² It was necessary to limit payoffs in order to achieve a suitable number of subjects.

6.5 Rationality

While poor understanding of the experiment was certainly present, the results also suggest that the calculating and self-serving *homo economicus* understanding of rationality may not be the most appropriate model of human behavior. First period withdrawals in open access are not significantly different from the ‘fair’ request of one third of the tokens ($p=0.894$). Almost a quarter of requests fall between 30-33% of the endowment. This cooperative behavior is better understood through *homo sociologicus*, a definition of rationality focusing on norms and reciprocity rather than solely self-interest (Bruni 2008; Engelen, 2007). Similar results have been found in many experimental studies, some of the most interesting of which are ultimatum games where subjects’ modal response is to split the endowment 50-50 (Gintis, 2000).

Homo sociologicus could also explain the increasing requests in SOD. Experimental studies have shown that subjects heavily utilize tools to punish defectors, even when at a cost to themselves (Gintis, 2000; Janssen et al, 2010; Ostrom et al, 1992) or when no direct benefit can be obtained due to group reorganization (Fehr & Gächter, 2000). In the absence of punishment tools, subjects may often choose to follow tit-for-tat strategies (Gintis, 2000). In the current study the only way social subjects can punish selfish subjects is by playing more selfish strategies. Thus, the increasing extraction rates in SOD may identify the reciprocal reaction of social subjects to extraction by selfish subjects.

A final argument to be made against the classical assumptions of rationality is that subjects in SOND that failed to find the optimal growth level of harvest all tokens in the final period clearly were not “weighing off the expected costs and benefits of actions and choosing the action that they consider to be the best” in the manner predicted by *homo economicus* (Engelen, 2007). The same is true for subjects facing fractional endowments because, while possible profit

was low, entering a request equal to the endowment was no more costly than entering a request of zero. It appears that subjects were not aggressively pursuing maximization but instead were satisficing with “good enough” (Simon, 1957). *Homo economicus* cannot explain this mismanagement in the presence of full information, regardless of the explanation. Modeling rationality is difficult, and *homo economicus* is a convenient assumption because its simplicity makes analysis and drawing conclusions easier. But humans are intellectually and socially complex actors operating within complex social structures - simplification may not be the best way to examine the results of experimental economics.

7. Conclusion

This paper uses experimental methods to examine the relative performance of open access and sole ownership policies in environments where renewable resources are characterized by equalizing dispersal. Renewable resource policies that assign sole ownership of a resource aim to increase efficiency by removing the perverse incentives subjects face in an open access regime. However, economic theory suggests that sole ownership fails when it provides only exclusive extraction rights and does not give complete control over the physical resource. Such a situation can occur when a mobile resource is capable of crossing ownership boundaries.

As a pilot study, this research has furthered the understanding of how renewable resource extractors respond to resource dispersal across management zones. As expected, subjects in the open access regime are largely indifferent to resource dispersal because the resource is almost entirely harvested in the first period. The hypothesis that sole owners facing dispersal will demand the entire resource in the first period was not supported by the results. In fact, dispersal did not affect sole ownership efficiency and actually reduced first period requests. However, subject behavior differed in the form of steadily increasing requests not seen by sole owners who

did not face dispersal. Likewise, some subjects actually achieved efficiencies of greater than 100% by harvesting tokens dispersed from other subjects' zones. Together, these findings suggest that the effect of dispersal is in long-run adjustments to aggressive behavior rather than in immediate changes to initial strategy. The logical extension of this finding is to ask two questions. First, in a longer experiment will this behavior continue to the point of resource exhaustion? And second, are the increasing requests part of a response by cooperative subjects to the aggressive requests of non-cooperative subjects?

While this research uses an experimental methodology because there are many challenges facing empirical research, it is clear that experimental work is not without its limitations. As the experimenter, my own anecdotal and observational evidence of subject confusion during this research leads me to question the accuracy of the results. The evidence presented here supports this natural skepticism, most notably the failure of most sole owners to fully exhaust the resource in the final period. Given that subjects were informed that the experiment would end, this is in violation of the usual assumptions made when invoking the self-interested rationality defined by *homo economicus*. Similarly, while a small portion of subjects appeared to fit within the *homo economicus* framework, the majority of subjects exhibited cooperative behavior or negative reciprocal response to aggressive subjects. If subjects are neither fully utilizing the information they are giving nor acting in purely self-interested ways, perhaps another definition of rationality may be more applicable to experimental research.

This research has presented new avenues of inquiry for experimentalists interested in renewable resource extraction. I recommend that future experimental research focus exclusively on sole ownership policy, take measures to address subject understanding, and examine more social definitions of rationality. Key to this will be a design that will examine the long-term

effects of dispersal on sole ownership behavior and analyze behavior at the individual level.

Based on the evidence presented here, it is my belief that such research will find behavioral response to dispersal and add to the understanding of renewable resource management policy.

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Appendix A: Figures & Tables

Treatment	n	Theoretical Efficiency	Observed Efficiency	Std. Deviation	Mean Length (periods)	Std. Deviation
OAND	27	0.50	0.569	0.218	2.6	1.601
OAD	27	0.50	0.558	0.278	3.1	1.121
SOND	29	1.00	0.764	0.147	4.9	0.557
SOD	30	0.50	0.764	0.283	5.0	0.000

Table 1. Summary of experimental results

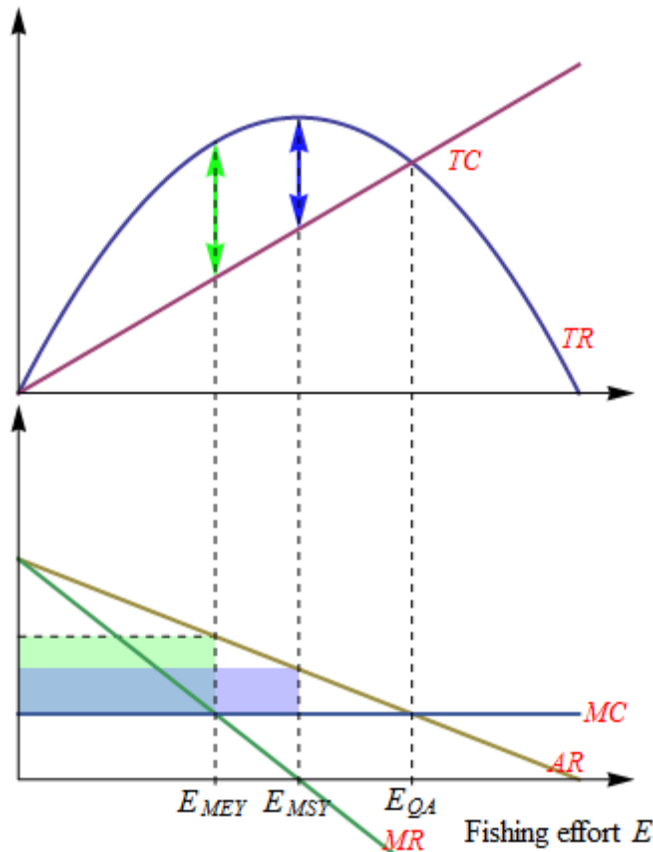


Figure 1: The Gordon Schaefer model.

Total Revenue (also representing population growth) increases when effort allows larger harvests, but decreases when too much effort reduces the resource stock beyond its maximum growth level. The model predicts over-allocation of effort in open access because individual firms receive the market's average revenue rather than their own marginal revenue (E_{QA}). This essentially occurs because part of the harvest earned by a new firm entering the industry would have been harvested by other firms.

Schaefer's Maximum Sustainable Yield (E_{MSY}) creates profit and maintains resource stock by harvesting such that the growth-maximizing stock level is maintained.

Gordon's Maximum Economic Yield is the optimal outcome (E_{MEY}) that maximizes profit by producing where $MR=MC$. This corresponds with the lowest level of effort and highest resource stock.

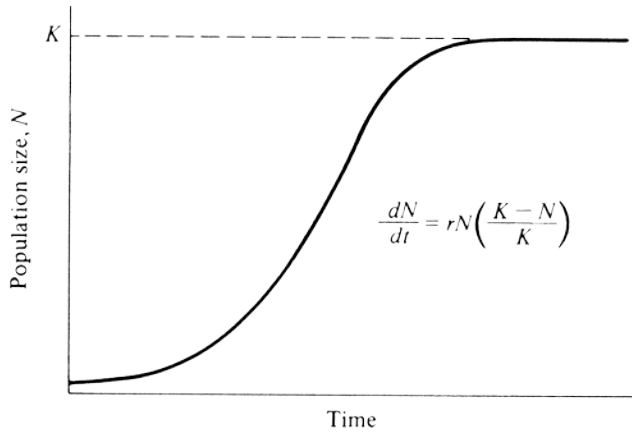


Figure 2: Standard population model depicting logistic growth. The population grows very slowly when the population density is very low or very high, and much faster when the population density is near half the carrying capacity.

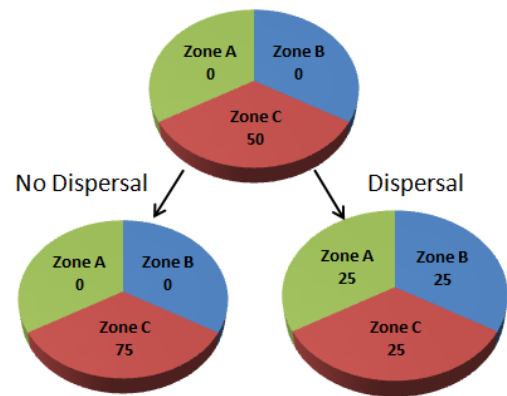
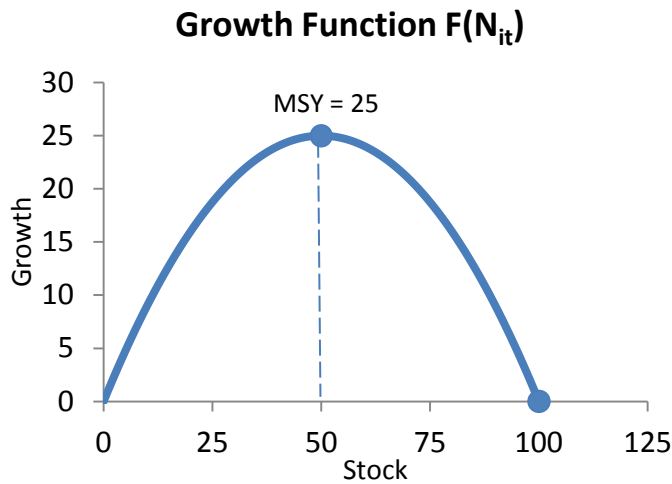


Figure 3: Logistic growth function used in this experiment with $K = 100$ and $r = 1$ (left). Example of equalizing dispersal where Zones A and B grow no tokens while Zone C grows 25 tokens (right).

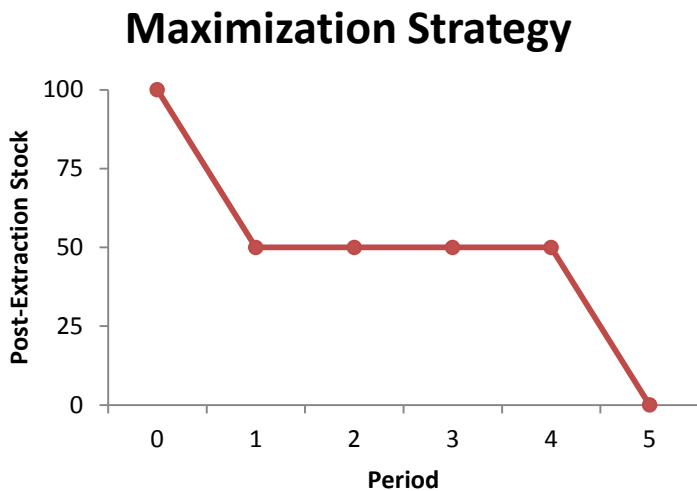


Figure 4: The maximization strategy (MAX) brings stock to MSY in the first period, harvests only growth in intermediate periods, and harvests all tokens in the final period.

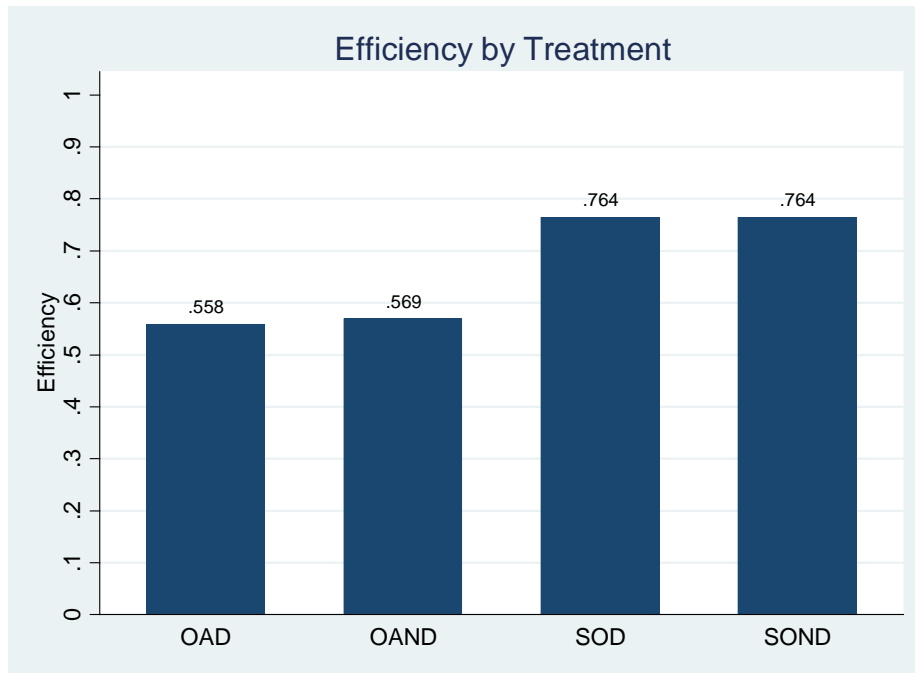


Figure 5: Mean efficiency by treatment. Differences between policies are significant at the 5% level while differences between dispersal conditions are not.

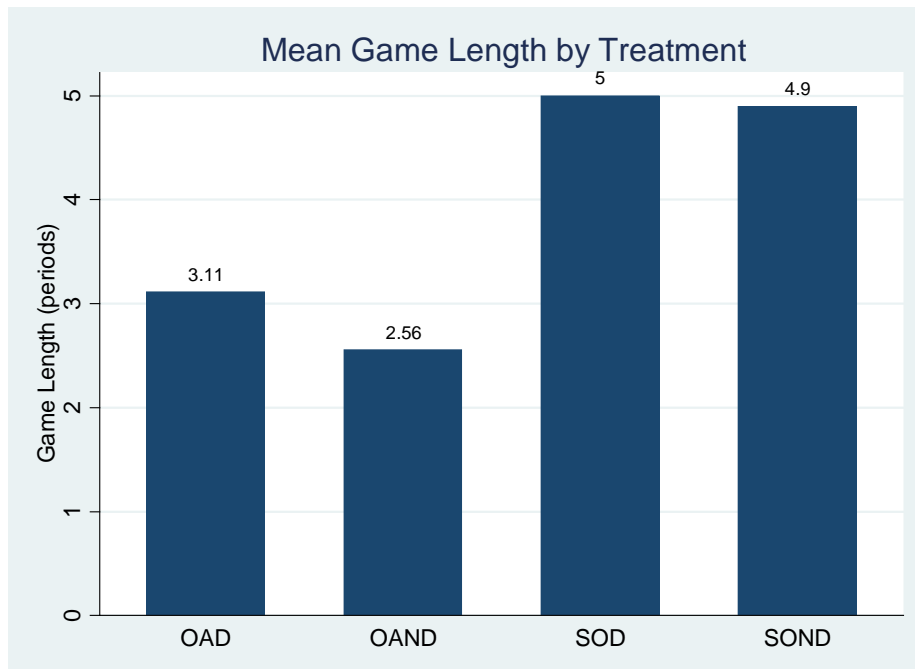


Figure 6: Mean game length by treatment. Differences between policies are significant at the 5% level while differences between dispersal conditions are not.

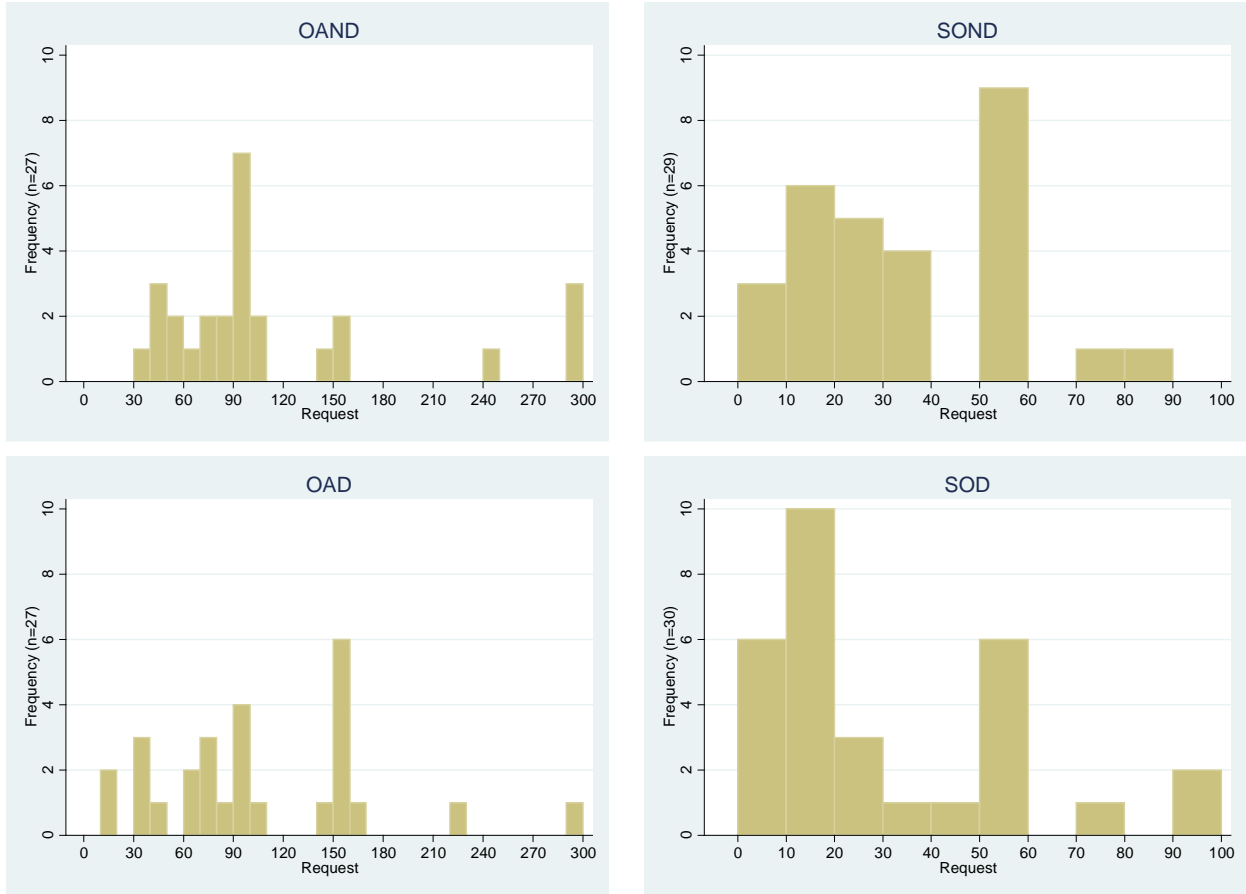


Figure 7: Histograms displaying frequency distribution of first period requests.

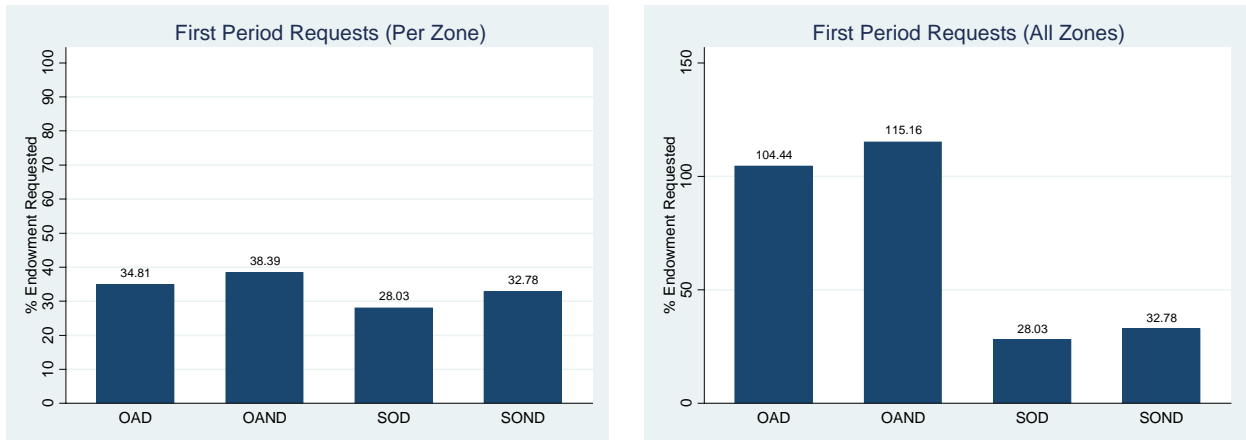


Figure 8: First period individual requests by treatment. Requests are shown per zone (left) and combined from all zones (right) to highlight the impact of multiple zones in open access treatments.

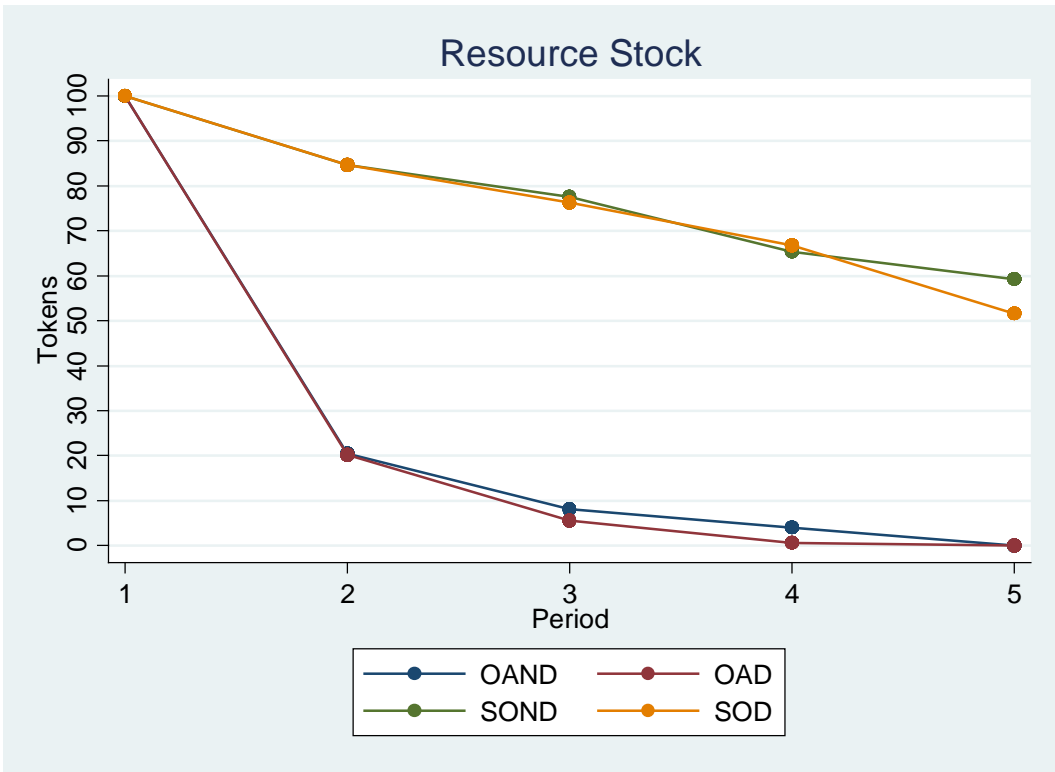


Figure 9: Extraction pattern by period: absolute token requests.

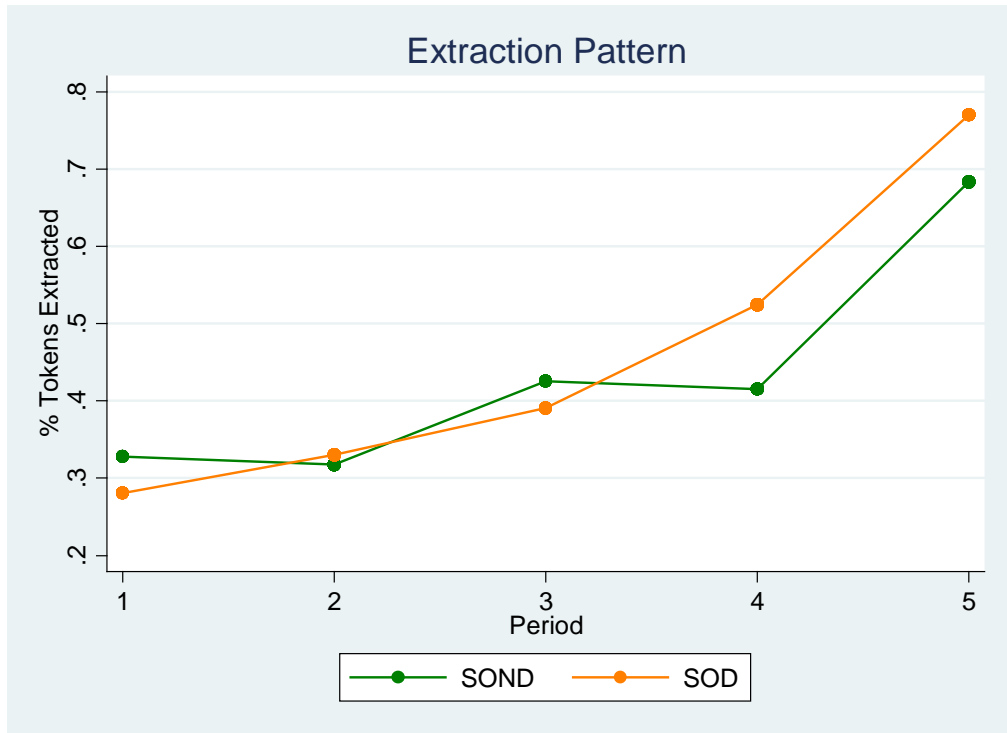


Figure 10: Extraction pattern by period: token requests as a percentage of available endowment.

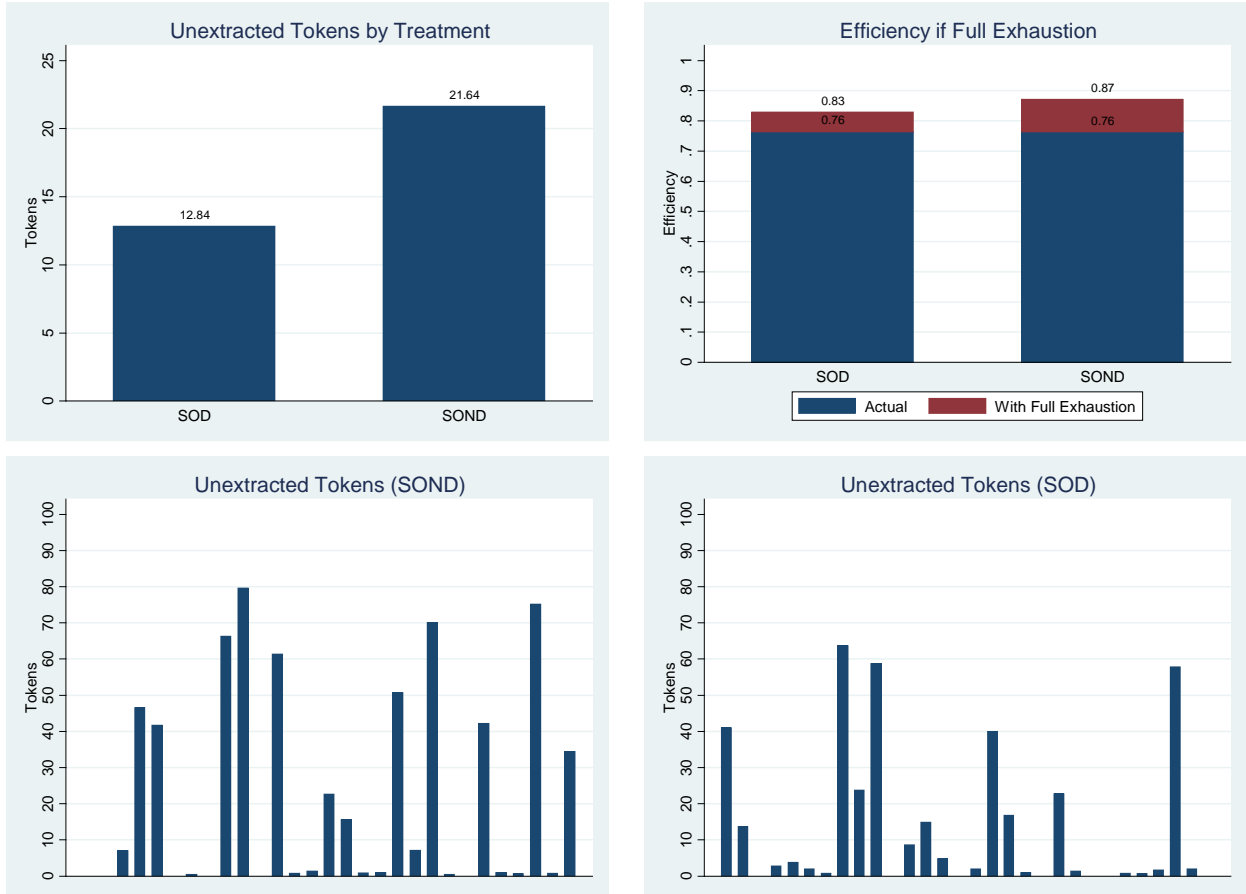


Figure 11: Tokens not extracted during final period (top left) and the resulting efficiency loss (top right). Graph depicting number of tokens remaining in final period with individual subjects on x axis (bottom).

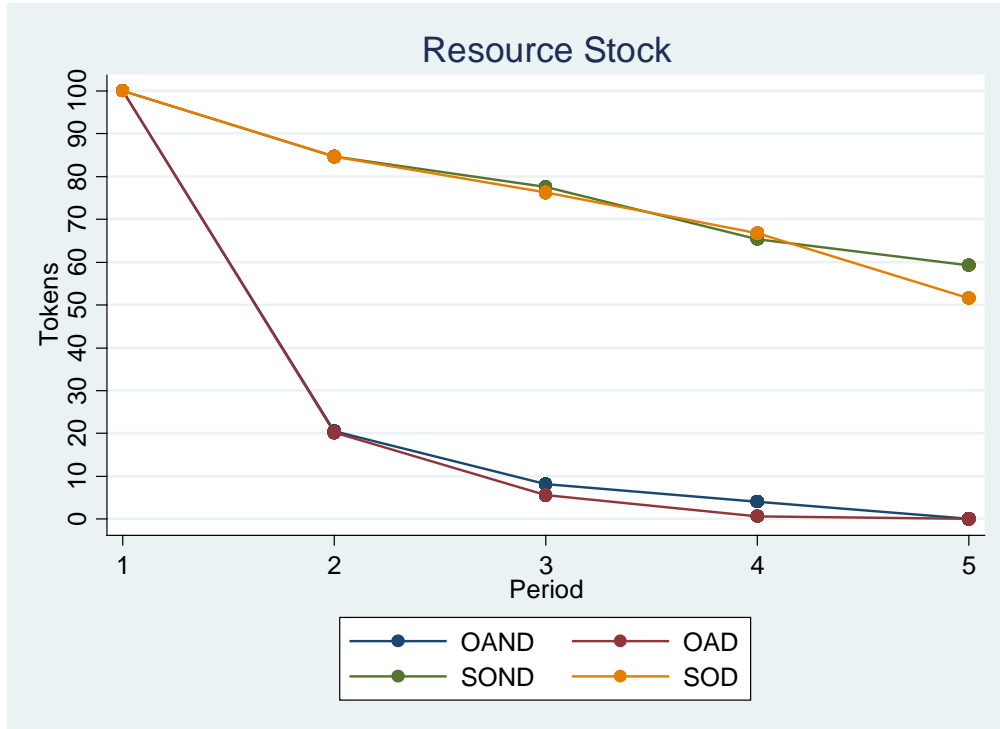


Figure 12: Deviation from the optimal stock of 50 tokens in periods 1 through 4 and 0 tokens in period 5.

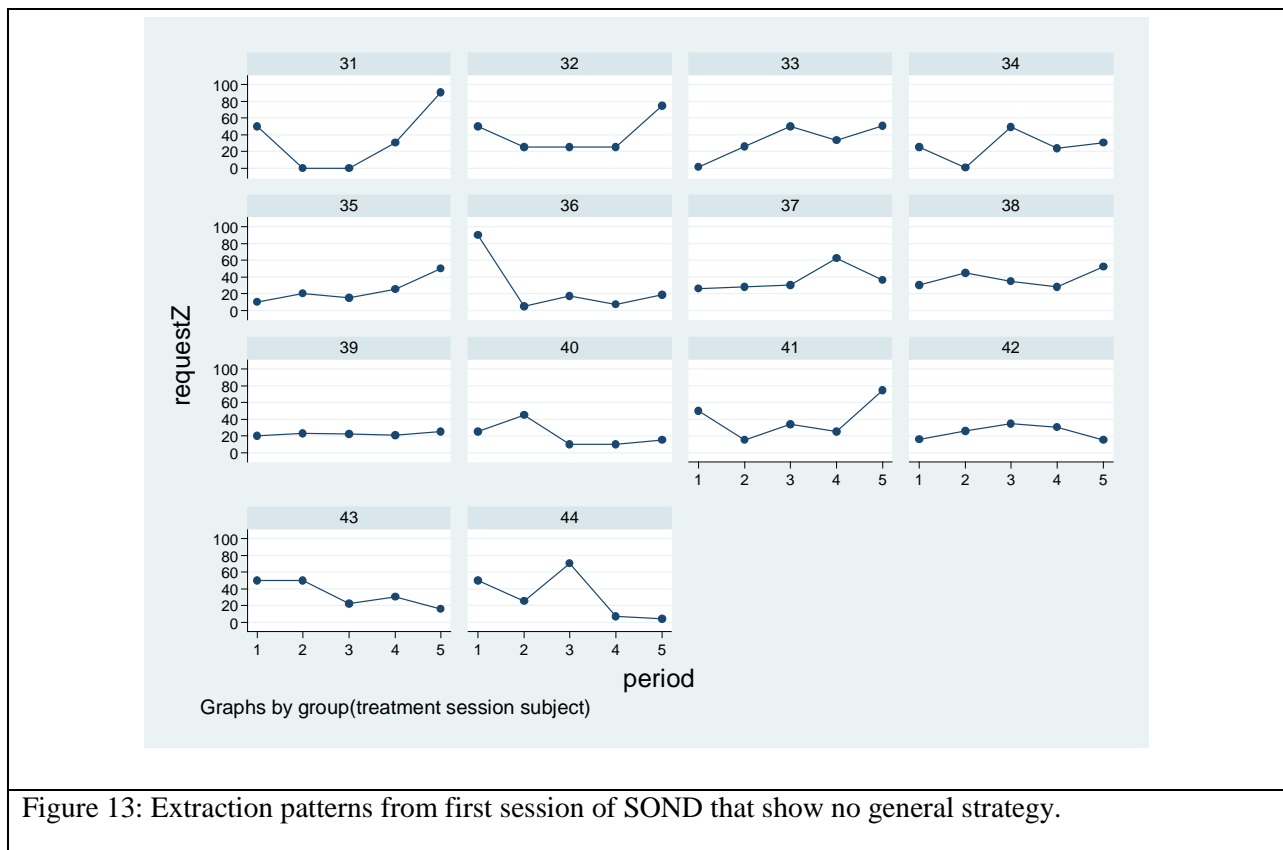


Figure 13: Extraction patterns from first session of SOND that show no general strategy.

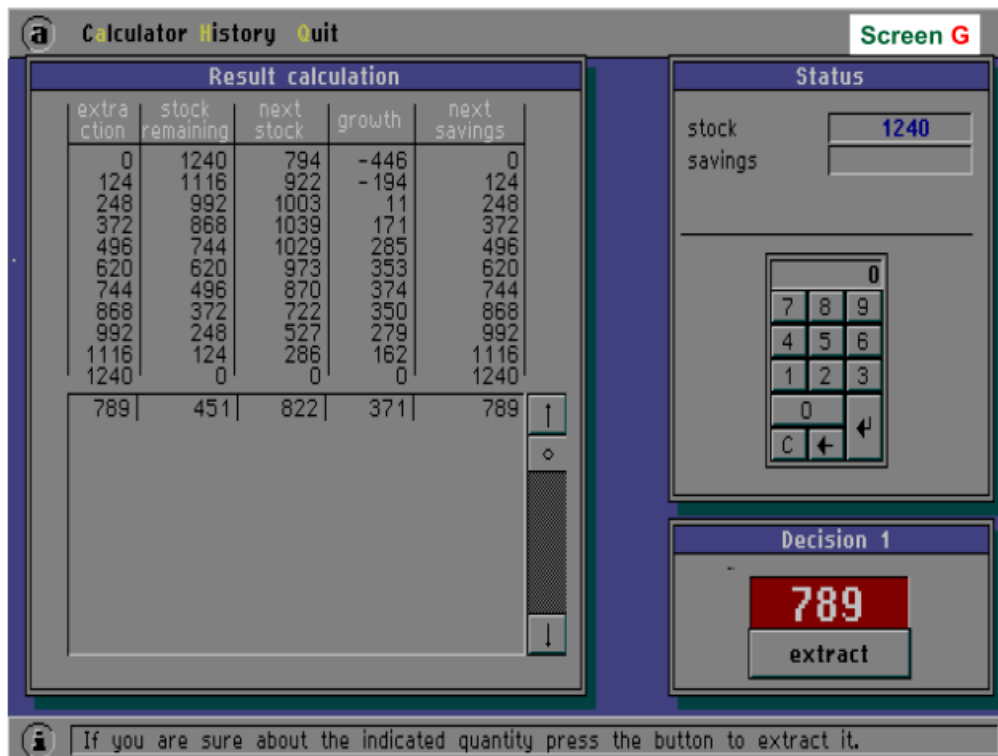


Figure 14: Calculation tool used in Hey et al (2008) to give subjects stock & growth information.

Appendix B: Recruitment Email

Subjects' names were gathered using the freely available information in the college's email system. The order of the subjects' names were randomized and any ineligible students were removed (those who assisted the experimenter, had prior knowledge of the experiment, or had previously participated). Recruitment emails were then sent to these students. An announcement was also placed in the "Student Digest," a collection of announcements sent to students in email form. The general wording was as follows:

You are invited to participate in an experiment on [date]. **By participating in the experiment you will earn \$5. You can also earn additional money based on your performance, up to \$20.** The experiment should take at most 45 minutes. The sessions are as follows:

- [Date, time, location]

To sign-up, please email [author email] which session you would like to participate in.

Spots will be filled on a first-come, first-served basis. The experiment is being conducted by Kevin Lugo, a senior Economics major, in conjunction with Professor John Cadigan. If you have already participated in one of my experiments last semester you may not participate again.

Questions should be addressed to Kevin Lugo [author email].

Each treatment was designed to have 30 participants for a total of 120 subjects. Extra participants were recruited in the event subjects did not show up and, if sent home, were given the show-up payment of \$5. Despite extra recruitment some sessions were short of the desired 15 subjects. For this reason 27 subjects participated in open access no dispersal, 27 in open access dispersal, 29 in sole ownership no dispersal, and 30 in sole ownership dispersal.

Appendix C: Experimental Materials

Instructions OAND

Introduction

Thank you for agreeing to participate in this experiment. At this time please turn off any cell phones or other electronic devices.

You will earn \$5 by participating in the experiment and may earn additional cash based on your performance. You get to keep any money that you earn over the course of the experiment. The experiment may take as long as 45 minutes.

When you are done with each screen, press “OK” to continue.

In this experiment you will be randomly and anonymously placed in a group with two other subjects.

You and the two other subjects will play through a series of periods in which you will make decisions that will earn you experimental tokens. These tokens will remain in your account for the duration of the experiment. At the end of the experiment these tokens will be exchanged for dollars at a rate of 1 token to \$0.05.

Experiment Design

There will be five periods. At the beginning of each period, subjects will choose a number of tokens to withdraw from three ‘zones’ labeled Zone A, Zone B, and Zone C. Your individual requests may not exceed the amount available in each zone. Each zone will begin the first period with 100 tokens.

In any period, if the group requests a total number of tokens that is less than the amount available in that zone, each player will receive the amount she requested from that zone.

If the total number of tokens requested from a zone by the group exceeds the amount available in that zone, each player will receive a number of tokens proportional to her share of the total group request. In other words, if you request R tokens, the group requests a total of X tokens, and T tokens are available, then if $X > T$ you will receive a number of tokens from that zone according to:

$$\text{Your Tokens} = \left(\frac{R}{X}\right) * T$$

At the end of each period, the number of tokens in a zone will grow based on the number of tokens remaining in that zone (T). Growth will follow the growth function:

$$\text{Growth} = T * \left[1 - \left(\frac{T}{100}\right)\right]$$

The number of tokens that grow will be added to the number of tokens remaining in the zone. This new total will be the number of tokens available in the next period. Each of the 5 periods will proceed in the same manner. Note that if, in any period, all remaining tokens are taken then there no growth occurs and there are 0 tokens available from that zone in all subsequent periods. You have been given a reference sheet with a table displaying the growth associated with every integer token amount. This table also shows the number of tokens that will be available in the next period in each of those circumstances.

After each period, subjects will view a summary of the results from that period. This will include your personal performance as well as the group request from each zone, the actual group withdraw from each zone, and the total group withdraw that period. You will also see how many tokens remain in each zone at the end of the period. Finally, you will see the cash value of the tokens you earned that period.

You may find it helpful to record the results of each period. You have been provided with a paper record sheet to assist you in this process.

Summary

- In each period you will choose how many tokens you wish to withdraw from zones A, B, and C.
- If the group request is **less than** the tokens available, you will receive your request.
- If the group request is **greater than** the tokens available, you will receive tokens proportional to your share of the group request.
- Based on the number of tokens available in each zone, the growth function described above will be used to determine the number of tokens available in the next period.
- The game will last 5 periods.

After the final period, please record your earnings on you receipt form and wait for further instructions.

Throughout this experiment you are not to communicate with other players in any way. You must keep your eyes on your own screens at all times and may not use any electronic devices. Breaching these rules will result in a forfeit of all compensation. If you have any questions, please ask them now.

Reference Sheet

Do Not Write On This Sheet

Growth Table

$$Growth = T * \left[1 - \left(\frac{T}{100} \right) \right]$$

Tokens	Growth	New Tokens	Tokens	Growth	New Tokens	Tokens	Growth	New Tokens	Tokens	Growth	New Tokens
0.00	0.00	0.00	25.00	18.75	43.75	50.00	25.00	75.00	75.00	18.75	93.75
1.00	0.99	1.99	26.00	19.24	45.24	51.00	24.99	75.99	76.00	18.24	94.24
2.00	1.96	3.96	27.00	19.71	46.71	52.00	24.96	76.96	77.00	17.71	94.71
3.00	2.91	5.91	28.00	20.16	48.16	53.00	24.91	77.91	78.00	17.16	95.16
4.00	3.84	7.84	29.00	20.59	49.59	54.00	24.84	78.84	79.00	16.59	95.59
5.00	4.75	9.75	30.00	21.00	51.00	55.00	24.75	79.75	80.00	16.00	96.00
6.00	5.64	11.64	31.00	21.39	52.39	56.00	24.64	80.64	81.00	15.39	96.39
7.00	6.51	13.51	32.00	21.76	53.76	57.00	24.51	81.51	82.00	14.76	96.76
8.00	7.36	15.36	33.00	22.11	55.11	58.00	24.36	82.36	83.00	14.11	97.11
9.00	8.19	17.19	34.00	22.44	56.44	59.00	24.19	83.19	84.00	13.44	97.44
10.00	9.00	19.00	35.00	22.75	57.75	60.00	24.00	84.00	85.00	12.75	97.75
11.00	9.79	20.79	36.00	23.04	59.04	61.00	23.79	84.79	86.00	12.04	98.04
12.00	10.56	22.56	37.00	23.31	60.31	62.00	23.56	85.56	87.00	11.31	98.31
13.00	11.31	24.31	38.00	23.56	61.56	63.00	23.31	86.31	88.00	10.56	98.56
14.00	12.04	26.04	39.00	23.79	62.79	64.00	23.04	87.04	89.00	9.79	98.79
15.00	12.75	27.75	40.00	24.00	64.00	65.00	22.75	87.75	90.00	9.00	99.00
16.00	13.44	29.44	41.00	24.19	65.19	66.00	22.44	88.44	91.00	8.19	99.19
17.00	14.11	31.11	42.00	24.36	66.36	67.00	22.11	89.11	92.00	7.36	99.36
18.00	14.76	32.76	43.00	24.51	67.51	68.00	21.76	89.76	93.00	6.51	99.51
19.00	15.39	34.39	44.00	24.64	68.64	69.00	21.39	90.39	94.00	5.64	99.64
20.00	16.00	36.00	45.00	24.75	69.75	70.00	21.00	91.00	95.00	4.75	99.75
21.00	16.59	37.59	46.00	24.84	70.84	71.00	20.59	91.59	96.00	3.84	99.84
22.00	17.16	39.16	47.00	24.91	71.91	72.00	20.16	92.16	97.00	2.91	99.91
23.00	17.71	40.71	48.00	24.96	72.96	73.00	19.71	92.71	98.00	1.96	99.96
24.00	18.24	42.24	49.00	24.99	73.99	74.00	19.24	93.24	99.00	0.99	99.99
									100.00	0.00	100.00