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Racing for the Water: Laboratory Evidence on Managing a Groundwater Commons

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Abstract

This paper examines strategic behavior in the context of a dynamic common-pool resource game with a unique symmetric subgame equilibrium. Solving the model for its optimal solution and its subgame perfect equilibrium provides benchmarks for behavior observed in laboratory experiments. Baseline experiments, which portray a "rule of capture" for establishing ownership with group size equal to 10, achieve an average efficiency of 30%. Experiments that restrict entry, with group size equal to 5, increase average efficiency to 44%. Experiments applying a stock quota show more marked improvement in efficiency, averaging 54%. The stock quota experiments come closest to producing data consistent with subgame perfection.

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1. Introduction

Between the poles of rent maximization and complete rent dissipation, wide latitude exists for institutions to manage or allocate common property resources (CPRs) with reasonable economic performance. Two topics addressed in previous research are salient. One concerns the role of limiting entry by agents into a commons. In the seminal article on the economics of CPRs, Gordon (1954) described how monopolist ownership would remove CPR externalities, thereby creating incentives for rent maximization. Eswaran and Lewis (1984), applying a model of a CPR as a time dependent repeated game, derived a related analytical result that the degree of rent accrual depends inversely on the number of agents depleting the resource. In the context of groundwater, Brown (1974) and Gisser (1983) reasoned that existing laws restricting entry into groundwater CPRs would improve rent accrual. Empirical experience with more than five agents, however, reached pessimistic conclusions in two cases. Libecap and Wiggins (1984) found that cooperative behavior in oil pool extraction occurred only with fewer than five firms. Otherwise, state law was required to coerce cooperation with roughly 10-12 firms. Indeed, with hundreds of firms operating in the East Texas oil fields there was no cooperation and, apparently, complete rent dissipation. Walker, Gardner, and Ostrom (1990) and Walker and Gardner (1992) reached a similar conclusion in analysis of data from laboratory experiments on noncooperative game CPRs. A high degree of rent dissipation or a high probability of resource destruction occurred even with access limited to eight agents.[1]

The second topic concerns the ability of additional regulations or property rights, other than entry restrictions, to mitigate CPR externalities in light of noncooperative behavior. Forms of property rights, such as firm-specific fishing rights or quotas (e.g., Levhari, Michener, and Mirman 1981), are widely recognized as reducing or removing the incentive for a race to exploit a CPR. Specific to groundwater, Smith (1977) recommended that rights to a share of the groundwater stock should replace Arizona's then-existing rule of capture, while Gisser noted that New Mexico's individual rights to annual water quantities, combined with a guaranteed time period of depletion, effectively define a share right in the stock. Both reasoned that this form of property right - stock quotas - would go far toward achieving optimal groundwater depletion.

Groundwater depletion is primarily a concern in the arid western United States. There, large quantities of water are mined from aquifer formations to satisfy agricultural, urban, and rural domestic demands. Individual state laws govern groundwater depletion in the 17 western states (Sax and Abrams 1986). The legal doctrines adopted by the states for groundwater rights vary in terms of entry rules, annual quotas, and stock quotas. Moreover, concern about the pace of groundwater mining spawned major legal reforms in five of the states within the last 25 years.[2] Despite the diversity of state legal systems, the various traits of groundwater rights have not been studied within an empirical economic framework.[3] Yet the efficient evolution of the agricultural-based economies and rural communities in the West depends on developing property rights that induce optimal depletion of groundwater CPRs.

This paper develops and empirically applies a general modelling framework couched in terms of depletion of groundwater CPRs. Section 2 qualitatively describes the modelling framework in terms of externalities present in a groundwater commons. Depletion from a fixed stock is modelled as a noncooperative game, following the literature on CPRs as dynamic games (Levhari and Mirman 1980; Eswaran and Lewis 1984; Reinganum and Stokey 1985). Section 3 describes an experimental design involving a baseline setting and two experimental treatments. The baseline represents the common-pool depletion of an aquifer according to a "rule of capture"; 10 players participate in the baseline. One treatment involves restricting entry to 5 players, while a second treatment involves imposing stock quotas-that is, rights to a share of the resource stock-on each player. Section 4 presents evidence from laboratory experiments that apply the experimental design. Performance is an efficiency measure, the ratio of rent earned to maximum possible rent. Given the high cost and imprecise measurement that confronts collection of field data, laboratory experiments offer a unique method for assessing the performance of various groundwater property rights and the applicability of game theory to behavior in such systems.

2. A Noncooperative Game Model of CPR Depletion

Producers depleting a CPR typically face three appropriation externalities (Eswaran and Lewis 1984; Gardner, Ostrom, and Walker 1990; Negri 1990; Reinganum and Stokey 1985): a strategic externality, a stock externality, and a congestion externality. These externalities induce inefficiently rapid depletion or destruction of CPRs, commonly described by the adage "tragedy of the commons." The model developed here is not meant to apply universally, in terms of all types of resources, physical conditions, or sustainability properties. Nevertheless, the externalities that are modelled and investigated in terms of groundwater depletion are among those confronting CPR users in a variety of other contexts, such as forests, fisheries, and irrigation systems.

Groundwater depletion for irrigated agriculture[4] creates the potential for all three CPR externalities (Negri 1989; Provencher and Burt 1993).[5] Individual agricultural producers invest in deep wells drilled into aquifer formations, and pump groundwater from the wells for application in crop production. The strategic externality occurs because, under some legal doctrines governing groundwater depletion, water use offers the only vehicle to establish ownership. Ownership through use creates a depletion game. The stock externality occurs because, with groundwater pumping costs, individual water depletion reduces the aquifer's water-table level, thereby increasing pumping costs for all producers. The congestion externality occurs by spacing wells too closely together, with a subsequent direct loss in pumping efficiency. Thus, one producer's current effort can reduce the current output of another producer. The congestion externality, however, is not a focus of this study.[6]

CPR externalities in groundwater depletion pose the problem of creating institutions, and in particular property rights, that provide incentives for more efficient intertemporal depletion of stocks.[7] As one conceivable property right, annual quotas could be assigned to agents in such a way as to mitigate externalities. This approach, however, is a planning solution; it requires perfect information on the part of a central planner to implement the optimal depletion path (Gisser 1983). By contrast, an entry restriction or a stock quota can be implemented and enforced with significantly less information. Yet, in principle, these forms of property rights provide only a partial solution to the externality problem. The model and the laboratory experiments that follow will illuminate these issues further.[8]

Consider a groundwater aquifer described by the state variable depth to water at time t, c_t. There are n agricultural producers using the water, indexed by i. Producer i withdraws an amount of water x_{it} in period t. The depth to water evolves according to the following discrete time equation:

$$(1) \qquad c_{t+1} = c_t + k\Sigma_i x_{it} - h.$$

The parameter k depends on the size and configuration of the aquifer; the parameter h represents a constant recharge rate. Here we examine the special case where h=0.

Water pumped to the surface is used in agricultural production. The instantaneous benefit accruing to producer i at time t, B_{it}, is quadratic:

$$(2) \qquad B_{it}(x_{it}) = ax_{it} - bx_{it}^2$$

where a and b are positive constants. This implies diminishing returns to production at the surface, an assumption that accords with production experience from aquifers like the Ogallala (Kim et. al., 1989). Producers are assumed homogeneous, so that (2) applies to each i. Notice also that since the parameters a and b are time independent, so is the benefit function.

On the cost side, the cost for producer i to pump water to the surface at time, C_{it}, depends on both water pumped to the surface and depth to water:

$$(3) \qquad C_{it}(x_{it},X_t,c_t) = (c_t + AX_t + B)x_{it},$$

where A and B are positive constants and X_t is the sum of all producers withdrawal at time t. Cost is proportional to water pumped to the surface. Cost is increasing in depth to water, and in total water pumped in a given period. The latter effect is due to the fact that depth to water increases within a period, as a function of current pumping. Given the common pool nature of groundwater, each producer has an incentive to pump the relatively cheap water near the surface before others do.

Solve the depletion problem in equations (1) through (3) for its optimal solution. An authority with total control over pumping maximizes net benefits from groundwater depletion over a planning horizon of length T by solving the following optimization problem:

$$\text{maximize } \Sigma_i \Sigma_t \, [B_{it}(x_{it}) - C_{it}(x_{it}, X_t, c_t)]$$

subject to (1),(2),(3), the initial condition c_1, and the terminal time T. Notice that in this maximization, there is no discounting of future benefits. The solution can be easily amended if discounting is desired.

Solve this optimization by dynamic programming. Let $V_t(c_t)$ denote the optimal value of the resource at time t, given that the depth to water is c_t. The recursive equation defining the value function is given by:

$$(4) \qquad V_t(c_t) = \max \Sigma_i \, [B_{it}(x_{it}) - C_{it}(x_{it}, X_t, c_t)] + V_{t+1}(c_{t+1}).$$

The transversality condition for this problem is that the value of the resource after time T is zero, regardless of the depth to water:

$$(5) \qquad V_{T+1} = 0.$$

By varying the transversality condition (5), one can map out a variety of optimal paths. In order for the resource to have a positive optimal value, it is necessary that the following condition on the parameters of the net benefit function be satisfied:

$$(6) \qquad a > c_1 + A + B.$$

Inequality (6) guarantees a positive net benefit to the first unit of water withdrawn from the aquifer. Assume this inequality throughout.

It remains to find the form of the optimal value function $V_t(c_t)$. Consider the last period T.

One can show, differentiating (4), and using (5), that the optimal decision in the last period is given by:

(7) $\Sigma_i x_{iT} = (a - c_T - B)/(2b/n + 2A)$.

Further, the optimal value function for the last period is given by:

(8) $V_T(c_T) = 0.5(a - c_T - B)^2/(2b/n + 2A)$.

One can show by mathematical induction that for any time t, the optimal decision function takes the form:

(9) $\Sigma_i x_{it} = L_t(a - c_t - B)$

and the optimal value function takes the form:

(10) $V_t(c_t) = K_t(a - c_t - B)^2$.

The proportionality factors L_t and K_t in equations (9) and (10) are given by the nonlinear recursive equations:

(11) $L_t = (1 - 2kK_{t+1})/(2b/n + 2A - 2k^2K_{t+1})$

and

(12) $K_t = L_t -(b/n + A)L_t^2 + K_{t+1}(1-kL_t)^2$.

One derives the optimal solution by starting the recursion with (5), substituting into (11) to get L_T, substituting into (12) to get K_T, and working back from there to the beginning, t = 1. Equations (7) and (8) represent the first two steps of the solution process. For all values of the 8-dimensional parameter space (a,b,n,A,B,k,c_1,T) satisfying inequality (6), one can show that the optimal solution path has each producer withdrawing water at a uniform rate. This rate is such that the last unit of water withdrawn at time T has zero net benefit.

For illustration, consider the parameter values chosen for our baseline design $(a,b,n,A,B,k,c_1,T) = (220,5,10,0.5,0.5,1,0,10)$. For these parameters, Table 1 gives the backward recursion solution for the series L_t and K_t. The optimal aggregate withdrawal in the first period is given by:

$$(13)\qquad \Sigma x_{i1} = (1/11)(220 - 0.5) = 19.95,$$

whence the optimal withdrawal by each individual producer is 19.95/10, or 1.995. The optimal value in cents of the entire resource, $V_1(c_1)$, from Table 1, is:

$$(14)\qquad V_1(c_1) = (10/22)(220 - 0.5)^2 = 21900.$$

Any other withdrawal path will have a lower value. The coefficient of resource utilization, or CRU (Debreu, 1951), measures how efficiently a resource is being used. The CRU, which lies between 0% and 100%, can be expressed as the ratio of the value of the resource from any other withdrawal path to its optimal value.

Withdrawal patterns associated with game equilibria are important to establish benchmarks for behavior observed in the laboratory experiments. In a noncooperative game, each producer maximizes his own net benefit without regard to the effect of this behavior on other producers. This is the basis for the externality created when a "rule of capture" defines resource ownership. Analyze the game played by producers in extensive form, and characterize its symmetric subgame perfect equilibrium. A strategy for producer i, x_i, is a complete plan for the play of the game, given the history available to the player when he has to make a decision. At the beginning of the game, player i's decision, Xi, is based on no history. Recall that X_t is the sum of all producers' withdrawals at time t:

$$(15)\qquad X_t = \Sigma x_{it}.$$

At time t=2, producer i's decision x_{12} depends on depth to water % which in turn depends on the previous period's water withdrawal. Write this dependence $x_{i2}(X_1)$. Proceeding inductively, write a complete plan of play as:

$$(16)\qquad x_i = (x_{i1},\ x_{i2}(X_1),\ldots,x_{iT}(X_1,\ldots,X_{T-1})).$$

Now solve the depletion game whose net benefit functions and transition equations are given by (1) through (3) for its symmetric subgame perfect equilibrium. Since the game is symmetric, it has such an equilibrium. A producer i chooses his strategy x_i to maximize net benefits from groundwater depletion over a planning horizon of length T by solving the following optimization problem:

$$\text{maximize } \Sigma_t\, B_{it}(x_{it}) - C_{it}(x_{it}, X_t, c_t)$$

subject to (1),(2),(3), the initial condition c_1, and the terminal time T.

Solve this optimization problem by dynamic programming. Let $V_{it}(c_t)$ denote the optimal value of the resource to producer i at time t, given that the depth to water is c_t. The recursive equation defining the value function is given by:

$$(17) \quad V_{it}(c_t) = \max B_{it}(x_{it}) - C_{it}(x_{it}, X_t, c_t) + V_{it+1}(c_{t+1}).$$

The transversality condition for this problem is that the value of the resource to producer i after time T is zero, regardless of the depth to water:

$$(18) \quad V_{iT+1} = 0.$$

It remains to find the form of the optimal value function $V_{it}(c_t)$. Consider the last period T. One can show, differentiating (17), and using (18), that the optimal decision in the last period is given by:

$$(19) \quad x_{iT} = (a - c_T - B)/(2b + (n+1)A).$$

Further, the optimal value function for the last period is given by:

$$(20) \quad V_{iT}(c_T) = 0.5(a - c_T - B)^2/(2b + (n+1)A).$$

One can show by mathematical induction that for general time t, the equilibrium decision function takes the form:

$$(21) \quad x_{it} = L_{it}(a - c_t - B)$$

and the equilibrium value function takes the form:

$$(22) \quad V_{it}(c_t) = K_{it}(a - c_t - B)^2.$$

The proportionality factors L_{it} and K_{it} in equations (21) and (22) are given by the nonlinear recursive equations:

$$(23) \quad L_{it} = (1 - 2kK_{it+1})/(2b + (n+1)A - 2k^2nK_{it+1})$$

and

$$(24) \quad K_{it} = L_{it} - (b + nA)L_{it}^2 + K_{it+1}(1 - knL_{it})^2.$$

One derives the symmetric subgame perfect equilibrium by starting the recursion with (18), substituting (18) into (23) to get L_{iT}, substituting L_{iT} into (24) to get K_{iT}, and working back from there to the beginning, t = 1. Equations (20) and (21) represent the first two steps of the solution process.

Since this is a symmetric equilibrium, the solution for producer i is the same for all producers. Note that the recursive equations (23) and (24) are different from those defining the optimal solution. Thus, the subgame perfect equilibrium is not an optimum. Suppose that the program is one period long (T=1). Then the equilibrium and the optimum both start at c_1. Comparing (11) and (23), one has that:

(25) $nL_{i1} = 1/(2b/n + ((n+1)/n)A) > 1/(2b/n + 2A) = L_t$.

The subgame perfect equilibrium withdraws too much water. This continues to hold true more generally: the subgame perfect equilibrium path withdraws too much water in the first period for all T. Table 2 shows the subgame perfect equilibrium path using the same parameters as for Table 1. The subgame perfect path is virtually exponential, thus differing markedly from the optimal path's constant depletion rate. The first two periods have very high depletion rates, while later periods have almost no depletion. This is precisely the phenomenon of "racing for the water." At this equilibrium, each agent has the incentive to deplete the relatively cheap water at the top of the aquifer before other agents capture it. This equilibrium naturally produces a lower payoff from the water resource. In particular, from Table 2, one has that aggregate value in cents at the subgame perfect equilibrium is:

(26) $nK_{iT}(a - c_1 - B)^2 = 10(0.0269)(219.5)^2 = 12960$.

Compared to the optimum, the subgame perfect equilibrium has an efficiency of 12960/21900 = 59%.

3. Experimental Design and Decision Setting

The experimental design focuses on three conditions: (1) a baseline with no restrictions on individual levels of appropriation, group size equal to 10, and T = 10, (2) a treatment with no restrictions on individual levels of appropriation, but group size restricted to n = 5 with the terminal round extended to T = 20, and (3) a treatment imposing a stock quota restriction on each individual's total level of appropriation (see Table 3).

Subject i makes a decision x_{it} in each round t. The decision x_{it} is itself integer-valued with a lower bound of 0 and an upper bound, if any, given by the institutions. The units of the decision are called "tokens." Payoffs according to the net benefit function are evaluated at integer values of the arguments of that function.[9] All experiments satisfy the following net benefit function parameterizations, measured in cents:

$a = 220 \quad b = 5 \quad A = .5 \quad B = .5 \quad c_1 = 0.$

As discussed above, with the additional parameter k= 1 governing the depth to water transition equation (1), the optimal solution for the case n = 10 is:

$V_1(c_1) = \$219 \qquad x_{it} = 2.$

As shown in Table 4, the treatment with n = 5 and T = 20 gives the same optimal value and individual withdrawal rate. The exhaustion condition is reached by half as many producers withdrawing the same amount of water per period for twice as many periods. Thus, holding the value of the resource constant, this parameterization allows us to investigate a pure number of producers effect.[10]

In contrast to the optimal value, the valuations generated by the subgame perfect equilibria are lower. As discussed above, for n = 10 the subgame perfect equilibrium has reached its maximum cumulative earnings, $130, by the fourth period, for an efficiency of 59%. For n = 5 and T = 20 the subgame perfect equilibrium has reached its maximum cumulative earnings, $136, by the sixth period, as shown in Table 5, with an efficiency of 62%. Thus, according to subgame perfection, restricting group size from 10 to 5 players increases efficiency by only 3%.

For our parameterizations (c, = 0, k = 1), Cr - c, = Cr represents the amount of groundwater ultimately pumped from the aquifer. A stock quota places an upper bound on the water an individual player can withdraw over the life of the resource. This type of quota mitigates the impact of especially high individual withdrawal paths.[11] In our experiments the stock quota was 25 tokens per individual.[12] Note, this quota does not act as a constraint to subgame perfect equilibrium behavior, which requires only 22 tokens per individual. Placing the stock quota at a level below 22 tokens per person would artificially lead to improvements in efficiency. Our purpose was to investigate the role of a stock quota on behavior without disturbing potential equilibrium behavior.

All experiments were conducted at Indiana University. Volunteers were recruited from graduate and advanced undergraduate economics courses. These subjects were paid in cash in private at the end of the experiment. Subjects privately went through a series of instructions (available from the authors upon request) and had the opportunity to ask the experimenter a question at any time during the experiment. The decision problem faced by the subjects can be summarized as follows.

> Each subject had a single decision to make each round, namely how many tokens to order. Each knew their individual benefit function (expressed in equation and tabular form). A base token cost of $0.01 was stipulated for round 1. The instructions explained that token cost increased by $0.01 for each token ordered by the group and token cost for an individual in a given round would be the average token cost for that round times the number of tokens the individual ordered in that round. The base cost for the next round was computed by adding one to the aggregate number of tokens ordered in previous rounds, and then multiplying this total by $0.01. All subjects made purchasing decisions simultaneously. Subjects were explicitly informed of the maximum number of rounds in the experiment. After each decision round, subjects were informed of the total number of tokens ordered by the group, the cost per token for that round, the new base cost for tokens purchased in the next round, and their profits for that round. Subjects were also told if the base token cost ever reached a level where there was no possibility of earning positive returns to buying tokens, the experiment would end. See Appendix A for a complete set of instructions.

4. Laboratory Results and Discussion

The experimental results are drawn from nine experiments conducted over the three design conditions: (1) a baseline condition where $n = 10$ and $T = 10$, (2) an entry restriction condition where $n = 5$ and $T = 20$, and (3) a stock quota condition where $n = 10$, $T = 10$, and the stock quota is 25. In each condition, we examine results from two experiments using subjects inexperienced in the decision environment and from one experiment using experienced subjects randomly recruited from the subject pool of the inexperienced runs.

An overview of our experimental results is presented in Table 6. For each experiment, aggregate payoffs, experimental efficiency, and duration of the experiment are displayed. The set of baseline and entry restriction experiments reflect an environment in which resource use is the only way to establish ownership. As expected, paths with later exhaustion periods are typically associated with higher efficiencies. With n = 10, the average exhaustion round was 2.67; with n = 5 the average increased to 6.33. In the stock quota experiments, the average increased to 5.33. While increasing the life of the resource is not an economic goal *per se*, it does help explain the increase in average efficiency across experimental settings.

> ***Summary Result 1:*** *In each of the three baseline experiments, efficiencies were well below the efficiency level generated by the optimum and even below that generated by the subgame perfect equilibrium.*

Table 7 reports detailed results for the three experiments with n= 10 and T=10, including the actual appropriation levels by decision round and summary statistics. In the first round of these experiments, subjects ordered on average 164 tokens, implying an average second round base cost of $1.65. This compares to an optimal order of 2 tokens per subject for a total order of 20 tokens in the first round and a second round base cost of $0.21. The subgame perfect equilibrium predicts an order of 14 tokens per subject for a total order of 140. This explosive appropriation of cheap tokens in the first round guarantees very low efficiencies. Efficiencies averaged only 30% of optimum.

> ***Summary Result** 2:* *In each of the three experiments that limit entry to 5 players, efficiencies again were below levels generated in both the optimum and the subgame perfect equilibrium. However, the average efficiency generated by this treatment was distinctly higher than that of the baseline experiments.*

Table 8 reports detailed results for the three experiments with n=5 and T=20. In the first round of these experiments, subjects ordered an average of 86 tokens, implying an average second round base cost of $0.87. This compares to an optimal order of 10 tokens in the first round and a second round base cost of $0.11. The subgame perfect path predicts an order of 16 tokens per subject for a total order of 80. Efficiencies averaged 44% of the optimum.

The set of three experiments using a stock quota rule are summarized in Table 9. These experiments were conducted in a manner identical to the baseline experiments where n = 10 and T = 10, except that each subject was constrained to order no more than 25 tokens over the course of the experiment. This treatment variable was announced in public.

Summary Result 3: In each of the three experiments using the stock quota rule, efficiencies increased markedly relative to baseline, but remained well below the optimum. Efficiencies averaged 54% of the optimum.

In the first round of these experiments, subjects ordered on average 125 tokens, implying an average second round base cost of $1.26. Thus, the upper bound on orders slowed down, but did not eliminate, the water race. These results call into question the optimistic conjectures made in previous research (e.g., Anderson et. al. 1983) about the ability of stock quotas to capture most of a groundwater CPR's scarcity rent.

Note that group behavior most closely resembles the subgame perfect equilibrium in the stock quota experiments. Efficiencies in experiments 1 and 2 (57% and 59%) are in line with subgame perfect equilibrium efficiency (59%). In these two experiments, first round orders averaged 11.8 tokens per subject, lower than the equilibrium prediction of 14; second round orders averaged 5.2 tokens per subject, slightly higher than the equilibrium prediction of 5. Interestingly, it is the experienced run in the stock quota design that resulted in the poorest performance, generating an efficiency 14% below that predicted by subgame perfection. More generally, this experiment demonstrates a point that holds true across all of our experiments. Individual behavior is quite diverse. Similar to earlier experiments reported by Ostrom, Gardner, and Walker 1994, average group behavior often follows a path similar to that predicted by noncooperative game theory. At the individual level, however, there is too much variation to argue strong support for the theory.

5. Conclusions

This paper considers the depletion of groundwater CPRs. A benchmark model is constructed with a fixed stock of groundwater and fixed exhaustion time. The optimal solution and subgame perfect equilibrium provide benchmarks for efficiencies observed in laboratory experiments. Entry restrictions and stock quotas are examined in terms of their impact on individual strategic behavior in laboratory experiments. Although the model and experiments are couched in terms of groundwater CPRs, the research is also informative to dilemmas encountered in other CPRs, such as tropical forests, fisheries, and cooperative irrigation systems.

The laboratory experiments produce several interesting findings. With group size equal to 10, the baseline condition, which portrays a "rule of capture" for establishing ownership, yields an average efficiency of only 30%. Restricting entry to n = 5, while still operating with a rule of capture, increases average efficiency to 44%. A stock quota enhances efficiency even further, with average efficiency rising to 54%. Although these property rules distinctly improve performance, substantial scarcity rent remains unappropriated.

The model and experiments contain a number of restrictive assumptions, including no resource recharge, no discounting, and a known finite horizon. These restrictions were made for analytical tractability and experimental operability. The simplicity of the design allows subjects to focus on the strategic and stock externalities without confounding the setting with other CPR dilemmas. Relaxing the restrictions would allow for a richer, yet more complex, decision setting.

The institutional setting of state governance of groundwater resources in the western United States provides several alternative designs to motivate further study of the relationship between property rights systems and rent accrual. In the early-to mid-1900s, independent state authority over groundwater resulted in adoption of four distinct legal doctrines governing groundwater use in the 17 western states. The variety across states of general doctrinal principles and specific regulations creates a diverse set of groundwater property-right systems. Our study focused on stylized versions of two aspects of these systems, entry restrictions and stock quotas. Future research, building on this foundation, will examine whether other groundwater property-rights systems can improve efficiency beyond that found here.

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Footnotes

1. The result that fewer than five firms are necessary for cooperation has received theoretical support from Selten (1971).

2. The five states are Arizona, Colorado, Kansas, Nebraska, and Oklahoma.

3. While several articles addressed the performance of various groundwater institutions, an empirical analysis has not been completed. The costliness of collecting data on groundwater use and the difficulty of applying game-theoretic models explains the reliance in that research on analytical results (Dixon 1988; Negri 1989; Provencher and Burt 1993), simulation methods (Dixon), or reasoned institutional arguments concerning the desirable properties of specific groundwater property-right systems (Anderson, et al. 1983; Gisser; Smith).

4. The model is developed for the case of irrigated agriculture because agriculture is the dominant water-consuming sector in the 17 western states. The sector commonly consumes 85-90% of total water consumption in those states. Groundwater provides roughly 37% of water withdrawn for irrigation, with surface water supplying the remainder (U.S. Department of the Interior 1993). Groundwater pumping distances vary substantially depending on aquifer conditions. Over the Ogallala Aquifer in the Great Plains region, for example, average depth-to-water in the Great Plains states in 1988 ran from 70 to 154 feet (U.S. Department of Commerce 1990).

5. Provencher and Burt also identified a risk externality that pertains to the case of agricultural irrigation using groundwater in conjunction with stochastic surface water supply. Study of the risk externality is beyond the scope of this paper.

6. Virtually every western state has a well-spacing statute to avoid this externality. Further, well spacing is less interesting in a modelling context because it does not require a dynamic model (Negri 1989).

7. See Blomquist (1992) for an insightful investigation of groundwater institutions in southern California.

8. This paper does not address the role of water markets in achieving optimal groundwater allocation. Since we assume homogeneous agents with stationary benefit functions, markets (or other forms of transaction) are not a necessary component of achieving optimality. Other research emphasizes the importance of markets for groundwater rights (Gisser; Smith).

9. It would have been preferable to have parameterized an experimental design with the subgame perfect equilibrium path and the optimal path each taking on integer values at each point at time. Given the complexity of this decision problem, meeting each of these criteria was impossible.

10. Alternatively, we could have held $T = 10$ and merely reduced n to 5. This parameterization would yield an arbitrary reduction in the value of the resource. Thus, the design we investigate examines the impact of reducing the number of producers in a situation where the resource value is held constant.

11. Alternatively, one could investigate the impact of placing flow quotas on individual producer's per period withdrawals. Further, one could investigate an even more complex environment where flow or stock quotas are marketable. In fact, we intend to pursue these types of settings in future research.

12. A stock quota of 20 would allow the players to follow the optimal path; 22 would allow players to follow the subgame perfect equilibrium path. In baseline experiments, subjects often ordered tokens in the last round that went beyond the economically valuable range. For comparisons, we chose a stock quota of 25 to allow this type of behavior in our stock quota design.

TABLE 1
Backward Recursion and Optimal Solution n=10

t	K_t	L_t	x_{it}	c_t	Cumulative Earnings
10	1/4	1/2	2.00	179.6	$219
9	2/6	1/3	2.00	159.6	$215
8	3/8	1/4	2.00	139.7	$207
7	4/10	1/5	2.00	119.7	$195
6	5/12	1/6	2.00	99.7	$179
5	6/14	1/7	2.00	79.8	$159
4	7/16	1/8	2.00	59.8	$136
3	8/18	1/9	2.00	39.9	$108
2	9/20	1/10	2.00	19.9	$76
1	10/22	1/11	2.00	0.0	$40

TABLE 2
Backward Recursion and Symmetric Subgame Perfect Equilibrium n=10

t	K_{it}	L_{it}	x_{it}	c_t	Cumulative Earnings
10	0.0229	0.0645	0.00	219.5	$130
9	0.0263	0.0634	0.00	219.4	$130
8	0.0268	0.0633	0.01	219.3	$130
7	0.0269	0.0632	0.04	218.9	$130
6	0.0269	0.0632	0.09	218.0	$130
5	0.0269	0.0632	0.25	215.5	**$130**
4	0.0269	0.0632	0.70	208.5	$130
3	0.0269	0.0632	1.90	189.5	$130
2	0.0269	0.0632	5.07	138.8	**$127**
1	0.0269	0.0632	13.88	0.0	$112

TABLE 3
Parameterization of Laboratory Experiments

	Number of Players	Number of Decision Periods	Water Use Quantity Constraints (w)
Baseline (n=10)	10	10	∞
Entry Restriction (n=5)	5	20	∞
Stock Quota Rule	10	10	$\Sigma_t \dot{x}_i(t) \leq 25$

[a] The quantity constraint for the stock quota states that accumulated multi-period water use cannot exceed a specified quantity.

[b] $\dot{x}_i(t)$ represent individual decisions for $i=1,\ldots,10$ and $t=1,\ldots,10$.

TABLE 4
Backward Recursion and Optimal Solution n=5

t	K_t	L_t	x_{it}	c_t	Cumulative Earnings
20	1/3	1/6	2.00	189.6	$219
19	1/4	2/8	2.00	179.6	$218
18	1/5	3/10	2.00	169.7	$216
17	1/6	4/12	2.00	159.7	$212
16	1/7	5/14	2.00	149.7	$207
15	1/8	6/16	2.00	139.7	$202
14	1/9	7/18	2.00	129.7	$195
13	1/10	8/20	2.00	114.7	$188
12	1/11	9/22	2.00	109.8	$179
11	1/12	10/24	2.00	99.8	$170
10	1/13	11/26	2.00	89.8	$160
9	1/14	12/28	2.00	79.8	$148
8	1/15	13/30	2.00	69.8	$136
7	1/16	14/32	2.00	59.9	$122
6	1/17	15/34	2.00	49.9	$108
5	1/18	16/36	2.00	39.9	$ 92
4	1/19	17/38	2.00	30.0	$ 76
3	1/20	18/40	2.00	20.0	$ 58
2	1/21	19/42	2.00	10.0	$ 40
1	1/22	20/44	2.00	0.0	$ 20

TABLE 5
Backward Recursion and Symmetric Subgame Perfect Equilibrium n=5

t	K_{it}	L_{it}	x_{it}	c_t	Cumulative Earnings
20	0.0325	0.0769	0.00	219.5	$136
19	0.0446	0.0738	0.00	219.4	$136
18	0.0512	0.0725	0.01	219.4	$136
17	0.0541	0.0719	0.01	219.3	$136
16	0.0555	0.0714	0.02	219.2	$136
15	0.0561	0.0714	0.03	219.0	$136
14	0.0564	0.0713	0.05	218.8	$136
13	0.0565	0.0713	0.08	218.4	$136
12	0.0566	0.0713	0.12	217.8	$136
11	0.0566	0.0713	0.19	216.8	$136
10	0.0566	0.0713	0.30	215.4	$136
9	0.0566	0.0713	0.46	213.0	$136
8	0.0566	0.0713	0.71	209.5	$136
7	0.0566	0.0713	1.11	203.9	$136
6	0.0566	0.0713	1.73	195.3	$136
5	0.0566	0.0713	2.68	181.9	$135
4	0.0566	0.0713	4.17	161.0	$132
3	0.0566	0.0713	6.48	128.6	$127
2	0.0566	0.0713	10.07	78.2	$113
1	0.0566	0.0713	15.65	0.0	$ 80

TABLE 6
Overview of All Experiments

Case	Aggregate Net Benefits	Efficiency	Periods to Exhaustion
Optimum	$219.00	100%	10 (n=10) or 20 (n=5)
Baseline (n=10)			
Base1	$ 88.50	40%	3
Base2	$ 38.80	18%	2
Base-Experienced1	$ 69.00	32%	4
Entry Restriction (n=5)			
Entry1	$ 83.00	38%	6
Entry2	$ 93.10	42%	5
Entry-Experienced1	$116.30	53%	8
Stock Quota			
Stock Quota1	$125.30	57%	7
Stock Quota2	$128.60	59%	4
Stock Quota-Experienced1	$ 98.30	45%	3

TABLE 7
SUMMARY RESULTS: BASELINE n=10 EXPERIMENTS

EXPERIMENT: BASE1 OVERALL EFFICIENCY = 40.4%

	TOKEN ORDER BY SUBJECT NUMBER											
	1	2	3	4	5	6	7	8	9	10		
ROUND											BASE COST	AVE COST	TOTAL ORDER
1	10	22	15	6	17	22	15	10	22	15	.01	.77	154
2	6	0	12	3	4	7	10	3	2	5	1.55	1.81	52
3	0	0	0	0	0	0	1	2	2	0	2.07	2.09	5

EXPERIMENT: BASE2 OVERALL EFFICIENCY = 17.7%

	TOKEN ORDER BY SUBJECT NUMBER												
	1	2	3	4	5	6	7	8	9	10			
ROUND											BASE COST	AVE COST	TOTAL ORDER
1	22	20	3	20	20	22	13	7	22	11	.01	.80	160
2	0	6	10	10	2	14	13	10	22	3	1.61	2.00	80

EXPERIMENT: BASE-EXPERIENCED-1 OVERALL EFFICIENCY = 31.5%

	TOKEN ORDER BY SUBJECT NUMBER												
	1	2	3	4	5	6	7	8	9	10			
ROUND											BASE COST	AVE COST	TOTAL ORDER
1	10	22	16	23	15	22	17	18	14	22	.01	.90	179
2	1	3	1	2	2	0	3	2	2	3	1.80	1.89	19
3	1	1	1	1	1	0	1	1	1	1	1.99	2.04	9
4	1	0	0	1	1	0	1	1	1	0	2.09	2.11	6

TABLE 8
SUMMARY RESULTS: Entry Restriction n=5 EXPERIMENTS

EXPERIMENT: Entry 1 OVERALL EFFICIENCY = 37.9%

	TOKEN ORDER BY SUBJECT NUMBER							
	1	2	3	4	5			
ROUND						BASE COST	AVE COST	TOTAL ORDER
1	15	22	5	5	22	.01	.35	69
2	10	22	8	15	22	0.70	1.08	77
3	0	3	10	18	3	1.47	1.64	34
4	5	2	4	3	2	1.81	1.89	16
5	0	1	2	6	1	1.97	2.02	10
6	0	1	1	1	1	2.07	2.09	4

EXPERIMENT: Entry 2 OVERALL EFFICIENCY = 42.5%

	TOKEN ORDER BY SUBJECT NUMBER							
	1	2	3	4	5			
ROUND						BASE COST	AVE COST	TOTAL ORDER
1	22	22	15	14	22	.01	.48	95
2	14	7	20	5	8	0.96	1.23	54
3	6	4	10	4	5	1.50	1.64	29
4	2	2	9	3	4	1.79	1.89	20
5	1	2	4	1	2	1.99	2.04	10

EXPERIMENT: Entry-EXPERIENCED 1 OVERALL EFFICIENCY = 53.1%

	TOKEN ORDER BY SUBJECT NUMBER							
	1	2	3	4	5			
ROUND						BASE COST	AVE COST	TOTAL ORDER
1	22	20	14	16	22	.01	.47	94
2	11	9	8	8	8	0.95	1.17	44
3	5	5	6	4	6	1.39	1.52	26
4	3	4	5	4	5	1.65	1.75	21
5	2	2	3	2	2	1.86	1.91	11
6	1	1	2	1	2	1.97	2.00	7
7	1	1	1	1	2	2.04	2.07	6
8	1	1	1	0	1	2.10	2.12	4

TABLE 9
SUMMARY RESULTS: STOCK QUOTA RULE EXPERIMENTS

EXPERIMENT: STOCK QUOTA 1 OVERALL EFFICIENCY = 57.2%

	TOKEN ORDER BY SUBJECT NUMBER												
	1	2	3	4	5	6	7	8	9	10			
ROUND											BASE COST	AVECO ST	TOTAL ORDER
1	15	15	10	14	13	22	8	20	4	10	.01	.66	131
2	2	0	4	6	6	3	2	5	5	0	1.32	1.48	33
3	2	4	10	2	3	0	3	0	2	3	1.65	1.79	29
4	0	0	1	2	2	0	1	0	2	0	1.94	1.98	8
5	2	0	0	1	1	0	1	0	1	0	2.02	2.04	6
6	0	0	0	0	0	0	1	0	0	1	2.08	2.09	2
7	0	0	0	0	0	0	1	0	0	0	2.10	2.10	1

EXPERIMENT: STOCK QUOTA 2 OVERALL EFFICIENCY = 58.7%

	TOKEN ORDER BY SUBJECT NUMBER												
	1	2	3	4	5	6	7	8	9	10			
ROUND											BASE COST	AVE COST	TOTAL ORDER
1	18	15	3	10	6	13	10	6	20	5	.01	.54	106
2	7	10	7	11	9	5	8	1	2	10	1.07	1.42	70
3	0	0	4	3	4	2	3	2	3	4	1.77	1.89	25
4	0	0	3	1	1	5	4	4	0	1	2.02	2.11	19

EXPERIMENT: STOCK QUOTA-EXPERIENCED 1 OVERALL EFFICIENCY = 44.9%

	TOKEN ORDER BY SUBJECT NUMBER												
	1	2	3	4	5	6	7	8	9	10			
ROUND											BASE COST	AVE COST	TOTAL ORDER
1	14	14	17	14	19	14	22	3	12	10	.01	.70	139
2	6	8	8	6	5	11	3	7	6	3	1.40	1.71	63
3	1	1	0	1	1	0	0	15	1	0	2.03	2.13	20

APPENDIX A

EXPERIMENT INSTRUCTIONS:

This is an experiment in decision making. Funds for conducting this research have been provided by several agencies of the Federal Government. The instructions are designed to inform you of the types of decisions you will be making and how you will earn money from your decisions. All money you earn during this experiment will be totalled and paid to you in private in cash at the end of the experiment. If you have any questions concerning the instructions, feel free *to raise your hand,* and one of the monitors will assist you.

The experiment consists of a sequence of decision rounds. There are 9 other participants in this experiment. *Each of your individual decisions will remain anonymous to the other participants.*

In each round, you will be asked to fill out an order form which designates how many tokens you wish to order for that round. *Tokens ordered in one round cannot be carried over to other rounds.*

Why would you want to order tokens? Because you can earn money from those tokens.

Tokens you order each round will: (1) earn you a cash BENEFIT which we describe below, but also (2) COST you money, which we also describe below.

After you privately fill out an order form, the monitor will collect the order forms. IMPORTANT - Your cash BENEFIT for the tokens you order depends only on how many tokens you order - Your COST of buying tokens, however, depends on how many tokens all participants order.

Let us explain further:

I. CASH BENEFITS FROM YOUR TOKENS

Each token you order earns you a cash return calculated using the following equation:

$\$2.20(T) - \$.05(T)^2$

where T is the number of tokens you order. This equation is the same for every participant and the same for each decision round. You do not have to solve this equation. LOOK at the Table referred to as "BENEFITS FROM TOKENS." ***This table shows the value of cash benefits for various token orders you might make in a given decision round.***

FOR EXAMPLE: Let's say you order 10 Tokens in a given decision round. That token order will earn you BENEFITS of $17.00.

Notice that the more tokens you order, the greater are your cash BENEFITS - up to 22 tokens.

DO YOU HAVE ANY QUESTIONS REGARDING BENEFITS FROM ORDERING TOKENS?

HOWEVER, YOU MUST PAY FOR THOSE TOKENS. HERE IS HOW THAT WORKS.

II. TOKEN COSTS

At the beginning of each round, we will post a BASE COST for tokens in that round. The base cost is the cost of the first token sold in that round. Each additional token costs $.01 more than the previous token sold.

For example, the base cost is $0.01 in the first round. Assume 30 tokens are ordered by the entire group in that round. The first token costs S.01, the second token costs $.02. the third token costs $.03, and so on until the thirtieth token, which costs $.30. The total cost of tokens to the group is $.01 + $.02 + $.03 + ... + $.30 = $4.65.

What you pay for your tokens equals your share of the total number of tokens bought times the total cost of the tokens to the group. In the example, if you bought 6 out of the 30 tokens, then your share of the total number of tokens bought is 6/30 or 20%, and your token cost is (20%)($4.65) = $.93. In this example, your average token cost is $.93/6 = $.155 per token. In any given round, it will always be the case that your average token cost is greater than the base cost but less than the highest token cost in that round. FURTHER, THE AVERAGE COST PER TOKEN IN A GIVEN ROUND WILL BE THE SAME FOR EACH PARTICIPANT BUT THE TOTAL TOKEN COSTS PER ROUND CAN BE DIFFERENT FOR EACH PARTICIPANT.

***Each round, the BASE COST for that round will be $.01 higher than the cost of the LAST token sold in the previous round.* This means that token costs will only GO UP during the experiment, NEVER DOWN. Tokens bought earlier in the experiment will always be cheaper than tokens bought later.**

In the example above, the base cost of tokens in the first round was $.01 and 30 tokens were ordered. The last token that round had a cost of $.30. This means that the base cost of tokens in the second round is $.30 + $.01 = $.31. The first token sold in the second round will cost $.31. The second will cost $.32, the third $.33, etc.

Now look at the TABLE referred to as the "COST OF TOKENS." ***This table shows how token costs change as more and more tokens are ordered during the experiment by the group of participants. Starting at the BASE COST far a given decision round, each token ordered by the group costs $.01 more than the previous token.***

DO YOU HAVE ANY QUESTIONS REGARDING TOKEN COSTS?

III. TOKEN BENEFITS AND COSTS FOR OTHER PARTICIPANTS

In each round of this experiment, every participant faces an identical BENEFITS SCHEDULE FOR TOKENS, THE SAME BASE COST FOR TOKENS, AND THE SAME AVERAGE TOKEN COST. Earnings in the experiment may differ between participants because they may place different orders for tokens.

IV. **FINAL INSTRUCTIONS**

You have an opportunity to earn a substantial amount of money in this experiment, depending on the decisions you make as well as on the decisions of the entire group. In the unfortunate event, however, that your accumulated earnings go below zero, your participation in the experiment will end and you will be asked to leave. However, we will not charge you for negative earnings, and you will be allowed to keep your $3.00 upfront payment.

NOTICE: The experiment will last UP to 10 ROUNDS. But, if the BASE TOKEN COST ever reaches a level at which individuals cannot earn a positive profit in subsequent rounds, the experiment will end.

AT THE BEGINNING OF EACH DECISION ROUND, you will be asked to fill out the TOKEN ORDER FORM for tokens you wish to order for that round. **FILL THIS ORDER FORM OUT WITH THE RED PEN YOU HAVE BEEN GIVEN. BEFORE WRITING YOUR ORDER DOWN, CONSIDER YOUR ORDER CAREFULLY. IF YOU DECIDE TO CHANGE YOUR ORDER AFTER YOU HAVE WRITTEN IT DOWN - CONTACT A MONITOR BEFORE MAKING THE CHANGE.**

The monitors will collect all forms to tabulate token orders and compute profits (BENEFITS - COSTS). After all computations are made, you will be informed of:

(1) the total number of tokens ordered by the group,
(2) your average token cost for the current round,
(3) your total BENEFITS for the current round,
(4) your total COSTS for the current round,
(5) your total PROFITS for the current round.

AND

(6) the BASE COST of tokens for the NEXT ROUND.

The NEXT page of INSTRUCTIONS summarizes the key steps in the experiment.

EXPERIMENTAL PROCEDURES: A SUMMARY OF KEY STEPS

1) Subjects place an order for tokens prior to the current decision round.

2) Tokens ordered cannot be carried over to the next round.

3) CASH BENEFITS from tokens ordered in a given round are shown in the Table labeled -BENEFITS FROM TOKENS."

4) At the beginning of each round, a BASE COST for tokens is posted. The base cost is the cost of the first token sold in that round. Each additional token costs $.01 more than the previous token sold.

4) The base cost in any round equals the cost of the last token purchased in the previous round plus $01.

5) An individual's token costs are a % of overall group token costs - equal to their share of total tokens ordered.

6) Experiments last up to 10 rounds. Before each decision round, participants fill out the order form for tokens for that round. After all tokens orders are collected and tabulated:

   YOU WILL BE INFORMED OF:

   (1) how many tokens in total were ordered by the group,
   (2) your average token cost for the current round,
   (3) your total BENEFITS for the current round,
   (4) your total COSTS for the current round,
   (5) your total PROFITS for the current round.

   AND

   (6) the BASE COST of tokens for the NEXT ROUND.

IF YOU HAVE ANY QUESTIONS ABOUT THE EXPERIMENT, PLEASE RAISE YOUR HAND NOW. IF NOT, PLEASE PROCEED TO THE NEXT PAGE WHICH TAKES YOU THROUGH A PRACTICE EXAMPLE.

PRACTICE EXAMPLES

These examples are for illustrative purposes only. The numbers used in the example have been chosen to simplify the illustration.

EXAMPLE 1:

Assume you are in the 4th Round of the Experiment and by the end of the 3rd Round the group had ordered a total of 30 Tokens.

Now suppose you place an order for 2 Tokens and the rest of the group (in total) orders an additional 4 Tokens - for a total group order of 6 Tokens.

Using the BENEFITS AND COSTS TABLE:

1) What will be your CASH BENEFIT?__________

2) What will be the BASE COST for the first token ordered in this round?__________

3) What will be YOUR TOTAL TOKEN COSTS this round?__________

4) What would be YOUR PROFIT for this round? __________

EXAMPLE 2:

Assume you are in the 4th Round of the Experiment and by the end of me 3rd Round the group had ordered a total of 180 Tokens.

Now suppose you place an order for 2 Tokens and the rest of the group (in total) orders an additional 4 Tokens - for a total group order of 6 Tokens.

Using the BENEFITS AND COSTS TABLE:

1) What will be your CASH BENEFIT?__________

2) What will be the BASE COST for the first token ordered in this round? __________

3) What will be YOUR TOTAL TOKEN COSTS this round?__________

4) What would be YOUR PROFIT for this round? __________

ARE THERE ANY QUESTIONS

BENEFITS FROM TOKENS

This Table Displays BENEFITS For Various Token Orders

TOKENS	BENEFITS		TOKENS	BENEFITS
1	$2.15		14	$21.00
2	$4.20		15	$21.75
3	$6.15		16	$22.40
4	$8.00		17	$22.95
5	$9.75		18	$23.40
6	$11.40		19	$23.75
7	$12.95		20	$24.00
8	$14.40		21	$24.15
9	$15.75		22	$24.20
10	$17.00		23	$24.15
11	$18.15		24	$24.00
12	$19.20		25	$23.75
13	$20.15		26	$23.40

TOKEN COSTS

THIS TABLE DISPLAYS THE SPECIFIC COST PER TOKEN FOR TOKENS PURCHASED BY THE GROUP

TOKEN NUMBER (COST)

1 ($0.01)	64 ($0.64)	127 ($1.27)	190 ($1.90)	253 ($2.53)	316 ($3.16)	379 ($3.79)	442 ($4.42)
2 ($0.02)	65 ($0.65)	128 ($1.28)	191 ($1.91)	254 ($2.54)	317 ($3.17)	380 ($3.80)	443 ($4.43)
3 ($0.03)	66 ($0.66)	129 ($1.29)	192 ($1.92)	255 ($2.55)	318 ($3.18)	381 ($3.81)	444 ($4.44)
4 ($0.04)	67 ($0.67)	130 ($1.30)	193 ($1.93)	256 ($2.56)	319 ($3.19)	382 ($3.82)	445 ($4.45)
5 ($0.05)	68 ($0.68)	131 ($1.31)	194 ($1.94)	257 ($2.57)	320 ($3.20)	383 ($3.83)	446 ($4.46)
6 ($0.06)	69 ($0.69)	132 ($1.32)	195 ($1.95)	258 ($2.58)	321 ($3.21)	384 ($3.84)	447 ($4.47)
7 ($0.07)	70 ($0.70)	133 ($1.33)	196 ($1.96)	259 ($2.59)	322 ($3.22)	385 ($3.85)	448 ($4.48)
8 ($0.08)	71 ($0.71)	134 ($1.34)	197 ($1.97)	260 ($2.60)	323 ($3.23)	386 ($3.86)	449 ($4.49)
9 ($0.09)	72 ($0.72)	135 ($1.35)	198 ($1.98)	261 ($2.61)	324 ($3.24)	387 ($3.87)	450 ($4.50)
10 ($0.10)	73 ($0.73)	136 ($1.36)	199 ($1.99)	262 ($2.62)	325 ($3.25)	388 ($3.88)	451 ($4.51)
11 ($0.11)	74 ($0.74)	137 ($1.37)	200 ($2.00)	263 ($2.63)	326 ($3.26)	389 ($3.89)	452 ($4.52)
12 ($0.12)	75 ($0.75)	138 ($1.38)	201 ($2.01)	264 ($2.64)	327 ($3.27)	390 ($3.90)	453 ($4.53)
13 ($0.13)	76 ($0.76)	139 ($1.39)	202 ($2.02)	265 ($2.65)	328 ($3.28)	391 ($3.91)	454 ($4.54)
14 ($0.14)	77 ($0.77)	140 ($1.40)	203 ($2.03)	266 ($2.66)	329 ($3.29)	392 ($3.92)	455 ($4.55)
15 ($0.15)	78 ($0.78)	141 ($1.41)	204 ($2.04)	267 ($2.67)	330 ($3.30)	393 ($3.93)	456 ($4.56)
16 ($0.16)	79 ($0.79)	142 ($1.42)	205 ($2.05)	268 ($2.68)	331 ($3.31)	394 ($3.94)	457 ($4.57)
17 ($0.17)	80 ($0.80)	143 ($1.43)	206 ($2.06)	269 ($2.69)	332 ($3.32)	395 ($3.95)	458 ($4.58)
18 ($0.18)	81 ($0.81)	144 ($1.44)	207 ($2.07)	270 ($2.70)	333 ($3.33)	395 ($3.96)	459 ($4.59)
19 ($0.19)	82 ($0.82)	145 ($1.45)	208 ($2.08)	271 ($2.71)	334 ($3.34)	397 ($3.97)	460 ($4.60)
20 ($0.20)	83 ($0.83)	146 ($1.46)	209 ($2.09)	272 ($2.72)	335 ($3.35)	398 ($3.98)	461 ($4.61)
21 ($0.21)	84 ($0.84)	147 ($1.47)	210 ($2.10)	273 ($2.73)	336 ($3.36)	399 ($3.99)	462 ($4.52)
22 ($0.22)	85 ($0.85)	148 ($1.48)	211 ($2.11)	274 ($2.74)	337 ($3.37)	400 ($4.00)	433 ($4.63)
23 ($0.23)	86 ($0.86)	149 ($1.49)	212 ($2.12)	275 ($2.75)	338 ($3.38)	401 ($4.41)	464 ($4.64)
24 ($0.24)	87 ($0.87)	150 ($1.50)	213 ($2.13)	276 ($2.76)	339 ($3.39)	402 ($4.02)	465 ($4.65)
25 ($0.25)	88 ($0.88)	151 ($1.51)	214 ($2.14)	277 ($2.77)	340 ($3.40)	403 ($4.03)	466 ($4.66)
26 ($0.26)	89 ($0.89)	152 ($1.52)	215 ($2.15)	278 ($2.78)	341 ($3.41)	404 ($4.04)	467 ($4.67)
27 ($0.27)	90 ($0.90)	153 ($1.53)	216 ($2.16)	279 ($2.79)	342 ($3.42)	405 ($4.05)	463 ($4.68)
28 ($0.28)	91 ($0.91)	154 ($1.54)	217 ($2.17)	280 ($2.80)	343 ($3.43)	406 ($4.06)	469 ($4.69)
29 ($0.29)	92 ($0.92)	155 ($1.55)	218 ($2.18)	281 ($2.81)	344 ($3.44)	407 ($4.07)	470 ($4.70)
30 ($0.30)	93 ($0.93)	156 ($1.56)	219 ($2.19)	282 ($2.82)	345 ($3.45)	408 ($4.08)	471 ($4.71)
31 ($0.31)	94 ($0.94)	157 ($1.57)	220 ($2.20)	283 ($2.83)	346 ($3.46)	409 ($4.09)	472 ($4.72)
32 ($0.32)	95 ($0.95)	158 ($1.58)	221 ($2.21)	284 ($2.84)	347 ($3.47)	410 ($4.10)	473 ($4.73)
33 ($0.33)	96 ($0.96)	159 ($1.59)	222 ($2.22)	285 ($2.85)	348 ($3.48)	411 ($4.11)	474 ($4.74)
34 ($0.34)	97 ($0.97)	160 ($1.60)	223 ($2.23)	286 ($2.86)	349 ($3.49)	412 ($4.12)	475 ($4.75)
35 ($0.35)	98 ($0.98)	161 ($1.61)	224 ($2.24)	287 ($2.87)	350 ($3.50)	413 ($4.13)	476 ($4.76)
36 ($0.36)	99 ($0.99)	162 ($1.62)	225 ($2.25)	288 ($2.88)	351 ($3.51)	414 ($4.14)	477 ($4.77)
37 ($0.37)	100 ($1.00)	163 ($1.63)	226 ($2.26)	289 ($2.89)	352 ($3.52)	415 ($4.15)	478 ($4.78)
38 ($0.38)	101 ($1.01)	164 ($1.64)	227 ($2.27)	290 ($2.90)	353 ($3.53)	416 ($4.16)	479 ($4.79)
39 ($0.39)	102 ($1.02)	165 ($1.65)	228 ($2.28)	291 ($2.91)	354 ($3.54)	417 ($4.17)	480 ($4.80)
40 ($0.40)	103 ($1.03)	166 ($1.66)	229 ($2.29)	292 ($2.92)	355 ($3.55)	418 ($4.18)	481 ($4.81)
41 ($0.41)	104 ($1.04)	167 ($1.67)	230 ($2.30)	293 ($2.93)	356 ($3.56)	419 ($4.19)	482 ($4.82)
42 ($0.42)	105 ($1.05)	168 ($1.68)	231 ($2.31)	294 ($2.94)	357 ($3.57)	420 ($4.20)	483 ($4.83)
43 ($0.43)	106 ($1.06)	169 ($1.69)	232 ($2.32)	295 ($2.95)	358 ($3.58)	421 ($4.21)	484 ($4.84)
44 ($0.44)	107 ($1.07)	170 ($1.70)	233 ($2.33)	296 ($2.96)	359 ($3.59)	422 ($4.22)	485 ($4.85)
45 ($0.45)	108 ($1.08)	171 ($1.71)	234 ($2.34)	297 ($2.97)	360 ($3.60)	423 ($4.23)	486 ($4.86)
46 ($0.46)	109 ($1.09)	172 ($1.72)	235 ($2.35)	298 ($2.98)	361 ($3.61)	424 ($4.24)	487 ($4.87)
47 ($0.47)	110 ($1.10)	173 ($1.73)	236 ($2.36)	299 ($2.99)	362 ($3.62)	425 ($4.25)	488 ($4.88)
48 ($0.48)	111 ($1.11)	174 ($1.74)	237 ($2.37)	300 ($3.00)	633 ($3.63)	426 ($4.26)	489 ($4.89)
49 ($0.49)	112 ($1.12)	175 ($1.75)	238 ($2.38)	301 ($3.00)	364 ($3.64)	427 ($4.27)	490 ($4.90)
50 ($0.50)	113 ($1.13)	176 ($1.76)	239 ($2.39)	302 ($3.02)	365 ($3.65)	428 ($4.28)	491 ($4.91)
51 ($0.51)	114 ($1.14)	177 ($1.77)	240 ($2.40)	303 ($3.03)	366 ($3.66)	429 ($4.29)	492 ($4.92)
52 ($0.52)	115 ($1.15)	178 ($1.78)	241 ($2.41)	304 ($3.04)	367 ($3.67)	430 ($4.30)	493 ($4.93)
53 ($0.53)	116 ($1.16)	179 ($1.79)	242 ($2.42)	305 ($3.05)	368 ($3.68)	431 ($4.31)	494 ($4.94)
54 ($0.54)	117 ($1.17)	180 ($1.80)	243 ($2.43)	306 ($3.06)	369 ($3.69)	432 ($4.32)	495 ($4.95)
55 ($0.55)	118 ($1.18)	181 ($1.81)	244 ($2.44)	307 ($3.07)	370 ($3.70)	433 ($4.33)	496 ($4.96)
56 ($0.56)	119 ($1.19)	182 ($1.82)	245 ($2.45)	308 ($3.08)	371 ($3.71)	434 ($4.34)	497 ($4.97)
57 ($0.57)	120 ($1.20)	183 ($1.83)	246 ($2.46)	309 ($3.09)	372 ($3.72)	435 ($4.35)	498 ($4.98)
58 ($0.58)	121 ($1.21)	184 ($1.84)	247 ($2.47)	310 ($3.10)	373 ($3.73)	436 ($4.36)	499 ($4.99)
59 ($0.59)	122 ($1.22)	185 ($1.85)	248 ($2.48)	311 ($3.11)	374 ($3.74)	437 ($4.37)	500 ($5.00)
60 ($0.60)	123 ($1.23)	186 ($1.86)	249 ($2.49)	312 ($3.12)	375 ($3.75)	438 ($4.38)	
61 ($0.61)	124 ($1.24)	187 ($1.87)	250 ($2.50)	313 ($3.13)	376 ($3.76)	439 ($4.39)	
62 ($0.62)	125 ($1.25)	188 ($1.88)	251 ($2.51)	314 ($3.14)	377 ($3.77)	440 ($4.40)	
63 ($0.63)	126 ($1.26)	189 ($1.89)	252 ($2.52)	315 ($3.15)	378 ($3.78)	441 ($4.41)	