DUKE ENVIRONMENTAL ECONOMICS WORKING PAPER SERIES
organized by the
NICHOLAS INSTITUTE FOR ENVIRONMENTAL POLICY SOLUTIONS

Efficiency Gains from Pre-Investment Resource Queues:
Coodinating Investment under Resource Uncertainty

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Working Paper EE 11-02
April 2011

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Efficiency Gains From Pre-Investment Resource Queues:

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Abstract

Farmers make investments, e.g. in sowing, before knowing how much water they will receive later in the season. The costs of the inefficiently high or low investment that may result can be significant. A spot market that efficiently allocates water once quantity is realized is unlikely to coordinate simultaneous efficient investments earlier in the season. We compare pre-established queues to a post-investment-&-resource-realization market in coordinating investment whose productivity depends on having the uncertain resource. We do experiments with two subject pools: UK university; and rural setting in NE Brazil. Our main result, robust across subject pools, is that the queues outperform the market, as they differentiate players *pre-investment* in terms of likelihood of getting a resource unit. That helps in particular for avoiding large deviations from efficient levels of investment.

JEL: C92, C93, D02

Keywords: queue, investment, coordination, experiments, field

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[1] Fonseca and Pfaff share lead authorship equally. We would like to thank Augusto Freitas and Tim Miller for their invaluable help in running the experiments. We also thank for helpful comments participants in talks at Columbia University, the University of Exeter and Ascona. Fonseca: University of Exeter; Phone: +44 (0)1392 262584; Fax: +44 (0)1392 263242; Email: m.a.fonseca@exeter.ac.uk. Pfaff: Sanford School of Public Policy, Duke University; Tel: +1 (919) 613-9240; Email: alex.pfaff@duke.edu. Osgood: International Research Institute for Climate and Society, Columbia University; Phone: +1 (845) 680-4461, Fax: +1 (845) 680-4865; Email: *deo@iri.columbia.edu*

1. Introduction

Uncertainty in water availability and in water rights is known to impose severe costs on farmers, a concern confronted in the first AER article (Coman 1911). Related information has substantial impact on investment (Bryant et al. 1993, Willis and Whittlesey 1998, Cai and Rosengrant 2004, Sunding et al. 1999, Moreno et al. 2005). Its importance extends to design of optimal institutions, e.g. establishment of rights for spot markets (Burness and Quirk 1979, Dinar and Letey 1991).

More generally, a central economic question is how to allocate scarce resources whose quantity is uncertain when a decision must be made. Complex such choices include decisions on investments that are complementary to a resource but made before resource quantity is known. Many investments and resources are complements, raising each other's impacts. In agriculture, around the globe farmers make investments that are complementary to water in crop production. Some are before knowing how much water will be available, in aggregate or for a given farmer.

Consider a group of farmers who share an uncertain quantity of water supplied by nature. Each faces investment decisions before the rainfall, such as in land preparation or seed purchase. Investments' returns depend on having water. If water is scarce and future allocation is unknown, there is potential for failure in investment coordination: too many or too few farmers may invest. If few do and water supply is high, or if all do and water supply is low, investment is inefficient. This "collective action" problem in irrigation, driven by uncertainty, investments, and property rights structures, has been studied in depth, for instance within the initial article published in the *American Economic Review* (Coman 1911). Commonly, water rights are allocated based on an appropriative rights queue. Farmers with senior rights (the beginning of the queue) are allocated water in sequence until the supply is gone. Often water cannot be transferred between farmers. In some cases, spot markets have been created to allow farmers to sell water to each other, after the resource quantity is known (Howitt 1998, Olmstead et al. 1997, Brozovic et al. 2002). In spite of these mechanisms, though, water allocation and investment under uncertainty remain "unsettled," as illustrated in the recent discussion of Coman's 1911 article (Ostrom 2011).

In light of this challenging agricultural decision problem, identifying the most efficient coordination institutions has value.[2] Inspired by a few examples of observed informal annual water rights leases between farmers (Cristi 2007, Skees and Akssel, 2005), we study gains from coordinating investment under resource uncertainty in a simple common governance structure, a queue for the resource that is established before water arrives and before investments are made. Here, farmers can bid for or are given water rights before quantities are known. We distinguish this from a spot resource market after both investments and the total water quantity are known. Such a market can allocate water efficiently but, by its very nature, occurs after water is known. Thus in contrast with the queue, it provides information only after investments have been made.

Does the governance institution affect investment coordination? Recent theoretical work (Small, Osgood and Pfaff 2010) shows that establishing a resource queue can raise efficiency. The queue transforms the farmers' common probability of receiving water into a differentiated probability according to queue slot. Early slots have a greater chance and all farmers know this in advance of investment. That could improve coordination and total investment. Specifically, investments appropriately proportional to expected water supply should become more likely.

Yet the theory allows that forward-looking individuals, facing an ex-post market, might not only figure out what investment level is efficient but also somehow coordinate expectations by each farmer about all the others' investments. This may not seem likely but clearly is possible. Thus, whether an institution like a queue helps to coordinate investment is an empirical question.

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[2] Water quantity options have also been explored. However, they are an incompletely implementable tool, since quantity delivery cannot be guaranteed at any price if nature does not deliver the water.

Unfortunately, empirically examining institutions to answer it requires queues and spot markets in numerous comparable settings, within each of which the uncertainty could be well quantified. That seems exceptionally unlikely and no more likely for most researchers is the possibility of obtaining permission to vary localities' actual water-allocation institutions in a systematic way.

Experiments are another option. Participants face financial incentives structured to be like farmers' actual investment problems (for agricultural settings see for instance Binswanger 1981; for auctions for natural resource management, see Cason and Gangadharan 2004). Critically, while varying the institutions the researcher can control the uncertainty that the participants face. We use both laboratory and artefactual field experiments (Harrison and List 2004). Most past experiments were in universities with undergraduate participants. There is growing recognition, however, of the importance of using field subjects as participants, whether that is within abstract experiments or in more natural settings (Levitt and List 2009; Herberich, Levitt and List 2009).

We examine the dominant appropriative rights queue institution (with and without the innovation of rights bidding) and an ex-post spot market for water to compare their impacts on the coordination of investments. In 'Market After investment and rain' (MA), all of the players decide whether to invest then, after resource supply is realized, bid for available resource units. This is essentially a spot market for water, as is often discussed (see discussion in Howitt 1998). While the most direct analog for our setup is an annual water auction by a centralized authority, from the perspective of bidding parties it matters little who is supplying the water they demand. Thus our MA institution represents various forms of existing spot markets with many sellers.

In 'Queue Before investment and rain' (QB), each player is simply assigned a place in the queue for the uncertain resource. This is similar to the case of appropriative water rights without the possibility of transfers, noting that we assign these rights randomly as opposed to on the basis of seniority or any other broadly recognized grounds. To be specific, no bid is required to obtain a queue place. While such assignment can yield inefficient water allocation (Burness and Quirk 1979), this simplest of queues is an important benchmark within our examination of investment. Critically, this simple queue differentiates players in terms of chances of obtaining the resource.

Our 'Market Before investment and rain' (MB), extends the previous queue institution by bringing back in the logic of markets and transfers so that the queue order is not simply assigned. Specifically we conduct an auction for the queue places, which proxy water rights (Howitt 1998). Again, as in the assigned queue (QB), before investment each player has a different probability of obtaining a unit of the resource. Here, though, players chose and paid for those probabilities.

Both the market for water rights (our MB) and the spot market for water (our MA) have close analogs in reality -- noting again that sellers could be private rights holders and/or public actors auctioning these assets. For instance, Cristi 2007 describes both within one site in Chile and Skees and Akssel 2005 describes both in Mexico. Also, each of these queues (MB and QB) has a realistic method of assigning rights (with and without market). Auctions to raise revenue are often important but so too are a myriad of political and other factors which affect allocations.

We compare three uncertainty conditions. Our baseline is certainty about resource supply (ten rounds, across which the resource level is shifted). Next we bring in the uncertainty, using a uniform distribution over possible resource realizations (ten rounds, with new resource draws each round). Finally, we increase scarcity using a geometric distribution over the same outcomes with far lower expected resource supply (ten rounds, with new resource draws in each round).

Always groups of five subjects interact. They are drawn from one of two subject pools. The first is water users in the state of Ceará, within Northeast Brazil. This pool is motivated by farmers in Ceará facing the problem we wish to study. Ceará is subject to seasonal-to-interannual climate and water shocks, in particular associated with ENSO, that affect crop outcomes and the returns from investments in land and seeds. The second pool is students at University of Exeter in England. It offers a robustness test and a window on lab versus field behavioral differences.

We find that both queues outperform a post-investment, post-resource-realization market. Both queues permit the participants to capture a greater share of the total possible returns from the investment choices they make. Both queues also have fewer large deviations from efficiency (in either direction, i.e. over- or under-investment) between the observed investment level and the expected resource supply that defines efficiency. Interestingly, despite the complexity of the bidding in the MB institution, it performs essentially the same as the predetermined QB. We also show that choices appear to reflect understanding of basic incentives, although there is somewhat greater variability in the behaviors observed in the field subject pool than within the lab subjects.

2. Theory

Let $N = \{1,2,3,4,5\}$ denote a set of risk-neutral players. Each must make a binary investment decision $i_j = 1$ (invest) or 0 (don't). Payoffs are a function of i_j as well as the availability of a resource. Let $w = \{0,1,2,3,4,5\}$ denote the possible total supplies of the resource and let $g(w)$ denote the probability distribution over w. We consider three types of distributions (Figure 1): certainty (six versions, one for each possible resource level); uniform distribution (assigning 1/6 to each possible resource level); and geometric distribution, assigning probabilities 0.339 to $w = 0$, 0.238 to $w = 1$, 0.167 to $w = 2$, 0.117 to $w = 3$, 0.082 to $w = 4$ and 0.057 to $w = 5$.

[figure 1 here]

For investment to pay requires a unit of the resource. Let w_j be an indicator for whether player *j* obtained a unit of the resource ($w_j = 1$) or not ($w_j = 0$). The payoffs are: if $i_j = 1$ and $w_j = 1$, 80; if $i_j = 1$ and $w_j = 0$, -40; if $i_j = 0$ and $w_j = 1$, 40; and if $i_j = 0$ and $w_j = 0$, 0. A loss given $i_j = 1$ and $w_j = 0$ is consistent with costly investment. If not investing, there is no loss if lacking the resource. Below we consider the equilibria of three resource allocation institutions.

2.1 Queue Before (QB) investment & resource realization

Here allocation of the available resource proceeds along a queue. Places in the queue q_j are just randomly assigned. Let $prob(w_j = 1 | q_j)$ denote the probability of player j obtaining a resource unit ($w_j = 1$) given his place in queue q_j. Given that conditional probability, investment will depend upon one's queue place. Players will invest if the expected value is higher than when not investing. Both expectations depend on the chance of having the resource. Thus you invest if:

(1) $prob(w_j = 1 | q_j)80 + (1 - prob(w_j = 1 | q_j))(-40) > prob(w_j = 1 | q_j)40$

Players higher in the queue will invest more often. One is indifferent about investing if $prob(w_j = 1 | q_j) = 1/2$, i.e. the chance of getting a resource unit is 50%. The implications for us of that investment rule are in Table 1, which provides the values of $prob(w_j = 1 | q_j)$ by queue place for each probability distribution we consider, as well as the investment decision implied.

[table 1 here]

Under the uniform distribution, the first two players in queue will invest with certainty. The third player will be indifferent, while the fourth and fifth players will not want to invest. Under the geometric distribution, only the first placed player will have a probability of obtaining a unit of the resource that is higher than ½. Hence, only that player will choose to invest.

2.2 Market Before (MB) investment & resource realization

Here queue places go to the highest bidder in a sequential first-price auction. We start by bidding for the first place in the queue. The highest bidder wins that place and pays the bid price. Given a tie, the place is allocated randomly to one of the highest bidders, who pays the bid price.

After the first queue place is allocated, the winner is excluded from the subsequent auctions and the remaining bidders bid for the second place. The process continues for all of the queue places.

Therefore MB is a six-stage game, with five bidding stages then an investment decision. Hence, a strategy consists of $\langle b_j^1, b_j^2, b_j^3, b_j^4, b_j^5, i_j \rangle$, where b_j^k is the bid player *j* makes for the *k*th place in the queue. We restrict our attention to subgame-perfect equilibria. The subgame-perfect equilibrium is $\langle v(1)-v(5), v(2)-v(5), v(3)-v(5), v(4)-v(5), 0; i_j \rangle$. The equilibrium bid for each queue place should be that queue place's expected value minus the value of obtaining fifth place.

Consider the investment stage. Players already know their queue places. Thus this stage functions like the fixed queue (QB). Investment decisions are governed by the same rule (though the payoffs are lower since here players pay for queue places). As in QB, optimal investment depends on queue place. No matter the probability distribution, fourth and fifth will not invest.

Knowing all those investment decisions, we can calculate the value of each place in the queue for each probability distribution and, as a result, the optimal bids for those queue places. Consider the auction for the fifth place. Given as resource units as bidders, only one player bids for last place so the equilibrium bid is $b_j^5 = 0$. We can compute the value or expected payoff for having this place, given that investment will never be optimal: $v(5) = prob(w_j = 1 \mid q_j = 5)40$.

Now consider the auction for the fourth place in queue. A player will never bid more than $v(4)-v(5)$, since losing the bidding for fourth and earning $v(5)$ in fifth place would be better than bidding more and winning the fourth place. From there, it is clear that no player should bid more than $v(q)-v(5)$ for any queue place $q<5$. We can apply the expected payoffs expressions above for each queue place and probability distribution to calculate the value for each place and, by implication, the most one should bid for a queue place. Table 1 displays for each queue place and each probability distribution the probability of getting water, the investment decision this implies, the value or expected payoffs from that place and investment decision, and finally the equilibrium bids for each queue place which will depend upon all of the preceding information.

A note concerning the assumption of risk neutrality is warranted. Purchasing a place in queue is equivalent to purchasing the right to choose between two lotteries. These lotteries will differ in expected value and variance according to the place in queue. For $prob(w_j = 1) > 0.5$, moving down the queue means that investing has a lower expected value and higher variance. In other words, there is a higher average return from being higher up in the queue and also less risk. In the part of the queue where $prob(w_j = 1) < 0.5$, in contrast, we observe a tradeoff between risk and expected return. Lower places have lower expected returns but also lower variances. If risk aversion matters, we should see a sharper drop in prices from first to second place in the queue, as it is a dominant strategy to bid one's queue-place value net of the value of having fifth place.[i]

2.3 Market After (MA) investment & resource realization

Here a spot market after investment and the resolution of uncertainty allocates resources. Players invest or not based on expectations of aggregate rain as well as the others' investments. Then resource units are realized and sold in a sequential first-price auction starting with the first unit of the resource. The highest bidder wins the auction and pays that price. In case of a tie, the resource unit is allocated randomly to one of the highest bidders, who pays that price. After the resource unit is allocated, the winner is excluded from the subsequent auctions and the remaining bidders bid for the second unit. The resource bidding continues until all of the units are allocated.

Hence, MA is a six-stage game with an investment decision and then five bidding stages. A strategy is a $\langle d_j; b_j^1, b_j^2, b_j^3, b_j^4, b_j^5 \rangle$, where b_j^k is the bid player *j* makes for the k^{th} resource unit. As before, we restrict our analysis to subgame-perfect equilibria. We work through the bidding equilibria, which follow investment and resource realization and work back to investment. This becomes relatively complicated even as summarized here, including because optimal investment depends on investment decisions of the others. Precisely the reason to expect underperformance of this institution in coordinating investment is that coordinating such expectations is very hard.

We start with the resource spot market following the investment and resource realization. Let I represent total investment. If $I > w$, i.e. more players invested than the number of resource units that later were supplied by nature, then the equilibrium price of each resource unit is 80. Even for the last resource unit, there will be at least two players who have invested and thus have the maximum valuation of 80. There are two possible equilibria: one bids the maximum amount; or all shade the maximum amount by ε. In either, no player can improve by changing his action. Thus equilibrium prices are either 80 or $80 - \varepsilon$. Applying this to all of the other resource units, there will always be excess demand, as in this analysis, and thus all units will be sold for 80.

If $I \leq w$, the price for the first I units will be $40 + \varepsilon$ and for the remaining units is 40. To see why, consider the auction for the final unit. All bidders have a valuation of 40, as they did not invest, so in the equilibrium at least one player bids 40. This logic applies up to the I^{th} unit. For that unit, there will be one bidder who invested and has a valuation of 80 who will win the auction by bidding $40 + \varepsilon$. It would not make sense for the unit sold just before to go for more, as investors can wait to outbid non-investors. Thus all previous units will sell for $40 + \varepsilon$ as well.

Turning to the investment stage, we consider the payoffs for investors and non-investors given the resource auction just described, noting that the investment decision has as an input not the actual level of resource units supplied but only the expected number. Also, each individual's investment decision will be made conditional on expectations of others' investment decisions.

Considering an investment, if $i_j = 1$ and $I \leq E(w)$, i.e. investment is relatively low and so the resource will be less scarce, then one can expect to successfully bid for a resource unit at 40 and, net 40 from earning 80. If $i_j = 1$ and $I > E(w)$, the resource will be scarce, then one either successfully bids for a resource unit, paying 80 and netting 0, or gets -40 without a resource unit. If $i_j = 0$ and $I \leq E(w)$, one either successfully bids at 40, netting 0, or gets 0 without resources. If $i_j = 0$ and $I > E(w)$, the resource will be scarce and one can expect to get 0 without a unit.

Now we consider how total investment *I* is determined. Consider $w = 0$. As not investing earns 0 and investing earns -40, it is a Nash equilibrium for all players not to invest. For $w = 5$, investing earns 80 and not investing earns 40, thus the unique Nash equilibrium is for all to invest. For $0 < w < 5$, one might or might not get the resource whether one has invested or not (linking to the expected payoff calculations above, either $I \leq E(w)$ or $I > E(w)$ may obtain).

Multiple asymmetric equilibria exist in which $I = E(w)$, resulting from $E(w)$ of the players being expected by all others to invest and the others being expected by all not to invest. How such expectations would be uniformly arrived upon is unclear, which is the big challenge. Starting from this situation, a player expected to invest who invests will obtain a resource unit for a price of 40, netting 40. By not investing, he would obtain 0 and so should not deviate. A player not expected to invest who does not invest has a payoff of zero with certainty. Investing while assuming that the others expected to invest do so will obtain a unit with some probability, netting zero, or not, netting -40. Thus his expected payoff from deviating is strictly negative.

An alternative is symmetric mixed strategy Nash equilibrium, in which all of the players invest with the same probability and the equilibrium depends on $E(w)$. If the number of units is known with certainty, the mixed strategy equilibrium prediction will vary with the number of available units. For the case of zero units, p=0; with one available unit, p=0.25; for two units, p=0.51; if three units are available, p=0.76, and if four units are available p=0.96. If the number of available units is the same as the number of players, then all players will invest with certainty.

Under uncertainty and the uniform distribution, the probability of investment is 0.85 and under the geometric distribution, the probability of investing is 0.3, reflecting the higher scarcity.[ii]

3. Experimental Methods

Each session had ten or fifteen participants. Brazil sessions took place in an internet cafe in the town center of Limoeiro do Norte, in the rural agricultural Jaguaribe Valley in the state of Ceará in the semi-arid and relatively poor Northeast region. The room had fifteen networked computers divided by physical separators. We ran 23 sessions in June 2007 with a total of 310 subjects. Average payment was $R17.15 ($8.73). The average daily salary in the area is $R18.15 ($10.47). The UK sessions were conducted in the FEELE laboratory at the University of Exeter. We ran eight sessions in Exeter in the Fall of 2007 and Spring 2008. A total of 90 subjects participated. We ran the sessions in both locations, with the software toolbox z-Tree (Fischbacher, 2007).

The Brazilian subject pool consisted of students from the local polytechnic institute and employees from local government agencies recruited through fliers in their work or study places. Most students are are not full-time but are children of local farmers who work in irrigated areas. They have the desired agricultural background for our sessions as well as the requisite literacy. Subjects had never taken part in experiments and no individual was in more than one session. The UK subjects consisted of undergraduate, from a wide range of subjects, recruited via email. This is the typical subject pool used in the large majority of experimental economics research.

Experimenters assigned each participant to a booth. Then instructions were distributed and read aloud by the experimenter.[iii] The subjects spent the following five to ten minutes re-reading the instructions and had the opportunity to ask any questions. Communication between subjects was not allowed during the session. Two trial rounds took place before the experiment to facilitate full comprehension. Their outcomes had no impact upon the subjects' payments.

The instructions said that the task in the experiment consisted of an investment decision. Subjects were told they were in a group of five people (they did not know with whom), each of whom had to choose between one of two options, A and B. The payoff that each option yielded depended on the possession of a unit of the resource. The probability of a given total number of resource units being available in each period was given to subjects on the screen. If a subject chose A and had obtained a unit of the resource, he would get a payoff of 80 "points"; otherwise he would get a payoff of -40 from A. If a subject chose B and had obtained a resource unit, he would get a payoff of 40; if he did not obtain a resource unit, his payoff from B would be zero. To avoid losses, subjects were endowed with 120 "points" in every period. The experiment consisted of 30 periods. At the end of each period, subjects learned the total resources in that period and the prices that resulted. Subjects were matched with the same others in each period.

Our three institutions described above were the main treatment. Thus we compare the choices made in the MA, MB and QB institutions. The second treatment was the probability distribution over the available resource units. We broke down each experiment into three ten-period blocks. Within periods 1 to 10, the number of available units was known with certainty. Within periods 11 to 20, we imposed a uniform distribution over 0 and 5, i.e. a 1/6 chance of a each outcome. Finally, in the last ten periods, we imposed a geometric distribution over 0 and 5, which meant that the probability of there being 0, 1, 2, 3, 4 or 5 units was 33.9%, 23.8%, 16.7%, 11.7%, 8.2% and 5.7% respectively. This implies a high degree of scarcity. Distributions were available on screen in each period but the experimenter publicly announced both these changes.

4. Results

We conjectured that institutions providing information about the likelihood of getting resources may outperform institutions that function only after the investment and the resource realization.

Below we consider two measures of the performance, i.e. of the quality of investment decisions. The first is a metric for 'crashes' or relatively large deviations of total investment from resources. The second is an aggregate efficiency measure, what share of potential earnings do players earn. Finally, we examine briefly whether all the individual behaviors appear to show understanding.

4.1 Investment 'Crashes'

Given the need to coordinate expectations in investing simultaneously, we conjectured that the market institution has the potential for big crashes, e.g. everybody or nobody investing; either can be individually rational, given specific expectations by each player concerning others. We limited the potential for truly extreme crashes by using groups of only five and by using as our second probability distribution one with high scarcity. Still, we look for 'crashes', by which we mean total investment two or more units away from the number of available resource units.

4.1.1 Queue Before (QB,MB) vs. Market After (MA)

[figure 2 here]

Figure 2 displays investment outcomes as deviations from the risk-neutral prediction (denoted as zero) in the Brazil and UK samples. Lower investment is depicted as a negative deviation while more investment is depicted as a positive deviation. Both queues appear to have lower frequency of crashes than the post-investment, post-resource-realization market. Of particular note, market appears to have more crashes in either direction. Lacking the queue’s differentiated probabilities of obtaining the resource, simultaneous investment produces 'large' over- and under-investments (noting that risk aversion may well not be a significant explanation of the latter for these stakes).

Table 2 considers this numerically. For under-investment under uncertainty, the queue institutions are not so different (it is difficult to under-invest under the high scarcity distribution). Under certainty, though, there is a significant difference, which is driven by the Brazil results.

Almost 20% of market groups had under-investment crashes, i.e. investment at least two units lower than the available resource. This occurred for less than 3% of the queue institution groups.

[table 2 here]

Under-investment even when the number of resource units is certain nicely illustrates the daunting challenge of coordinating expectations. Even when all five players know exactly the number of the resource units, they often are unable to sufficiently anticipate others' investments. UK participants have fewer crashes under certainty within the market (3%) than the Brazil pool, although by comparison we note no crashes at all occurred in the queue institutions in the UK. While in periods 21-30 it is difficult to under-invest given so few available resources, for the uniform probability distribution in periods 11-20 the UK market institution has about 18% of groups with under-investment crashes while averaging the queue institutions finds under 13%.

Over-investment crashes also occur under certainty. In the UK, it is only 5% of the time with the market although never in the queues (and over-investment by one unit is much more likely (25%) in the market institution than for queues (5%)). Brazil over-investment crashes are consistent with the UK, in that over 9% of the groups feature 'large' over-investments under certainty in the market institution while on average under 5% do in the queue institutions.

For over-investment under uncertainty, while in the uniform probability distribution there were essentially zero over-investment crashes for any institution and subject pool, for geometric such crashes were bound to occur. Again the UK and Brazil results are consistent in the sense of queues outperforming the market. In the UK, over 16% of groups have over-investment crashes under the market institution while on average across the queue institutions fewer than 3% do. In Brazil, over 30% of groups have over-investment crashes with uncertainty under the geometric distribution for the resource market institution, while only 18% do within the queue institutions.

4.1.2 Two Queue-Formation Options (QB vs. MB)

We examine two queue institutions. The difference between them is in complexity. We did want to consider one very simple queue institution. Yet also, for comparing to the market, we did not want the relative complexity of market interaction to be present only within the resource market. In addition, it is quite realistic that queue places would be sold, either auctioned by government with funds being used for unrelated demands that do not affect the purchasers of queue places (consistent with our experiment) or instead simply endowed then traded among the participants.

If anything, we had a prior that simplicity might help a simple fixed queue (QB) relative to a market in queue places (MB). Yet we find little to separate the two in terms of investment crashes. With certainty in the UK, there are neither under-investment nor over-investment crashes in the queue institutions (though less efficiency for QB is discussed further below). Under certainty in Brazil, across the institutions similarly few under-investment crashes occur. For over-investment with certainty in Brazil, the more complex MB institution has a bit over 5% of groups, while the simpler QB institution has only about 2% of groups with such crashes.

Under uncertainty using the uniform distribution, there are no over-investment crashes in the UK nor in Brazil for either queue. For under-investment, again the queues performed about the same and in both participant pools. In the UK, there are close to 12% crashes within each queue institution while in Brazil about 18% of groups in QB have under-investment crashes while a bit fewer (almost 15%) do in the MB institution, which seems not a major difference.

Under uncertainty using the geometric distribution, not surprisingly neither in the UK nor in Brazil are there any under-investment crashes. For over-investment, MB and QB perform about the same and in both subject pools. In the UK, there are quite few in either institution (2%

and 3%) while in Brazil there are quite a few more but the two institutions produce essentially the same 18% of over-investment crashes. In sum, the two queues perform very similarly here.

4.2 Investment Efficiency

Another measure of aggregate investment efficiency is the deviation from the maximum possible (expected) payoff in the game. That maximum will be obtained when the presence of *X* resource units (in certainty or in expectation) is exactly matched by *X* players deciding to invest. Investing without a resource unit brings a private and social loss of 40. Not investing if resources will go unused foregoes a potential private and social gain of 40. We compute for each group and round of decisions the absolute value of this efficiency loss to best compare across group-rounds.

[table 3 here]

4.2.1 Queue Before (QB,MB) vs. Market After (MA)

The striking and main result in Table 3 is a loss of efficiency in a market under certainty. As noted above, this highlights a huge challenge of coordinating expectations of others' choices. In this average efficiency table, the market institution is the final column (each institution having sub-columns by pool) and we present averages for the two queue institutions in the third column.

The queue institutions clearly outperform the post-investment resource market in terms of efficiency loss in the first ten periods, i.e. with certainty about the available units of the resource. The differences across the UK sub-columns and for Brazil are significant ($p<0.01$, M-U test).[iv] Again, the queue institutions possess all the necessary information for efficiency under certainty (each individual knows the number of resource units and their places in the queue). The market lacks that ordering, so choices that depend on expectations of others' choices truly are difficult.

Under uncertainty, however, much of the superiority of the queue institutions goes away. That is, the queues 'catch up' in terms of inefficiency. The market does worse too but queues suffer the big change, though all the differences are compressed with the geometric distribution.

4.2.2 Two Queue-Formation Options (QB vs. MB)

Given our prior that the fixed queue (QB) gains from being simple, it is surprising that in the first twenty rounds a queue-place market (MB) performs better ($p<0.05$, M-U test, UK data), although we find no significant differences between the queues under the geometric distribution. This result suggests consideration of why efficiency results from having to purchase one's place.

Since purchasing one's place is costly, that could induce additional attention to be paid, which then informs investment. An alternative explanation is a kind of sorting, e.g. aggressive (perhaps less risk averse) types tend to bid high for places in the queue and also tend to invest, while less aggressive types tend to land lower in the queue and, all else equal, also not to invest. If subjects self-sort queue based on their type, be that aggression or risk aversion, it could avoid timid types not investing when they should and also bold types investing when they should not. Sorting is not possible in QB, since queue places are randomly assigned from round to round.

Alternatively, the explanation may just be arbitrary mistakes, independent of institution. We consider individual behavior below but note here that the queue differences which favor MB within our results are found only at the end of the queue and only within the Brazilian sample. We find no significant differences in behavior between the MB and QB institutions in the UK.

4.3 Examining Individual Behavior

In Table 3, a significant fraction of the underperformance of QB relative to MB was in the first ten rounds, i.e. under certainty. We would have expected efficiency for both the queues since in each one, all players know the number of resource units and their places in the queue.

Yet both pools in the QB, and the Brazil pool under MB, all show significant loss of efficiency. This motivates our examination of whether individual behaviors appear to reflect understanding.

4.3.1 Investment Decisions

4.3.1.1 When did rationality fail?

We now look at the frequency with which subjects picked the correct action in the first ten periods of the experiment, i.e. in which they were certain about the resources available. In the UK, 98% of choices in MB were individually rational. In all of the other queue treatments, the percentage of correct choices is about 88% (consistent with the efficiency discussion above). That the overwhelming majority of individual choices were correct is, to first order, encouraging.

[table 4 here]

Closer inspection of the data reveals that the bulk of incorrect choices come from one or two subjects in each treatment who consistently made the incorrect choice (not investing when it was optimal to invest). As noted above, and as in Table 4, the MB/QB difference results from subjects at the end of the queue in the Brazil sample. The only significant differences are there. Investment if last in the queue under a uniform distribution is higher in QB ($p<0.01$, M-U test).

4.3.1.2 Heterogeneous pools?

We now turn to behavior under uncertainty and compare pools: a standard population in the UK; and the children of farmers as well as others in rural Northeast Brazil. In this sense, we compare standard lab experiments to artefactual field experiments (per Harrison and List 2004). Summarizing (details are in an appendix), the Brazil pool invests more often when not optimal, while the UK pool investment more when it is optimal to invest. Yet both pools, internally, are consistent with theory: investment falls significantly going down the queue (all tests significant, $p<0.01$ using a J-T test); holding queue place constant, investment is higher under the uniform.[v]

[table 5 here]

In the market institution, efficiency requires that subjects consider the expected number of available resource units. Table 5 shows that investment was indeed rising with the expected number of resource units in the Brazil and the UK samples ($p<0.01$ for both samples, J-T test).

4.3.2 Auction Behavior

Bidding for queue places (in MB) conveys player perceptions of the value of each place. Bidding for resource units (in MA) conveys perceptions of resource scarcity, a function of how many invested. It is of interest to consider changes in the probability distribution from certainty (periods 1-10) to uniform (11-20) to geometric with increased scarcity (periods 21-30).[vi]

4.3.2.1 Bidding for queue places (pre-investment in MB)

Under certainty, a place is worth 80 where a resource is a guaranteed and otherwise zero. With uncertainty, the value of a place depends on the probability of obtaining a resource unit. We find in the first ten periods, with certain resources, average bids and prices are far lower than the risk-neutral Nash equilibrium, in Brazil and UK (differences significant, $p<0.01$, M-U test). They fall as we move down the queue, unlike in our theory. This is consistent with previous experimental evidence that prices are less competitive as the number of actors diminishes.[vii] That point seems critical under uncertainty too, where average prices exceed the risk-neutral predictions early places in the queue but decline as one moves down the queue in both samples. Thus queue-bidding behaviors do not seem like confusion relative to prior market observations. Another form of consistency is that often the UK and Brazil data are not significantly different.[viii]

4.3.2.2 Bidding for resource units (post-investment in MA)

Optimal bids depend on the number who invested and the realized amount of resources. Recall, if many invest so that the resource is scarce, the equilibrium price will be equal to 80, while without scarcity those who invested should pay a price of 41 and others should pay 40. Table 7 shows average auction prices for both scarcity and its lack. While average prices are close to the risk neutral Nash prediction, we find that they are slightly above prediction with scarcity and slightly above prediction when there is no scarcity. Again we see consistency with prior experimental evidence of lessening bidding pressure and with theory, as bids and prices fall as we move down the queue and again the pool differences are few. Further, we usually reject that across all units bids are equal, including the case in which they increase across the units when the subjects had invested enough for the resource to be scarce).

5. Discussion

We considered agricultural investments that are made under resource uncertainty in experiments with two quite distinct pools of subjects: in a UK university; and in a rural setting in NE Brazil. To study the coordination of agricultural investments under varied appropriative irrigation rights, we compared a queue that provides pre-investment differentiation in the chance of receiving the necessary resource with a resource market after the investment and resource quantity are known. We considered two versions of the appropriative rights queue institution, one with all the places in the queue exogenously (and randomly) assigned and one with a novel water rights auction.

The results support our theoretical conjecture that the queue's additional information can outperform the spot water markets utilized in agriculture. Our main result, which is robust across our two quite different subject pools, is that investment is more efficient within the two queues. Markets for water rights that occur before a planting decision must be made, or rain has fallen, therefore appear to be more efficient than spot markets for the water after rainfall has occurred. Large deviations from efficiency are less frequent and a higher fraction of earnings is realized.

Further, this is based on individual behavior qualitatively consistent with theory (given a caveat that as in prior research the bids and prices fell with the number of bidders (see Normann 2008)).

Given that not surprisingly the strongest evidence involves frequency of 'large' deviations from efficient investment, two shifts in design could help to explore robustness and magnitudes. First, more players in a group would allow much more potential for uncoordinated investment. Second, we might use probability distributions whose means are farther from their endpoints.

This type of result emphasizes the potential for institutional design to contribute to the interface of an important sector like agriculture with evolving policies for climate adaptation. Each of our treatments has analogs in observed institutions, i.e. these design choices all exist. Further, research on climate change and perhaps in particular adaptation has often focused upon forecasts without much consideration of institutions, creating an important gap in policy support.

Our results emphasize that what is important in freeing up individual behaviors to adapt to a forecast could be individualized information, even without any bidding in any market at all, though those gains are compatible with markets as we have also demonstrated. Yet identifying the bare essentials for gains is important given social constraints, e.g. on having water markets.

The benefit of the queue in individualizing information also highlights complementarity for adaptation between advances in natural and social science. While improved forecast accuracy without question can help, the institutions into which any given forecast will enter also matter.

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Appendix (NOT FOR PUBLICATION) [Figures & Tables follow below]

<u>QB Instruction Set</u>

Welcome to our experiment. Please read these instructions carefully; your payment for this experiment will depend on your decisions and the decisions of others.

Please refrain from communicating with the other participants during the entire experiment. If at any point you require assistance, please raise your hand and the experimenter will come to you. Your payment will be made at the end of the experiment.

Before the experiment begins you will be assigned an experimental ID number, through which you will make your decisions and receive your payment at the end. Your ID number is written on the top right hand corner of this instruction set. Please keep this number private until you leave the experiment.

Task Description

In every period you will receive an endowment of 120 ECU. Your task is to make a choice between two alternatives, A and B. The payoff associated with either alternative is dependent on the availability of a resource. Access to the resource is done on a pre-specified order or queue. Your position in the queue will be indicated on the decision screen in every period. There are 5 people in this experiment and each one requires one unit of the resource. Therefore, the first person in the queue will be able to receive the first unit of the resource; the person in second place will obtain the second unit of the resource and so on, until there are no more available units.

The payoff from choosing A or B depends on whether you obtain a resource unit or not. If you choose A and obtain a resource unit, your payoff will be 80 Experimental Currency Units (ECU). If you choose A and do not obtain a resource unit, your payoff will be -40 ECU. If you choose B and obtain a resource unit, your payoff will be 40, whereas if you choose B and you do not obtain a resource unit, your payoff will be 0. The following table summarizes this information:

	With resource	Without resource
A	80	-40
B	40	0

You will have to make your choice of product BEFORE you know how many units of the resource but AFTER you know your place in the queue. You will do so by clicking on the relevant option on the decision screen.

The number of resource units is between 0 and 5. Its number will be randomly determined by the computer. The probability of having a given number of resource units will be displayed alongside your payoff matrix and your decision form.

Once everyone makes their choice, you will then be informed of whether you were able to obtain the resource and your associated payoff for the period. Your final payoff for each period will be equal to your endowment plus the payoff resulting from your choice of A or B.

There will be 30 periods in this experiment. Your payment for the experiment will be the sum of the payoff of 4 periods of the experiment, which will be chosen at random. 10 ECU are worth £0.25.

Summary

1. You are informed of you place in the queue;

2. Given your place in queue, you must choose between A and B;

3. You will then be informed of how many resource units are available and whether you obtained a resource unit or not;

4. You will then be informed of the final payoff for the period.

MB Instruction Set

Welcome to our experiment. Please read these instructions carefully; your payment for this experiment will depend on your decisions and the decisions of others.

Please refrain from communicating with the other participants during the entire experiment. If at any point you require assistance, please raise your hand and the experimenter will come to you. Your payment will be made in cash at the end of the experiment.

Before the experiment begins you will be assigned an experimental ID number, through which you will make your decisions and receive your payment at the end. Your ID number is written on the top right hand corner of this instruction set. Please keep this number private until you leave the experiment.

Task Description

Your task is to make a choice between two alternatives, A and B. The payoff associated with either alternative is dependent on the availability of a resource. There are 5 people in this experiment and each one requires one unit of the resource. Access to the resource is done on a pre-specified order or queue. Therefore, the first person in the queue will be able to receive the first unit of the resource; the person in second place will obtain the second unit of the resource and so on, until there are no more available units. Places in the queue will be allocated individually through an auction.

The rules of the auction are as follows. In every period you will be given an endowment of 120 ECU that you may use to bid for a place in the queue. In order to bid for the first place in the queue, you will be asked to type down your bid on a bid form. The person with the highest bid will be given the first place in the queue and will pay the amount he or she bid. In the event that more than one person has the highest bid, one person will be selected at random and pay that price. After the outcome of the auction is determined, you will receive feedback on whether you have won the auction or not and the winning price. No information will be given with regards to the other participants' bids. The auction will be repeated for the next place in the queue, up to the fifth and last place. Participants who have already obtained a place in the queue will not participate in subsequent auctions.

Once you know your place in the queue, you will have to make you choice between A and B. The payoff from choosing A or B depends on whether you obtain a resource unit or not. If you choose A and obtain a resource unit, your payoff will be 80 Experimental Currency Units (ECU). If you choose A and do not obtain a resource unit, your payoff will be -40 ECU. If you choose B and obtain a resource unit, your payoff will be 40, whereas if you choose B and you do not obtain a resource unit, your payoff will be 0. The following table summarizes this information:

	$w_j = 1$	$w_j = 0$
Invest	80	-40
Not Invest	40	0

You will have to make your choice of product BEFORE you know how many units of the resource but AFTER you know your place in the queue. You will do so by clicking on your choice in a decision screen.

The number of resource units is between 0 and 5. Its number will be randomly determined by the computer. The probability of having a given number of resource units will be displayed alongside your payoff matrix and your decision form.

Once everyone makes their choice, you will then be informed of whether you were able to obtain the resource and your associated payoff for the period. Your final payoff will be equal to your endowment plus the payoff based on your choice of A or B minus the amount you spent bidding for a place in the queue.

There will be 30 periods in this experiment. Your payment for the experiment will be the sum of the payoff of 4 periods of the experiment, which will be chosen at random. 10 ECU are worth £0.25.

Summary

1. You first bid for a place in queue;

2. Given your place in queue, you must choose between A and B;

3. You will then be informed of how many resource units are available and whether you obtained a resource unit or not;

4. You will then be informed of the final payoff for the period.

MA Instruction Set

Welcome to our experiment. Please read these instructions carefully; your payment for this experiment will depend on your decisions and the decisions of others.

Please refrain from communicating with the other participants during the entire experiment. If at any point you require assistance, please raise your hand and the experimenter will come to you. Your payment will be made at the end of the experiment.

Before the experiment begins you will be assigned an experimental ID number, through which you will make your decisions and receive your payment at the end. Your ID number is written on the top right hand corner of this instruction set. Please keep this number private until you leave the experiment.

Task Description

Your task is to make a choice between two alternatives, A and B. The payoff from choosing A or B depends on whether you obtain a resource unit or not. There are 5 people in this experiment and each one requires one unit of the resource. If you choose A and obtain a resource unit, your payoff will be 80 Experimental Currency Units (ECU). If you choose A and do not obtain a resource unit, your payoff will be -40 ECU. If you choose B and obtain a resource unit, your payoff will be 40, whereas if you choose B and you do not obtain a resource unit, your payoff will be 0. The following table summarizes this information:

	$w_j = 1$	$w_j = 0$
Invest	80	-40
Not Invest	40	0

You will have to make your choice of product BEFORE you know how many units of the resource are available. You will do so by typing your choice in a decision box on screen.

The number of resource units is between 0 and 5. Its number will be randomly determined by the computer. The probability of having a given number of resource units will be displayed alongside your payoff matrix and your decision form.

Once everyone makes their choice, you will be informed of how many resource units are available. Then the resource units will be sold individually through an auction. You will be given an endowment of 120 ECU that you may use to bid for a resource unit. The rules of the auction are as follows. In order to bid for a resource unit, you will be asked to type down your bid on a bid form. The person with the highest bid will be given the resource and will pay that price. In the event that more than one person has the highest bid, one person will be selected at random. After the outcome of each auction is determined, you will only receive feedback on whether you have won the auction or not, as well as the winning bid.

The auction will be repeated for the next available unit, until there are no more available units. Participants who obtain a resource unit will not participate in subsequent auctions.

Once all resource units are allocated, you will be informed of your final payoff for the round. The final payoff will be equal to your endowment plus the payoff based on your choice of A or B minus the amount you spent bidding for a resource unit.

There will be 30 rounds in this experiment. Your payment for the experiment will be the sum of the payoff of 4 rounds of the experiment, which will be chosen at random. 10 ECU are worth £0.25.

Summary

1. You must choose between A and B;

2. You will then be informed of how many resources units are available;

3. The existing resource units will be made available through an auction;

4. Once all resource units are allocated, you will be informed of the final payoff for the round.

Equilibrium mixed strategy in MA

As outlined in the main text, the MA game can be reduced to an investment game, where the payoff of each player is based on his investment decision, the total number of players who invest and the available number of *w*. When

$0<w<5$ and under uncertainty, the only symmetric equilibrium of this game is in mixed strategies.

In a mixed strategy equilibrium, players choose the probability of investing, p_j, such that their counterparts are indifferent between investing and not investing (i.e. the expected payoff of investing equals the expected payoff of not investing). We wish to consider the mixed strategy Nash equilibrium where $p_j = p$ for all *j*.

Recall from equation (3) that if the number of players investing is smaller than or equal to *w*, the resulting payoff from investing is 40; if the number of investors exceeds *w*, the payoff from investing is either 0 (if one obtains a unit of the resource for a price of 80) or -40 (if one fails to obtain a unit of the resource.) The payoff from not investing always equals 0 – in this case, either one obtains a unit of the resource for a price of 40 or one does not obtain a unit at all.

The symmetric mixed strategy Nash equilibrium of this will depend on the number of available units of the resource, *w*. We consider each case in turn.

Certainty, w=1:

$$p^4((0)(1/5)+(-40)(4/5))+4p^3(1-p)((0)(1/4)+(-40)(3/4))+$$
$$6p^2(1-p)^2((0)(1/3)+(-40)(2/3))+4p(1-p)^3((0)(1/2)+(-40)(1/2))+$$
$$(1-p)^4(40)=0 \Leftrightarrow p=0.246$$

Certainty, w=2:

$$p^4((0)(2/5)+(-40)(3/5))+4p^3(1-p)((0)(2/4)+6p^2(1-p)^2((0)(2/3)+(-40)(1/3))+$$
$$4p(1-p)^3(40)+(1-p)^4(40)=0 \Leftrightarrow p=0.511$$

Certainty, w=3:

$$p^4((0)(3/5)+(-40)(2/5))+4p^3(1-p)((0)(3/4)+(-40)(1/4))+$$
$$6p^2(1-p)^2(40)+4p(1-p)^3(40)+(1-p)^4(40)=0 \Leftrightarrow p=0.763$$

Certainty, w=4:

$$p^4((0)(4/5)+(-40)(1/5))+4p^3(1-p)(40)+6p^2(1-p)^2(40)+4p(1-p)^3(40)+$$
$$(1-p)^4(40)=0 \Leftrightarrow p=0.955$$

Uncertainty, uniform distribution:

$$40+p^4((0)(1/5)+(-40)(4/5))+4p^3(1-p)((0)(1/4)+(-40)(3/4))+$$
$$6p^2(1-p)^2((0)(1/3)+(-40)(2/3))+4p(1-p)^3((0)(1/2)+(-40)(1/2))+$$
$$(1-p)^4(40)+p^4((0)(2/5)+(-40)(3/5))+4p^3(1-p)((0)(2/4)+(-40)(2/4))+$$
$$6p^2(1-p)^2((0)(2/3)+(-40)(1/3))+4p(1-p)^3(40)+(1-p)^4(40)+$$
$$p^4((0)(3/5)+(-40)(2/5))+4p^3(1-p)((0)(3/4)+(-40)(1/4))+6p^2(1-p)^2(40)+$$
$$4p(1-p)^3(40)+(1-p)^4(40)+p^4((0)(4/5)+(-40)(1/5))+4p^3(1-p)(40)+$$
$$6p^2(1-p)^2(40)+4p(1-p)^3(40)+(1-p)^4(40))=0 \Leftrightarrow p=0.850$$

Uncertainty, geometric distribution:

$$0.339(-40)+0.238(p^4((0)(1/5)+(-40)(4/5))+$$
$$4p^3(1-p)((0)(1/4)+(-40)(3/4))+6p^2(1-p)^2((0)(1/3)+(-40)(2/3))$$
$$4p(1-p)^3((0)(1/2)+(-40)(1/2))+(1-p)^4(40))+$$
$$0.167(p^4((0)(2/5)+(-40)(3/5))+4p^3(1-p)((0)(2/4)+(-40)(2/4))+$$
$$6p^2(1-p)^2((0)(2/3)+(-40)(1/3))+4p(1-p)^3(40)+(1-p)^4(40))+$$
$$0.117(p^4((0)(3/5)+(-40)(2/5))+4p^3(1-p)((0)(3/4)+(-40)(1/4))+$$
$$6p^2(1-p)^2(40)+4p(1-p)^3(40)+(1-p)^4(40))+$$
$$0.082(p^4((0)(4/5)+(-40)(1/5))+4p^3(1-p)(40)+6p^2(1-p)^2(40)+$$
$$4p(1-p)^3(40)+(1-p)^4(40))+0.057(80)=0 \Leftrightarrow p=0.29$$ [illegible]

Figure 1.

Probability distribution over outcomes of w.

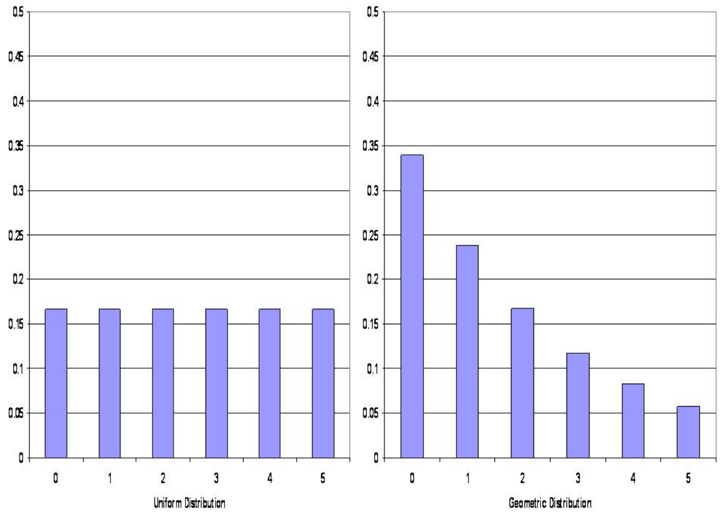

Figure 2.

Histograms of investment outcomes as deviations from risk-neutral prediction.

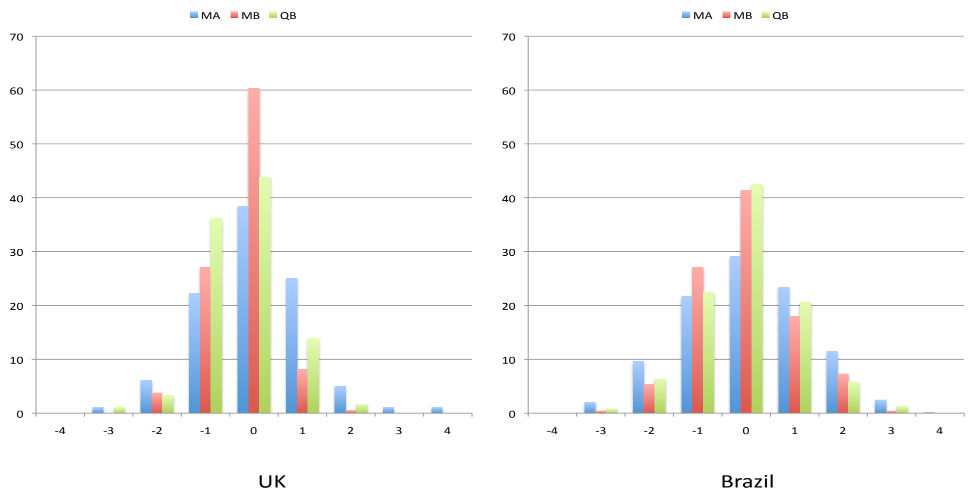

Table 1.

Equilibrium Queue Prices and Investment Decisions, MB.

	Uniform Distribution				Geometric Distribution			
Queue Place	$prob(w_j = 1)$	Invest	Value	Bid	$prob(w_j = 1)$	Invest	Value	Bid
1	0.83	1	60.13	53.33	0.66	1	39.44	37.04
2	0.67	1	40.13	33.33	0.42	0	17.04	14.64
3	0.50	0.5	20.13	13.33	0.26	0	10.36	7.96
4	0.33	0	13.47	6.67	0.14	0	5.68	3.28
5	0.17	0	6.8	0.00	0.06	0	2.40	0.00

Table 2.

Relative Frequency of Investment Outcomes as Deviations from Risk-neutral Predictions

UK										
Periods	Treat	Deviation from RN Prediction								
		-4	-3	-2	-1	0	1	2	3	4
1-10	MA	0	0	3.33	16.67	48.33	26.67	5	0	0
	MB	0	0	0	4.69	92.19	3.13	0	0	0
	QB	0	0	0	35	58.33	6.67	0	0	0
11-20	MA	0	3.33	15	30	30	21.67	0	0	0
	MB	0	0	11.67	53.33	31.67	3.33	0	0	0
	QB	0	3.33	10	58.33	26.67	1.67	0	0	0
21-30	MA	0	0	0	20	36.67	26.67	10	3.33	3.33
	MB	0	0	0	25	55	18.33	1.67	0	0
	QB	0	0	0	15	46.67	35	3.33	0	0
Brazil										
Periods	Treat	Deviation from RN Prediction								
		-4	-3	-2	-1	0	1	2	3	4
1-10	MA	0	3.04	16.09	30	25.65	15.65	6.96	2.17	0.43
	MB	0	0	2.67	20	54.67	17.33	4.67	0.67	0
	QB	0	0.83	2.5	21.25	56.25	17.08	1.67	0.42	0
11-20	MA	0	3.04	12.61	29.13	35.65	18.7	0.87	0	0
	MB	0	1.33	13.33	46	34.67	4.67	0	0	0
	QB	0	1.67	16.67	37.08	32.08	11.67	0.83	0	0
21-30	MA	0	0	0	6.09	26.09	36.09	26.52	5.22	0
	MB	0	0	0	15.33	34.67	32	17.33	0.67	0
	QB	0	0	0	9.17	39.17	33.33	15	3.33	0

Table 3.

Average Efficiency Loss

	MB		QB		Q&M B		MA	
Period	UK	Brazil	UK	Brazil	UK	Brazil	UK	Brazil
1-10	4.67	25.87	23.33	23.50	14.00	24.41	42.67	66.26
11-20	53.33	65.87	66.67	73.67	60.00	70.67	67.33	82.26
21-39	52.00	70.13	54.67	61.17	53.33	65.85	58.67	74.26

Table 4.

Fraction of Investment Decisions Conditional on Queue Place

Period	Queue Place	QB UK	QB Brazil	MB UK	MB Brazil	RN Prediction
11-20	1	0.93	0.87	1.00	0.89	1.00
	2	0.80	0.68	0.87	0.78	1.00
	3	0.32	0.45	0.33	0.44	0.50
	4	0.08	0.17	0.07	0.14	0.00
	5	0.02	0.21	0.00	0.03	0.00
21-30	1	0.78	0.76	0.72	0.72	1.00
	2	0.33	0.44	0.23	0.49	0.00
	3	0.08	0.21	0.02	0.25	0.00
	4	0.03	0.12	0.00	0.04	0.00
	5	0.03	0.12	0.00	0.03	0.00

Table 5.

Fraction of Investment Decisions Conditional on Expected Number of Resource Units, MA.

Periods			1-10				11-20	21-30
$E(w)$	0	1	2	3	4	5	2.5	1.5
Prediction	0.00	0.25	0.51	0.76	0.96	1.00	0.85	0.30
UK	-	0.28	0.40	0.40	0.90	0.92	0.50	0.30
Brazil	-	0.37	0.48	0.52	0.63	0.72	0.51	0.40

Table 6.

Average Bids and Prices for Queue Places, UK and Brazil

		UK				Brazil			
		Queue Place				Queue Place			
Periods		1	2	3	4	1	2	3	4
	Prediction*	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00
1-10	Avg price*	74.73‡	57.47‡	40.52‡	19.05‡	76.95‡	70.82‡	54.89‡	25.99‡
		(11.62)	(27.34)	(30.39)	(27.41)	(9.98)	(19.58)	(30.64)	(32.25)
	N	60	60	60	60	150	150	150	150
	Prediction*	53.33	33.33	13.33	6.67	53.33	33.33	13.33	6.67
11-20	Avg price*	64.28†	54.08†	30.02†	4.42†	72.79‡	66.44‡	44.85‡	17.47*
		(17.97)	(22.42)	(23.22)	(8.94)	(14.01)	(17.44)	(27.84)	(24.45)
	N	60	60	60	60	150	150	150	150
	Prediction*	37.04	14.64	7.96	3.28	37.04	14.64	7.96	3.28
21-30	Avg price*	46.25	27.72	6.78	0.58‡	61.87‡	46.41‡	18.30	2.44‡
		(25.07)	(23.88)	(11.05)	(1.25)	(24.98)	(29.28)	(25.17)	(8.54)
	N	60	60	60	60	150	150	150	150

Table 7.

Average Prices for Resource Units Conditional on Aggregate Investment, UK and Brazil

	UK			
	If I>w		If I<=w	
	Prediction	Avg Price	Prediction	Avg Price
Unit 1	80.00	73.58 (12.29)	40.00	59.81 (23.03)
Unit 2	80.00	74.36 (11.11)	40.00	51.51 (25.06)
Unit 3	80.00	75.26 (10.72)	40.00	44.60 (26.26)
Unit 4	80.00	77.73	40.00	35.07 (30.16)
	Brazil			
	If I>w		If I<=w	
	Prediction	Avg Price	Prediction	Avg Price
Unit 1	80.00	77.53 (8.70)	40.00	67.28 (19.21)
Unit 2	80.00	74.65 (11.56)	40.00	59.23 (22.96)
Unit 3	80.00	67.80 (18.87)	40.00	47.80 (18.87)
Unit 4	80.00	60.20 (30.08)	40.00	60.20 (30.08)

[i] There is an longstanding debate dating back to the first auction experiments (Cox, Smith and Walker, 1988) as to whether risk aversion matters in laboratory experiments. Rabin (2000) shows that if experimental subjects were to reject low-stake gambles, this would imply absurdly high coefficients of risk aversion, illustrated by the following example. “Suppose that, from any initial wealth level, a person turns down gambles where she loses $100 or gains $110, each with 50% probability. Then, she will turn down 50-50 bets of losing $1,000 or gaining *any* sum of money.” (p.1282). Nevertheless, since our experiments in Brazil involve relatively higher stakes than a traditional lab experiment, we feel this caveat is warranted.

[ii] Derivations of the mixed strategy equilibria are in the Appendix.

[iii] A copy of the English version of the instruction set is available in the Appendix. The experimenter who designed the instructions was fluent in both English and Portuguese. Nevertheless, we piloted the Brazilian Portuguese instructions with local research assistants in order to minimize the risk of translation errors.

[iv] For presentational ease we will use M-U to denote the non-parametric Mann-Whitney test of equality of means between two random variables (Mann and Whitney, 1947) and J-T to denote the Jonkerhee-Thepstra test (Jonkerhee, 1954), which extends the M-U test to n variables.

[v] In the UK sample, frequency of investment decisions is significantly larger for first three queue places in both QB ($p<0.10$, $p<0.01$ and $p<0.05$ respectively, M-U test) and MB ($p<0.01$, $p<0.01$ and $p<0.05$ respectively, M-U test). In the Brazilian sample, in QB the investment frequency is significantly larger for first and second places ($p<0.10$ and $p<0.05$, respectively, M-U test), while in MB, investment frequency is significantly larger for first, second, third and fourth places ($p<0.10$, $p<0.01$, $p<0.10$ and $p<0.01$, respectively, M-U test).

[vi] If there is learning, our experimental design cannot easily disentangle it from these shifts.

[vii] Dufwenberg and Gneezy (2001) analyze the effect of the number of competitors in Bertrand markets where subjects repeatedly interact in fixed pairings. They find that Bertrand duopolies are significantly less competitive than 3-firm and 4-firm markets.
See Normann (2008) for a review.

[viii] Specifically, the only queue places for which there was a statistically significant difference in average prices between Brazilian and UK subjects was fourth place in periods 11-20. Regarding average bids, we found significant differences for first, second and fourth place ($p<0.05$ M-U test) in periods 11 20, as well as second and third place ($p<0.05$, M-U test) in periods 21-30.