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An Experimental Test of a Search Model under Ambiguity

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Abstract

The objective of this study is to design a laboratory experiment to explore the effect of ambiguity on a subject's search behavior in a finite-horizon sequential search model. In so doing, we employ a strategy to observe the potential trend of reservation points that is usually unobserved. We observe that subjects behaving consistently across treatments reduce their reservation points in the face of ambiguity over point distribution. Our result is consistent with the theoretical implication obtained by Nishimura and Ozaki (Journal of Economic Theory 2004).

Journal of Economic Literature Classification Numbers: C91, D81

Keywords: Experiment, Search Model, Ambiguity, Reservation Point

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1. Introduction

We picture a situation in which the prospects of labor market conditions in the future are "uncertain" in the sense that a wage offer distribution is unknown. In this situation, does an increase in uncertainty lead to unemployed workers searching for longer or shorter periods? In the literature on job search models, it is well known that an increase in "risk," in the sense of Rothschild and Stiglitz (1971), leads to individuals searching for longer periods. However, it can also be considered that an increase in uncertainty about the prospects of labor market conditions may make individuals more cautious and discourage them from searching for longer periods because they could become less confident in finding more-appealing job offers in the future. Considering the notion of *ambiguity* (*Knightian uncertainty*: Knight, 1921) differentiated from that of risk[1], Nishimura and Ozaki (2004) theoretically show that an increase in ambiguity decreases the reservation wage and thereby induces individuals to search over a shorter period.[2] The intuition behind this finding is clearly conveyed in their words as follows: "When people lose confidence in their forecast about what happens in the future, they generally prefer certainty to uncertainty. An immediate acceptance of the wage offer implies that the uncertainty is turned into certainty" (Nishimura and Ozaki 2004, p.301). The purpose of this paper is to design a laboratory experiment of a finite-horizon sequential search model with ambiguity in the sense that an offer distribution is unknown, and to ascertain whether the result of Nishimura and Ozaki (2004) is supported by the experimental results.

[1] In this paper, the two terms Knightian uncertainty and ambiguity are used interchangeably. For a survey, see Etner et al. (2012).

[2] Nishimura and Ozaki (2004) apply the Multiple-prior Expected Utility (MEU) theory and its variants to a job search model. See Gilboa and Schmeidler (1989) for details about the MEU theory.

Laboratory experiments comprise a popular way to test the theoretical predictions of search models (Boone et al. 2009, Cox and Oaxaca 1989, Harrison and Morgan 1990, Schunk 2009, Schunk and Winter 2009). A direct-response treatment with accept-or-reject choice has been often employed in the experiments of search models, but we cannot observe a trend of reservation points in this type of treatment. To solve this problem, some have directly elicited the reservation points of subjects by asking them to input their reservation point every round before a point is randomly drawn (Brown et al. 2011, Cox and Oaxaca, 1992). However, testing the direct implication of Nishimura and Ozaki (2004) in a laboratory experiment still comes with two challenges. The first is that subjects tend to finish their search hastily in laboratory experiments on search models, according to the past literature (e.g., Schunk and Winter 2009). Therefore, we cannot observe a long trend of reservation points even though we employ the design where subjects input their reservation point every round before a point is drawn. Second, the lower the reservation point is, the earlier the subjects finish the search, thereby creating upward attrition bias on the observed reservation points as the game approaches the final round because the subjects whose reservation point is higher survive in the later rounds. Thus, the fact that subjects gradually exit from the search makes it difficult to observe not only all the reservation points up to the final round but also the true reservation points that they would have set at later rounds of the search if they had not ended the search at the early rounds.

To overcome these challenges, we design a strategic-method treatment to retrieve, without causing any bias, all the reservation point paths, which is relevant for testing our experimental hypothesis.[3] In our experiment, we therefore conduct two

[3] Cox and Oaxaca (2000) conduct laboratory experiments of job search under unknown distributions, but they only investigate the impact on search durations. In the context of ambiguity other than in job search models, see Attansi

types of 20-round search activities. In the first type, the subjects are asked to engage in a sequential search where they simply decide whether to accept or reject the offered points (direct-response treatment).[4] In the second type, the subjects are asked *ex ante* to declare their reservation points at each round *provided that they move on to the next round*, and then begin the actual search in accordance with the reservation points that subjects had already typed in (strategy-method treatment). Since this design elicits the reservation points of the subjects who might have finished their search activities at earlier rounds, the retrieved reservation points should contain no upward bias. It is particularly notable that this design also enables us to circumvent the possibility that subjects fail to report their true reservation points ex ante. We check whether the subjects behaved consistently across the strategy-method treatment and direct-response treatment where they simply had to decide whether to accept or reject the point. By using those consistent observations, we then test how the subjects change their reservation points when faced with ambiguity. We find that the presence of ambiguity decreases the reservation points, only when we limit our sample to the consistent observations, thus supporting the theoretical result shown by Nishimura and Ozaki (2004).

2. Experimental design

An individual subject faces games of 20 rounds by way of a finite-horizon sequential search model in which recall is not allowed. A point is drawn randomly from a given point distribution by a computer faced by a subject in the first round, and

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et al. (2014), Brunette et al. (2014), Chen et al. (2007), Cohn et al. (2011), Della Seta et al. (2014), Eichberger et al. (2008), Hayashi and Wada (2010), and Viefers (2012).

[4] In our experiment, we use "point" to prevent subjects from associating "wage" with their actual job search activity.

the subject then clicks either the “accept” or “reject” button on the screen. If the subject accepts the point, the search activity is concluded, and the accepted point is converted to a payment in this game. If the subject rejects the point, he or she moves on to the second round where a point is again drawn from the given point distribution. The subject can continue to search in this manner until the 20th round, and if the subject rejects a point drawn in the last round, the search activity is automatically terminated, and no point is obtained. Points are not discounted over the rounds.

To represent the effect of ambiguity, we employ two types of point distribution in the direct-response treatments. In the first treatment (T1), subjects are provided with common information of a uniform distribution with a lower bound of 1 and an upper bound of 3000. In the second treatment (T2), the subjects are told that, in each round, the computer randomly selects a point from an unknown distribution except that it has a lower bound of 1 and an upper bound of 3000, and that a different distribution *may* be randomly selected every round by the computer. This prevents the subjects from updating their information about the true point distribution in a Bayesian manner and rules out the learning effect on search behavior. Throughout the experiment, subjects are not informed about the true point distribution, but to facilitate a comparison of (T1) and (T2), the distribution is actually set the same as the uniform distribution with a lower bound of 1 and an upper bound of 3000. Our experiment might not be designed with proper manners because we do not completely inform subjects on the true distribution, but we believe that our experimental design is inevitable in experiments of choices under ambiguity. By controlling the distribution shape in this way, the comparison of these two treatments allows us to identify the difference in search behavior caused uniquely by ambiguity. If the distribution actually changes every round, we would be unable to identify whether the difference between the two treatments in search duration is attributable to ambiguity or to variations in distributions actually drawn.

If we had changed the actual distributions every round in (T2) and repeated this treatment many times, the expected distribution faced by the subjects would have converged to that of the treatment (T1), thereby allowing us to extract the exact effect of ambiguity on the subjects' search activities. However, in practice, it is very difficult to implement this method. The subjects would have to play this game so many times in the treatment (T2) until the expected distribution drawn by the subjects in (T2) sufficiently converges to that of (T1), which is impractical in terms of the budget and time constraints in standard laboratory experiment. In addition, the subjects would lose their concentration and then not take serious effort to play the games if they are required to play so many times for many hours.

While these direct-response treatments with accept-or-reject choice (T1 and T2) are simple and easy to implement, it provides us with little information on how the ambiguity would change the trend of reservation points up to the final round. We could ask subjects to directly type in their reservation point instead of asking them to click on accept or reject buttons, but this would not help us much to test precisely the theoretical result obtained by Nishimura and Ozaki (2004). There are two reasons for this. First, most subjects tend to finish searching long before the final round in laboratory experiments, according to the past literature (e.g., Schunk and Winter, 2009). Therefore, we cannot observe a long trend of reservation points even though we employ the experimental design in which subjects input their reservation points every round before a point is randomly drawn. Second, the lower the reservation point, the earlier the subjects finish the search, thereby creating upward attrition bias on the observed reservation points as the game approaches the final round because the subjects whose reservation point is higher survive in the later rounds. This attrition bias is expected to become large as the game approaches the final round.

We supplement our experiment with another type of treatment (strategy-method treatment) to observe the potential but true trend in reservation points. In particular, the third treatment (T1-commit) is a search activity in which a subject ex ante commits to a series of reservation points, assuming that their points are drawn from the uniform distribution with a lower bound of 1 and an upper bound of 3000. The actual experiment proceeded as follows. First, the subjects were told to type in the minimum point that they are willing to accept (i.e., reservation point) in the first round, and then fill in the reservation point in the second round, *provided that they had moved on to the second round*. The same procedure is undertaken round by round until the 20th round. After typing 20 numbers of the reservation point, each subject clicks the button to start the actual search. The computer randomly picks a first-round point and compares it with the first-round reservation point that a subject had already typed in. If the point drawn is lower than the first-round reservation point, the search activity continues with the computer drawing a second-round point. Otherwise, the computer stops searching and gives the subject the drawn point. The computer continues the same procedure until the search ends.

The last treatment (T2-commit) is similar to T1-commit, except that subjects are faced with the unknown distribution as in T2.

One obvious challenge with this method is the reliability of reservation points. Since they commit ex ante before actually playing a game, subjects engage in search activity in an unnatural manner, and then the observed reservation point may not necessarily represent their true reservation point. To address this point, we compare the reservation points in T1-commit (T2-commit) to their search outcome in T1 (T2) in which subjects engage in search activity in a natural manner, and examine whether the observed reservation points are consistent with their actual responses in a simple reject-or-accept search game.

Each of the two treatments has its merits and demerits. The direct-response treatment with accept-or-reject choice is in line with a real search activity. However, subjects usually stop searching early, and therefore we cannot collect large-scale data of search behaviors. In addition, this treatment creates upward attrition bias on the reservation points in the latter rounds. The strategy-method treatment allows us to retrieve all the reservation points over the 20 rounds without causing any attrition bias, but the search process appears unnatural. There is no doubt that both treatments are complementary in the experimental design. Therefore, it is necessary to conduct these two treatments to test a theoretical prediction by Nishimura and Ozaki (2004).

Because we conducted the within-subject experiment, a reservation point at each round in T1 (T2) should equal the reservation point at the corresponding of T1commit (T2-commit). If not, we can say that subjects behave inconsistently or that they may somehow misunderstand this experiment’s rule. To rule out the bias caused by misunderstanding, we extract only subjects whose behaviors in the direct-response treatment are consistent with those in the strategy-method treatment and estimate the effect of ambiguity on search behavior.

In particular, we define a subject as having *consistent behavior* in T1-commit (T2-commit) if the following conditions are satisfied:

- for any given round in all T1 (T2) games, a subject accepts the offered point if the offered point is no less than the reservation point at the corresponding round of T1-commit (T2-commit); and
- for any given round in all T1 (T2) games, a subject rejects the offered point if the offered point is lower than the reservation point at the corresponding round of T1-commit (T2-commit).

Overall, the mean survival rates for direct-response treatments (T1 and T2) are not significantly different from those for strategy-method treatments (T1-commit and T2-commit). The mean difference is -0.02 (the p-value=0.260) for T1 versus T1-commit, and -0.03 (the p-value=0.121) for T2 versus T2-commit. However, we also evaluate the effect of ambiguity on a trend in reservation points by limiting our sample to observations with consistent behavior.

Our experiment consists of two sessions. Each experimental session consists of 11 games and one practice game as follows:

Session 1: (T1-practice), (T1), (T2), (T1), (T2), (T1-commit), (T1), (T2), (T1), (T2), (T1), (T2-commit).

Session 2: (T1-practice), (T2), (T2), (T2), (T2), (T2-commit), (T1), (T1), (T1), (T1), (T1), (T1-commit).

The experiment was conducted in the experimental laboratory at Osaka University. Subjects consisted of 44 undergraduate and graduate students (21 in session 1 and 23 in session 2). Each participant sat in an individual booth, from which he or she could not observe other subjects. The experiments were run entirely on computers using Z-tree (Fischbacher, 2007). Prior to the experiment, subjects were provided with the instruction sheet with details about the task as well as some quizzes to confirm that they correctly understand the instruction. Subjects were informed that (i) their payment was truncated at JPY 0 (i.e., they could not incur any losses from the search task); and (ii) they would earn an attendance fee of JPY1000 (USD8.44)[5]. At the end of the experiment, one of the results from the 11 games was randomly selected to determine the final payment, in which one experimental point is converted to JPY1.

3. Results

Fig. 1 plots the average survival rate of the search activity at each round. The Averages are calculated from the observations in the reject-or-accept type treatments only (T1 and T2). We observe a dip in the trend of reservation points when the subjects face an ambiguity. Interestingly, no significant difference was observed in the first two rounds, but the negative effect of ambiguity became gradually larger as the game went on, with the maximum difference being 11.4 percentage points at the seventh round.

To account for the ordering effect of the treatments as well as for possible correlations across the treatments within a subject, we estimated the following equation:

$$D_{it} = \alpha + \beta \cdot Unknown_t + \gamma \cdot obtainedpoints_{it-1} + \boldsymbol{I}_i + \varepsilon_{it}, \qquad (1)$$

where D_{it} denotes the search duration of subject *i* for the *t*th game, $Unknown_t$ is a dummy variable indicating that the point distribution is unknown, and $obtainedpoints_{it-1}$ denotes a point obtained in the previous game. $\boldsymbol{I}_i$ is a vector of

[5] We use the exchange rate of JPY 118.53 to USD 1 for January 10, 2015.

subject-specific effects. We add a point obtained in the previous game to rule out the possibility of a previous point anchoring the behavior of subjects in the next game, indicating the possibility that the order of the games matters.

Table 1 presents the estimation results on search duration, controlling for the points obtained in the previous game and subject-specific effects. The sample consists of observations from the reject-or-accept type treatments only (T1 and T2). While $Unknown_t$ significantly reduces the search durations in Columns (1) and (2), Column (3) indicates the negative effect of ambiguity on search duration with only a moderate level of significance (p-value = 0.06) after the covariates are controlled for. However, Fig. 1 and Table 1 are only suggestive of accepting the theoretical result obtained by Nishimura and Ozaki (2004). One wonders whether the subjects set themselves a lower reservation point in T2 compared to in T1 or happened to be offered lower points in T2 than in T1. To distinguish the two possibilities, we need to observe the true trend in reservation points and confirm that the subjects finished their search early precisely because they set lower reservation points under an unknown distribution.

Fig. 2 shows our results on the average reservation points. The averages are calculated from observations in the strategy-method type treatments only (T1-commit and T2-commit), where we could obtain complete information about the trends of reservation points. While we observe no big difference in reservation points on the left panel of Fig. 2, we found a large dip on the trends of reservation points on the right panel, in which the sample is limited to consistent observations. To control for subject-fixed effects as well as anchoring effects we estimated the following equation:

$$RevPoint_{its} = \alpha + \beta \cdot Unknown_t + \gamma \cdot obtainedpoints_{it-1} + \boldsymbol{I}_i + \boldsymbol{S}_s + \varepsilon_{its},$$

(2)

where $RevPoint_{its}$ denotes the reservation point of subject *i* at the *s*th round of the *t*th game, $obtainedpoints_{it-1}$ denotes a point obtained in the previous game, and $\boldsymbol{S}_s$ is a vector of round dummies.

Table 2 confirms our finding in Fig. 2. The sample consists of observations from the strategy-method type treatments only (T1-commit and T2-commit). While we observe no significant effect of ambiguity on reservation points in Columns (1) and (2), a significant negative effect of ambiguity is observed in Columns (3) and (4), where the sample is limited to observations with consistent behavior. On average, ambiguity reduces the reservation point by about 54 points.

4. Conclusion

This paper designed a laboratory experiment of a finite-horizon sequential search model with ambiguity, in the sense that an offer distribution is unknown, and tested whether the result of Nishimura and Ozaki (2004) is supported by the experimental results. To do so, it is important to find ways to recover the true trends of reservation points. However, there are two problems. The first problem is that most subjects finish their search activities long before the final round (e.g., Schunk and Winter 2009), which makes it difficult to recover the long trend of reservation points. As the second problem, the lower the reservation points, the earlier the subjects finish their search. Thus, it generates an upward attrition bias on the value of reservation points, and this bias is expected to become large as the game approaches the final round.

To overcome these problems, we conducted a strategy-method treatment as well as a direct-response treatment. In the strategy-method treatment, we asked the subjects ex ante to declare their reservation points at each round *provided that they move on to the next round*, and then begin the actual search based on the reservation points the subjects had already entered.

Our results show that the presence of ambiguity in point distribution significantly decreased the reservation points only when we limit our sample to those subjects with consistent behavior. In our most preferred estimation, ambiguity reduces the reservation point by about 54 points. Thus, our experiment supports the theoretical result of Nishimura and Ozaki (2004) for limited but reliable observations.

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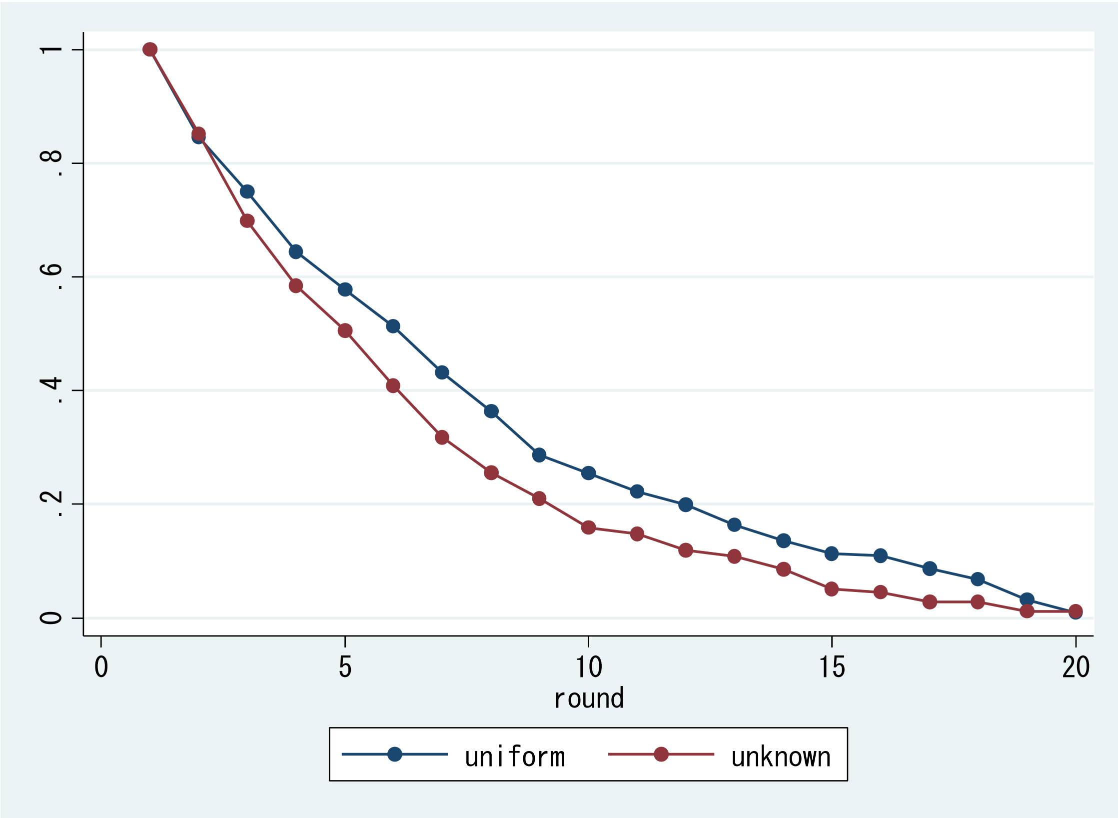

Fig. 1
Average Survival Rate (sample = game-level observations from T1 and T2)

Note. The blue line represents averages for T1 (N=44×5, mean duration = 6.81 rounds, mean survival rate = 0.282). The red line represents averages for T2 (N=44×4, mean duration = 5.63 rounds, mean survival rate = 0.34). The difference in the mean duration between T1 and T2 is 1.18 (p-value = 0.018). The difference in the mean survival rate between the two treatments is -0.059 (p-value<0.0001). The figure does not control for subject-specific effect and points obtained in the previous games.

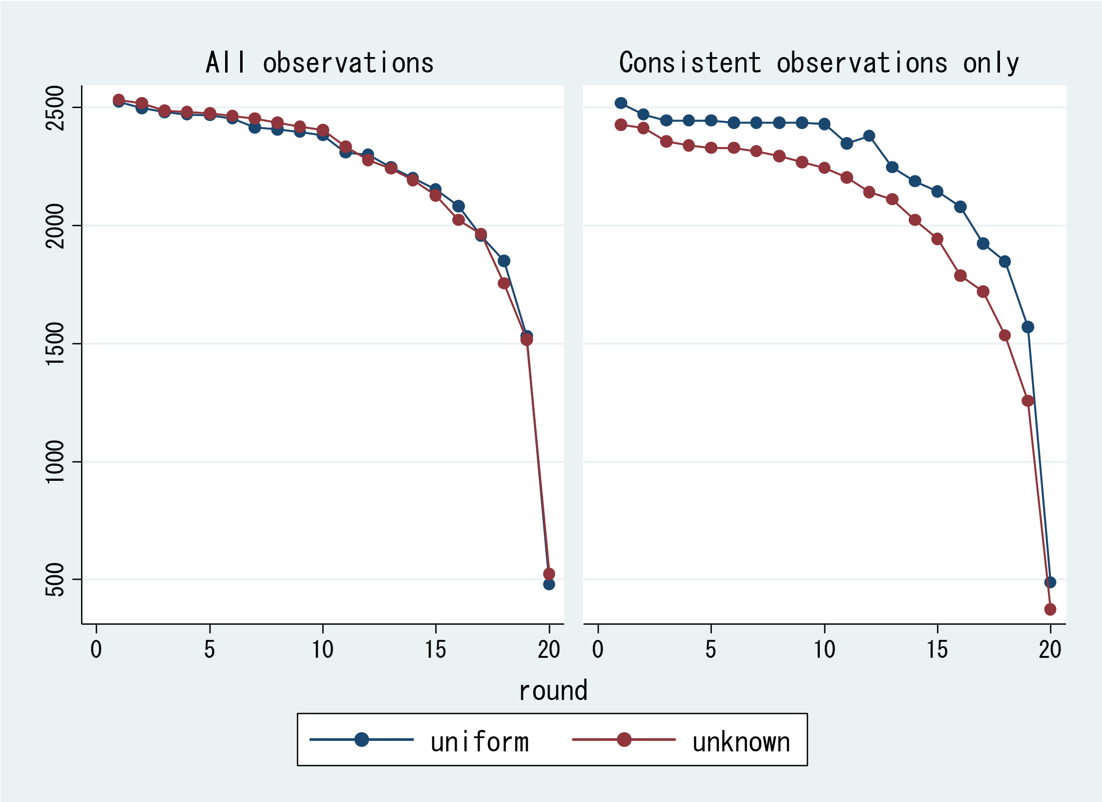

Fig. 2
Average Reservation Points (sample = round-level observations from T1-commit and T2-commit)

Note. The left-hand panel represents averages for all observations (T1-commit: N = 44×20, mean = 2179.12; T2-commit: N = 44×20, mean = 2180.38). The difference in mean reservation points between the two groups (T1-commit and T2-commit) is -1.26 (p = 0.97). The right-hand panel represents averages for consistent observations (T1-commit: N = 16×20, mean = 2184.73; T2-commit: N = 20×20, mean = 2019.63). Difference in mean reservation points between the two groups (T1-commit and T2-commit) is 165.11 (p = 0.001). The figure does not control for subject-fixed effects.

Table 1
Search Duration under Knightian Uncertainty

	Y = Search Duration Sample = T1 and T2		
	(1)	(2)	(3)
Unknown (=1)	-1.1784 ***	-1.1120 **	-0.8330 *
	(0.4373)	(0.4660)	(0.4631)
Points obtained in the previous game		0.0028 ***	0.0015
		(0.0008)	(0.0010)
Constant	6.8090 ***	-0.4610	2.8450
	(0.4860)	(2.2210)	(2.4870)
Subject-fixed effects	No.	No.	Yes.
R-squared	0.0141	0.0470	0.0200
N	396	352	352

Note: Robust standard errors clustered by subject are in parentheses. *** 1%, ** 5%, * 10% significance. The sample consists of game-level observations from all T1 and T2 treatments.

Table 2

Knightean Uncertainty on Reservation Point

	Y = Reservation point Sample = T1-commit and T2-commit (round-level observations)			
	(1)	(2)	(3)	(4)
	All obs.	All obs.	Consistent obs.	Consistent obs.
Unknown (=1)	1.26	-1.81	-52.50 ***	-53.76 ***
	(20.87)	(20.36)	(13.94)	(10.82)
Points obtained in the previous game		0.07		-0.10 ***
		(0.05)		(0.03)
Constant	2527.00 ***	2353.00 ***	2496.00 ***	2756.00 ***
	(32.63)	(135.40)	(45.54)	(109.20)
Subject-fixed effects	Yes.	Yes.	Yes.	Yes.
Round dummies	Yes.	Yes.	Yes.	Yes.
Adjusted R-squared	0.743	0.743	0.738	0.738
N	1760	1760	720	720

Note. Robust standard errors clustered by subjects are in parentheses. *** 1%, ** 5%, * 10% significance. Sample consiste of round-level obervations from T1-commit and T2-commit treatments.