Recent Developments of Experimental measurements:

Risk, Ambiguity, and Time Preferences

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Introduction

- This workshop will introduce some (selective) recent advances of experimental methods in measuring risk, ambiguity, and time preferences.

- Before proceeding, let us take a moment to think about the following questions:

  – Why do we, as economists, care about measuring those preferences?

  – Why do we want to rely on experimental methods?

Economic significance of measuring the individual preferences

- Traditional economic analysis assumes that choices are rational:
  - Decision makers choose their preferred alternatives from the feasible set given the information available to them.

- In this standard view, heterogeneity in choices is attributed to heterogeneity in *preferences*, *information*, *beliefs*, or *constraints*.

- Consider one persistent puzzle in economics: *why do households with similar observed chacteristics accumulate radically different amounts of wealth*?
  - Venti and Wise (1998); Bernheim et al (2003).

- Wealth is partly the result of innumerable financial decisions - saving, asset holdings, etc. - which are usually thought to be made sensitively with regard to those individual preferences.

- The following questions still remain to be answered:
  - Does heterogeneity in preferences account for the variation in wealth?
  - If so, how much variation in wealth can be explained by heterogeneity in preferences?

Experimental methods

- We focus mainly on experimental methods recently developed and tested in the laboratory, and also brought in the field environment.

- The advantage of laboratory experiment is the tight control of decision environments - e.g., controlling information and constraints.

- Hence, laboratory experiment is a useful source of testing theory and accumulating evidence in economics (Falk and Heckman, 2009).

References

[1] Bernheim, D., J. Skinner, and S. Weinberg (2003), "What Accounts for the Variation in Retirement Wealth among U.S. Households?" *American Economic Review*, 91(4), 832-857.

[2] Falk, A. and J. Heckman (2009), "Lab Experiments Are a Major Source of Knowledge in the Social Sciences," *Science*, 326, 535-538.

[3] Venti, S. and D. Wise (1998), "The Cause of Wealth Dispersion at Retirement: Choice or Chance?" *American Economic Review Papers and Proceedings*, 88(2), 185-191.

Risk Preferences

and

Economic Rationality

Expected utility theory

- The standard model of decisions under uncertainty is based on von Neumann and Morgenstern Expected Utility Theory (EUT).

- EUT has a very simple, appealing way of combining *probabilities* and monetary *consequences*;

  - It is linear in probabilities;

  - Risk attitude is solely captured by the curvature of utility function over consequences.

- Experimentalists have tested particular axioms on which EUT is based, following Allais (1953).

- Empirical violations of EUT raise criticisms about the status of the EUT axioms as the touchstone of rationality.

- These criticisms have generated the development of various theoretical alternatives to EUT (Starmer, 2000).
  - One common feature in many of non-EUTs is that risk attitude relies on nonlinear transformation of probabilities and the curvature of utility function.

- The experimental investigation of these theories has led to new empirical regularities.

Experiments à la Allais

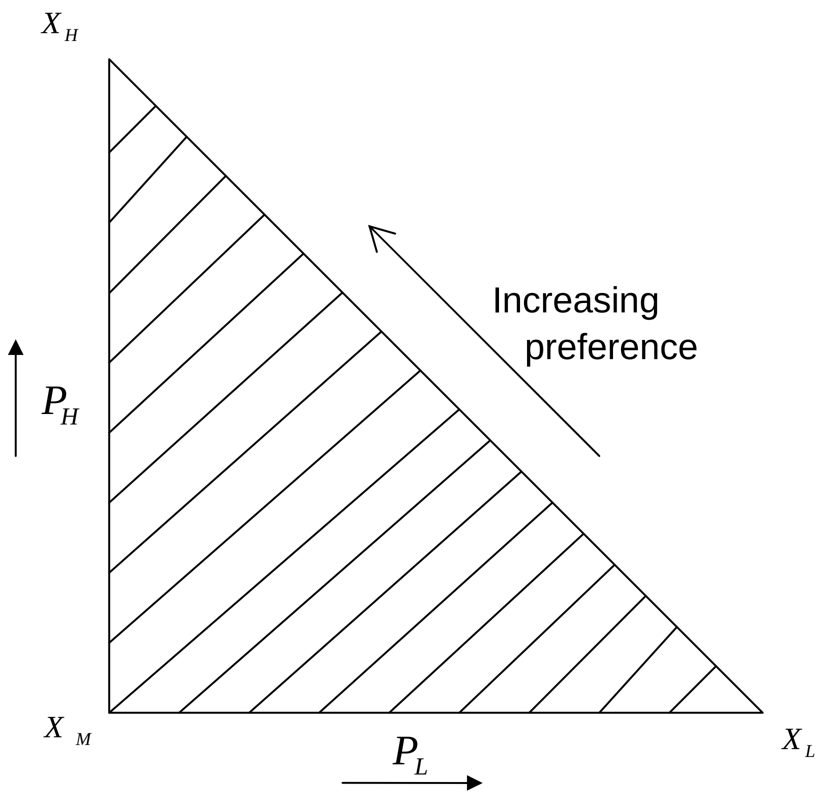
- Traditional lab experiments use several pairwise choices of lotteries to test theories of choice under risk.

- Each theory predicts indifference curves with distinctive shapes in the Marschak-Machina probability triangle.

- By choosing alternatives that theories rank differently, each theory can be tested against the others.

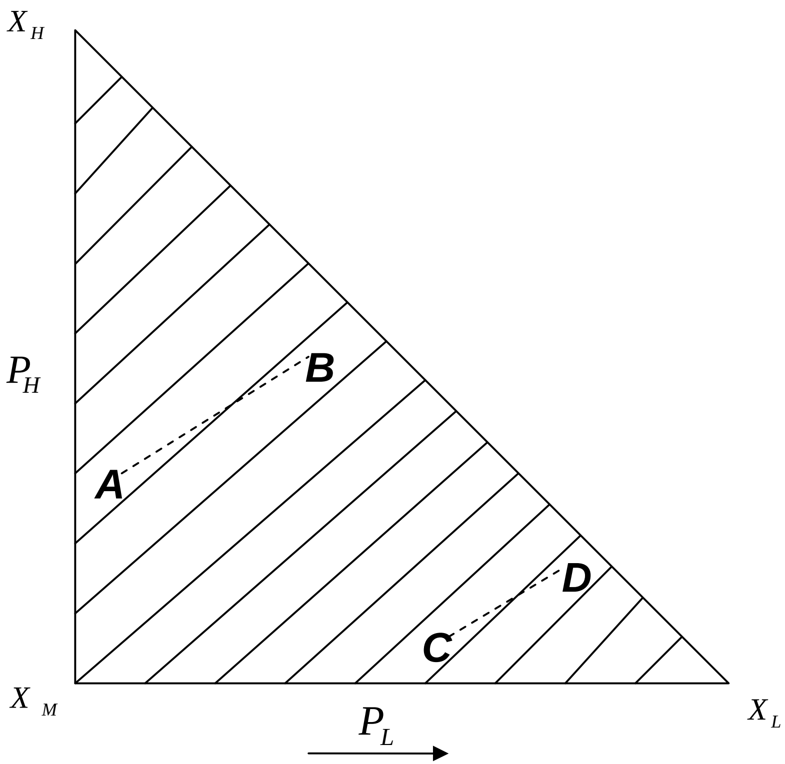
- The criterion typically used to evaluate a theory is the fraction of choices it predicts correctly.

The Marschak-Machina probability triangle



$X_H > X_M > X_L$ are three outcomes

A violation of EUT



EUT requires that indifference lines are parallel so one must choose either ***A*** and ***C***, or ***B*** and ***D***.

Multiple price lists

- An experimental design intending more directly to measure risk preferences is so-called Multiple Price Lists (MPL) design (Holt and Laury, 2002 and Harrison et al. 2004).

- An individual subject is asked to make a series of binary decisions between risky and safe lotteries.

- MPL design has several potential concerns: (i) it only elicits interval responses; (ii) it faces a particular inconsistent behavior - multiple switch points; (iii) it can be susceptible to framing effects.

TABLE 1—THE TEN PAIRED LOTTERY-CHOICE DECISIONS WITH LOW PAYOFFS

Option A	Option B	Expected payoff difference
1/10 of $2.00, 9/10 of $1.60	1/10 of $3.85, 9/10 of $0.10	$1.17
2/10 of $2.00, 8/10 of $1.60	2/10 of $3.85, 8/10 of $0.10	$0.83
3/10 of $2.00, 7/10 of $1.60	3/10 of $3.85, 7/10 of $0.10	$0.50
4/10 of $2.00, 6/10 of $1.60	4/10 of $3.85, 6/10 of $0.10	$0.16
5/10 of $2.00, 5/10 of $1.60	5/10 of $3.85, 5/10 of $0.10	−$0.18
6/10 of $2.00, 4/10 of $1.60	6/10 of $3.85, 4/10 of $0.10	−$0.51
7/10 of $2.00, 3/10 of $1.60	7/10 of $3.85, 3/10 of $0.10	−$0.85
8/10 of $2.00, 2/10 of $1.60	8/10 of $3.85, 2/10 of $0.10	−$1.18
9/10 of $2.00, 1/10 of $1.60	9/10 of $3.85, 1/10 of $0.10	−$1.52
10/10 of $2.00, 0/10 of $1.60	10/10 of $3.85, 0/10 of $0.10	−$1.85

Convex budget set design

- Choi et al (2007a, 2007b, 2010) present subjects with a standard economic decision problem that can be interpreted:
  - as a portfolio choice problem (the allocation of wealth between two risky assets);
  - as a consumer decision problem (the selection of a bundle of contingent commodities from a standard budget set).
- The decision problems are presented on a user-friendly graphical interface that allows for the collection of a rich individual-level data set.

Research questions

Consistency

$\Longrightarrow$ Is behavior under uncertainty consistent with utility maximization?

Structure

$\Longrightarrow$ Is the observed data consistent with a utility function with some special structural properties?

Heterogeneity

$\Longrightarrow$ To what degree do consistency and risk preferences differ across subjects?

$\Longrightarrow$ Do subjects' socio-economic characteristics explain their variations?

Economic relevance

$\Longrightarrow$ Does heterogeneity in consistency / risk preferences account for the variations in real economic decisions and their resulting well-being?

Decision-making quality

- Recent literature allows heterogeneity in choices driven by heterogeneity in what might be called the *quality* of decision-making.
  - Ameriks et al (2003); Bernheim and Garrett (2003); Agarwal et al (2009); Banks et al (2010).

- In this new view, there are potentially important wedges between actual choices and the choices that people would make if they had skills / knowledge to make higher quality decisions.

- These wedges are important because it suggests there are circumstances where "revealed" preferences may not be "true" preferences.

Consistency as decision-making quality

- In general, how can we tell if someone has made a low quality decision?

- What, precisely, do we mean by "decision-making quality"?

- Choi et al (2010) propose to identify decision-making quality with economic rationality.

Twin problems

Identification problem

$\Longrightarrow$ to distinguish differences in decision-making quality from unobserved differences in preferences, information, beliefs or constraints.

Measurement problem

$\Longrightarrow$ to define and implement a quantitative measure of decision-making quality that is economically interpretable.

- We address the identification problem using experimental method:
  - Experiment provides controls for some unobservables (such as information and constraints);
  - Consistency is independent with preference type;
  - Helping to isolate heterogeneity in decision-making quality from heterogeneity in preferences, information, beliefs or constraints.

- We utilize the theory of revealed preference and the experimental technique, developed by Choi et al (2007b), to address the measurement problem:

  - In contrast with measures of cognitive ability or financial knowledge, consistency measures have a coherent economic interpretation.

  - The theoretical framework is valuable for drawing conclusions that go beyond the particular setting of the experiment.

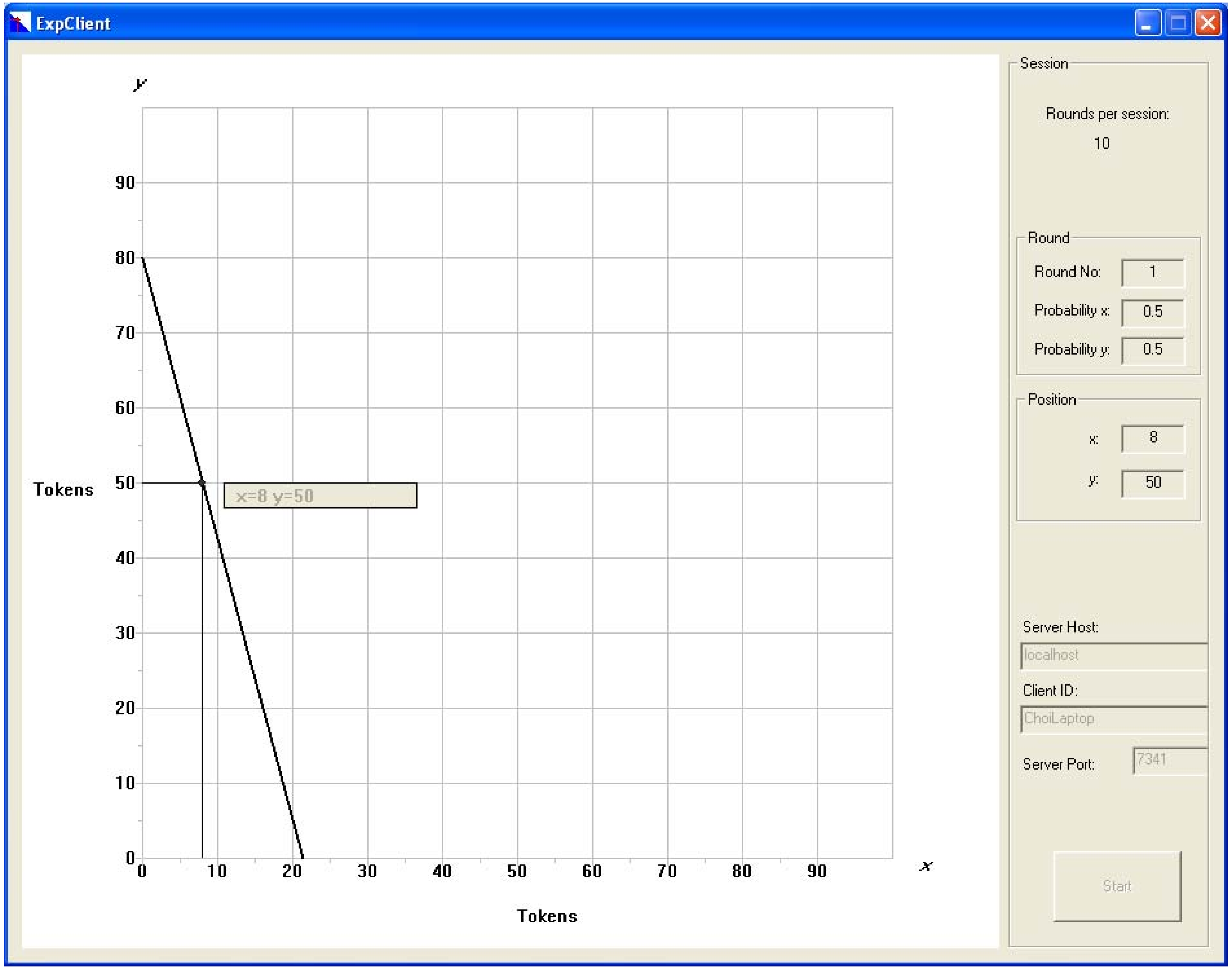
Decision in the Experiment

- Subjects are presented with a standard portfolio choice problem. There are two states of natures, $s = 1, 2$, that occur equally likely, and two Arrow securities corresponding to the two states.

- Subjects are allowed to choose any non-negative portfolio $x = (x_1, x_2)$ satisfying the budget constraint

$$p_1 x_1 + p_2 x_2 = 1.$$

- A graphical experimental interface displays randomly generated budget sets from which subjects make choices by "pointing and clicking".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x=8 y=50
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x
Tokens
Session
Rounds per session:
10
Round
Round No:
1
Probability x:
0.5
Probability y:
0.5
Position
x:
8
y:
50
Server Host:
localhost
Client ID:
ChoiLaptop
Server Port:
7341
Start

Experimental environments

- Subject pool
  - Choi et al (2007b) use U.S. undergraduate students;
  - Choi et al (2010) utilize a representative sample of the Dutch population in the Netherlands (http://www.centerdata.nl/en/centerpanel).

- The CentERpanel is an internet panel of over 2000 households and 5000 household members.
  - The comprehensive household survey, dating back to 1993, collects panel members' demographic and economic variables.

Experimental procedures - CentERpanel

- The experiment was conducted in May 2009. Among 2340 panel members who were randomly chosen for inviation, 1372 members logged on to the experiment.

- 1182 members (86.2%) completed the experiment while 190 subjects (13.8%) did not.

- Each subject repeated 25 independent decisions, one of which was randomly selected for payment at the end.

Descriptive statistics

	Final sample	Drop-outs	Non-participants
Female	45.43	37.89	50.00
Age			
Age 16 - 34	18.53	3.16	26.14
Age 35 - 49	26.14	12.11	32.13
Age 50 - 64	35.62	38.42	27.58
Age 65 +	19.71	46.32	14.15
Education			
Low	33.59	42.63	30.99
Medium	29.70	22.63	31.61
High	36.72	34.74	37.40
Income			
Less than EUR 2500	22.42	34.73	21.28
EUR 2500 - 3499	25.13	26.32	18.90
EUR 3500 - 4999	28.85	16.32	28.93
EUR 5000 +	23.60	22.63	30.89
Occupation			
Paid work	53.13	39.47	62.91
House work	11.59	7.89	8.78
Retired	20.90	42.63	13.95
Others	14.38	10.00	14.36
Household composition			
Partner	80.88	67.89	82.64
# of kids	0.84	0.32	1.09
# of observations	1182	190	968

Revealed preference

- Let $\{(p^t, x^t)\}_{t=1}^{25}$ be some observed individual data (p^t denotes the t-th observation of the price vector and x^t denotes the associated portfolio).

- A utility function $U(x)$ *rationalizes* the observed behavior if it achieves the maximum on the budget set at the chosen portfolio

$$U(x^t) \geq U(x) \text{ for all } x \text{ s.t. } p^t \cdot x^t \geq p^t \cdot x.$$

- A portfolio x^t is *directly revealed preferred* to a portfolio x if $p^t \cdot x^t \geq p^t \cdot x$.

- A portfolio x^t is *(indirectly) revealed preferred* to x if there is a chain of directly revealed preferred portfolios linking x^t to x.

- **Generalized Axiom of Revealed Preference (GARP)** *If x^t is revealed preferred to x^s, then x^s is not strictly directly revealed preferred (i.e. $p^s \cdot x^s \leq p^s \cdot x^t$) to x^t*

- GARP is tied to utility representation through the following theorem, which was first proved by Afriat (1967).

Rationality as decision-making quality

- **Afriat's Theorem** *If the data satisfies GARP, then there exists a utility function that rationalizes the observed choices. Moreover, the utility function may be chosen to be increasing, continuous and concave.*

- We identify decision-making quality with economic rationality as above: better choices satisfy GARP better.

  - It may be because they are more purposeful and reflect more consistent treatments of tradeoffs, regardless of preferences, information or beliefs.

Measuring quality

- The use of GARP to measure quality faces a challenge because it offers an exact test (either the data satisfy GARP or they do not).

- The literature provides a variety of goodness-of-fit indices to quantiy the extent of GARP violations, which is to measure decision-making quality from our perspectives.

- The main index is Afriat's (1972) Critical Cost Efficiency Index (CCEI).

Afriat's index

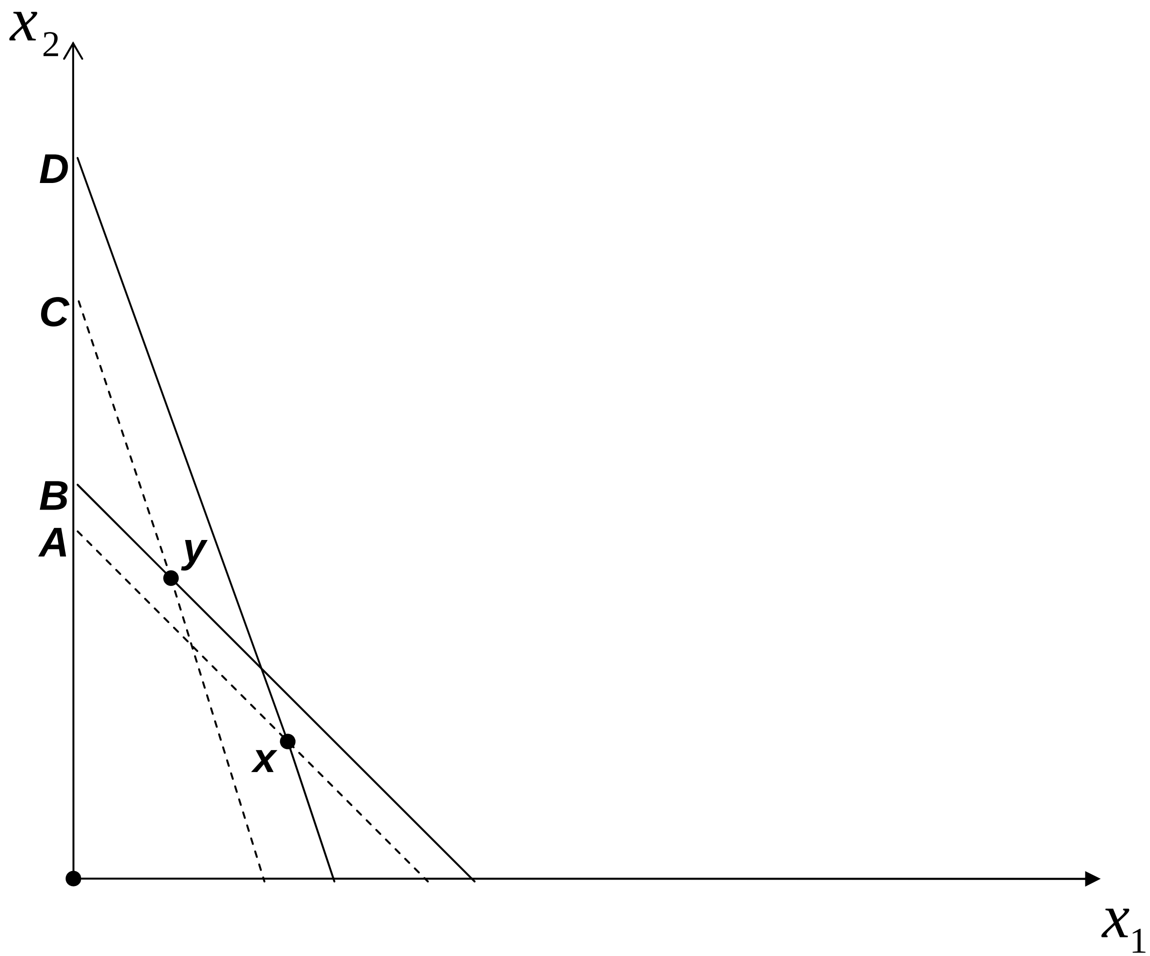
- **Afriat's critical cost efficiency index (CCEI)** *The amount by which each budget constraint must be relaxed in order to remove all violations of GARP.*

- For any number $0 \leq e \leq 1$, define the direct revealed preference relation $R^D(e)$ as $x^i R^D(e) x^j$ if $ep^i \cdot x^i \geq p^i \cdot x^j$.

- Let $R(e)$ to be the transitive closure of $R^D(e)$. The CCEI is the largest value of e such that the relation $R(e)$ satisfies GARP.

- The CCEI is bounded between zero and one. The closer it is to one, the smaller the perturbation required to remove all violations and thus the closer the data are to satisfying GARP.

The construction of the CCEI for a simple violation of WARP



The agent is ‘wasting' as much as *A/B*<*C/D* of his income by making inefficient choices.

Advantages of the measure and experimental method

- *Portable*: can be applied to many other choice domains.

- *Practical and powerful*: enough variations in budget sets to provide a strong test of consistency.

- *Autonomous*: CCEI is independent of preferences.

- *Quantifiable and interpretable*: CCEI allows one to judge the welfare effects of decision-making quality.

Table 2. CCEI scores

	Mean	Std. Dev.	Percentiles 10	25	50	75	90	# of obs.
All	0.881	0.141	0.676	0.808	0.930	0.998	1.000	1182
Female	0.874	0.147	0.666	0.796	0.928	0.998	1.000	537
Age								
16-34	0.920	0.119	0.734	0.881	0.979	1.000	1.000	219
35-49	0.906	0.123	0.708	0.853	0.966	1.000	1.000	309
50-64	0.863	0.142	0.666	0.784	0.901	0.985	1.000	421
65+	0.843	0.164	0.595	0.770	0.882	0.981	1.000	233
Education								
Low	0.863	0.143	0.665	0.782	0.906	0.987	1.000	397
Medium	0.881	0.140	0.689	0.814	0.926	0.998	1.000	351
High	0.899	0.137	0.686	0.842	0.963	1.000	1.000	430
Household monthly income								
€0-2500	0.856	0.154	0.617	0.769	0.911	0.983	1.000	269
€2500-3499	0.885	0.133	0.705	0.809	0.925	0.999	1.000	302
€3500-4999	0.882	0.141	0.649	0.817	0.932	0.999	1.000	345
€5000+	0.901	0.131	0.729	0.836	0.968	1.000	1.000	266
Occupation								
Paid work	0.896	0.131	0.705	0.833	0.950	1.000	1.000	628
House work	0.873	0.151	0.649	0.795	0.937	0.999	1.000	137
Retired	0.839	0.158	0.597	0.767	0.876	0.971	1.000	247
Others	0.891	0.129	0.712	0.809	0.936	0.998	1.000	170
Household composition								
Partner	0.878	0.142	0.673	0.802	0.927	0.998	1.000	956
Children	0.899	0.128	0.704	0.835	0.959	1.000	1.000	490

Power of Test

The power of Bronars' (1987) test is defined to be the probability that a hypothetical subject whose choice is uniformly distributed over the budget line violates GARP.

The power of test depends on the number of decisions made by each random subject.

CCEI	# of decisions		
	10	25	50
0.95 – 1.0	0.202	0.043	0.001
0.9 – 0.95	0.171	0.100	0.007
0.85 – 0.9	0.133	0.146	0.026

How powerful is GARP?

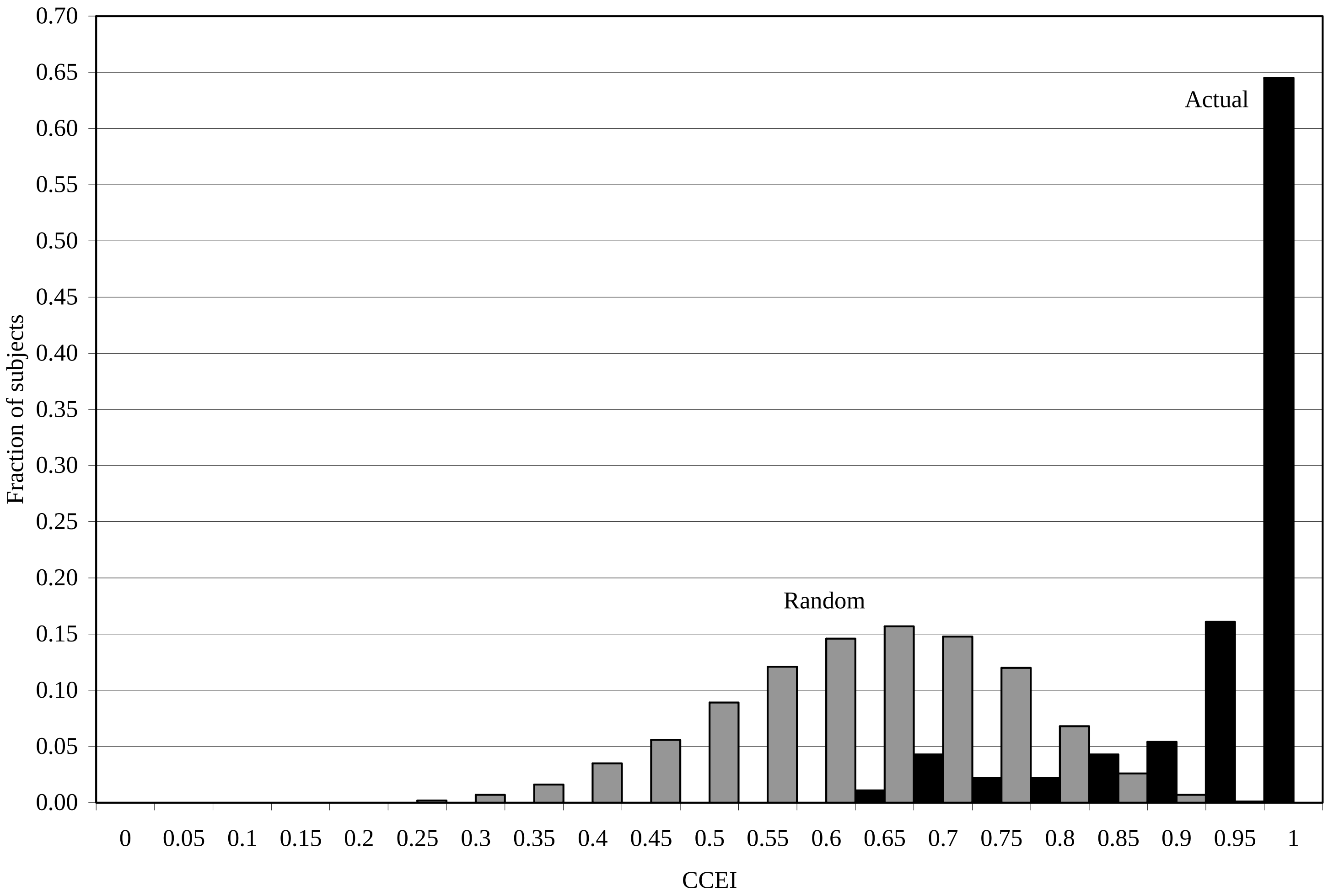
- We generate a random sample of hypothetical subjects with the power utility function, $u(y) = \frac{y^{1-\rho}}{1-\rho}$, with different levels of error.

- The likelihood error is assumed to be a decreasing function of the utility cost of an error. Specifically, the choice density of x^* on a budget line is

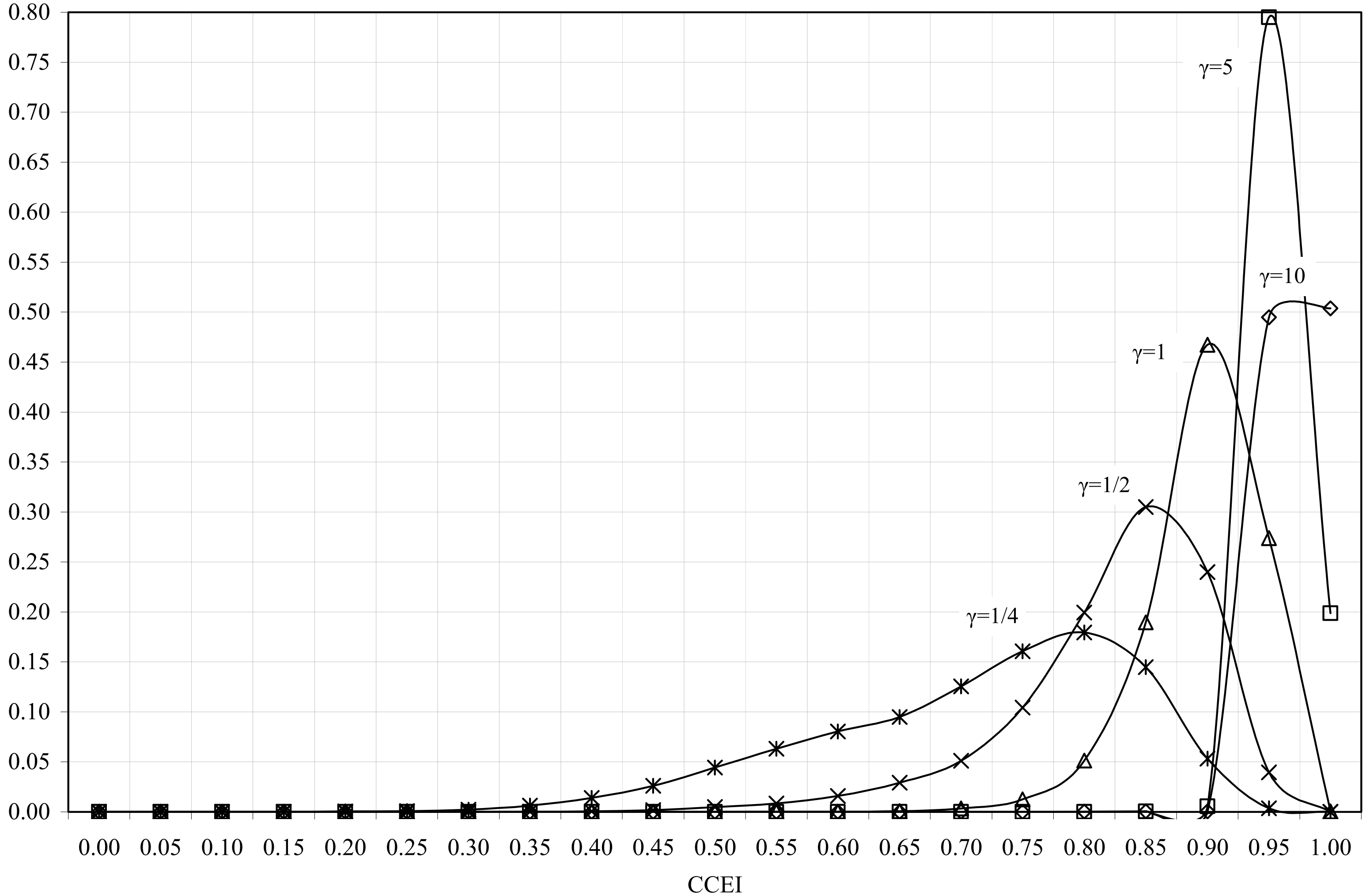
$$f(x^*) = \frac{\exp(\gamma \cdot u(x^*))}{\int_{x:p\cdot x=1} \exp(\gamma \cdot u(x))}.$$

- If utility maximization is not the correct model, is our experiment sufficiently powerful to detect it?

Figure 4: The distributions of GARP violations Afriat's (1972) efficiency index (CCEI).



The distribution of CCEI scores ρ=1/2 and γ=1/4,1/2,1,5,10



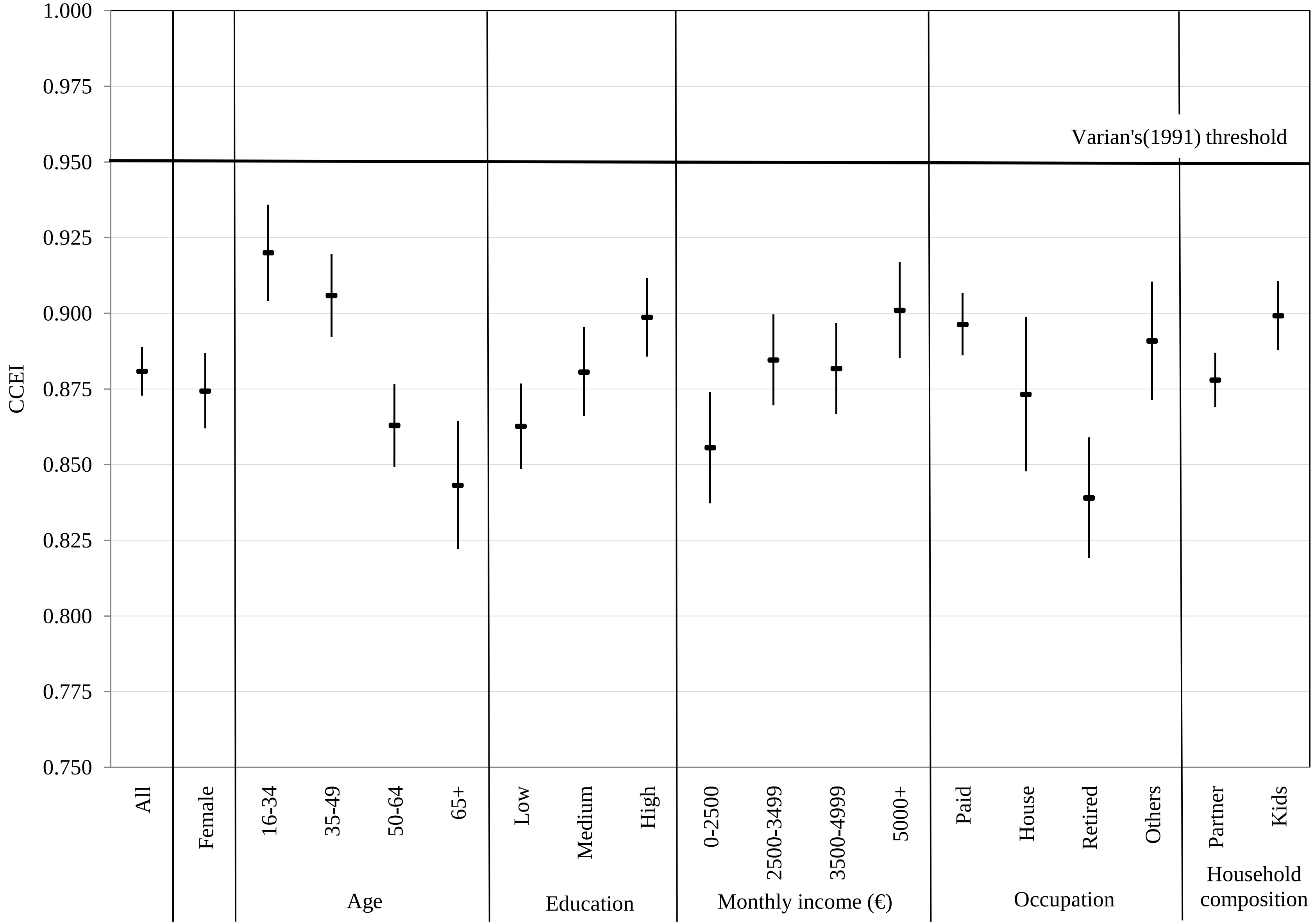
Who is (more) rational?

- We correlate heterogeneity in CCEI and the demographic differences among experimental subjects.

- Our data are based on the non-randomly selected subsample of participants. We correct for the possible sample selection bias using Heckman's (1979) method.

- Exclusion restriction – the number of completed CentERpanel questionnaires as a fraction of the total invitations to participate in the three months preceding our experiment.

Figure 1. Mean CCEI scores



The correlation between the CCEI scores and subjects' individual characteristics
(sample-selection)

	Drop-outs		Drop-outs + non-participants	
	Outcome	Selection	Outcome	Selection
Constant	.888*** (.022)	.544* (.311)	.891*** (.023)	-2.077*** (.209)
Female	-.024*** (.009)	.084 (.103)	-.024*** (.009)	-.031 (.068)
Age				
35-49	-.016 (.011)	-.556** (.230)	-.016 (.011)	-.133 (.102)
50-64	-.051*** (.011)	-1.024*** (.220)	-.052*** (.011)	-.393*** (.102)
65+	-.050** (.021)	-1.556*** (.263)	-.051** (.020)	-.824*** (.154)
Education				
Medium	.009 (.011)	.191 (.122)	.009 (.011)	-.036 (.081)
High	.026** (.011)	.168 (.117)	.026** (.011)	.006 (.084)
Income				
€2500-3499	.025** (.012)	.303** (.125)	.025** (.012)	.281*** (.094)
€3500-4999	.019 (.013)	.426*** (.141)	.019 (.014)	.186** (.094)
€5000+	.033** (.014)	.064 (.147)	.033** (.014)	.080 (.106)
Occupation				
Paid work	.028 (.018)	-.202 (.172)	.029 (.018)	-.040 (.131)
House work	.046** (.020)	.108 (.200)	.046** (.020)	.083 (.148)
Others	.037** (.019)	.081 (.196)	.037* (.019)	.110 (.147)
Household composition				
Partner	-.026** (.011)	.262** (.119)	-.027** (.011)	.123 (.092)
# of kids	.001 (.004)	.145** (.068)	.001 (.004)	.031 (.036)
Participation ratio		1.231*** (.205)		3.387*** (.125)
ρ	-.028 (.083)		-.047 (.063)	
Log peudolikelihood	210.856		-371.973	
# of obs.	1372		2340	

Omitted categories: male, age under 35, low education (primary and lower secondary education), household gross monthly income under €2500, retired, and not having a partner. Standard errors in parentheses. *, **, *** indicate 10, 5, 1 percent significance levels, respectively.

Beyond consistency - alternative measures of quality

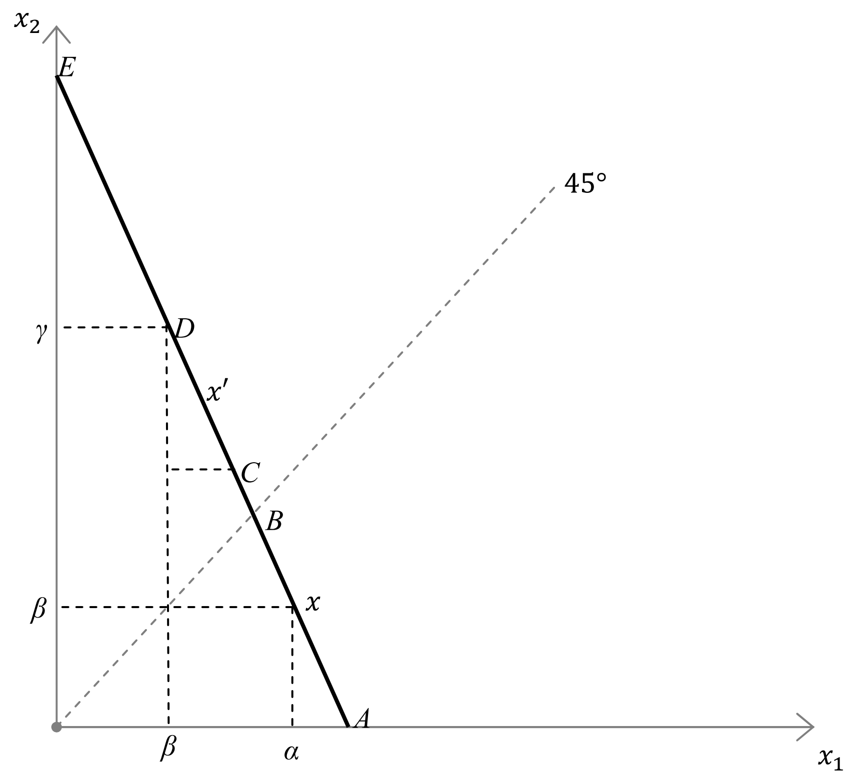
- Violations of monotonicity with respect to first-order stochastic dominance (FOSD) are poor choices, regardless of risk attitudes.

- A decision to allocate *less* tokens to the *cheaper* account violates dominance but need not involve a violation of GARP.

- We use expected payoff calculations (largest upward probabilistic shift) to assess how nearly choice behavior complies with dominance.

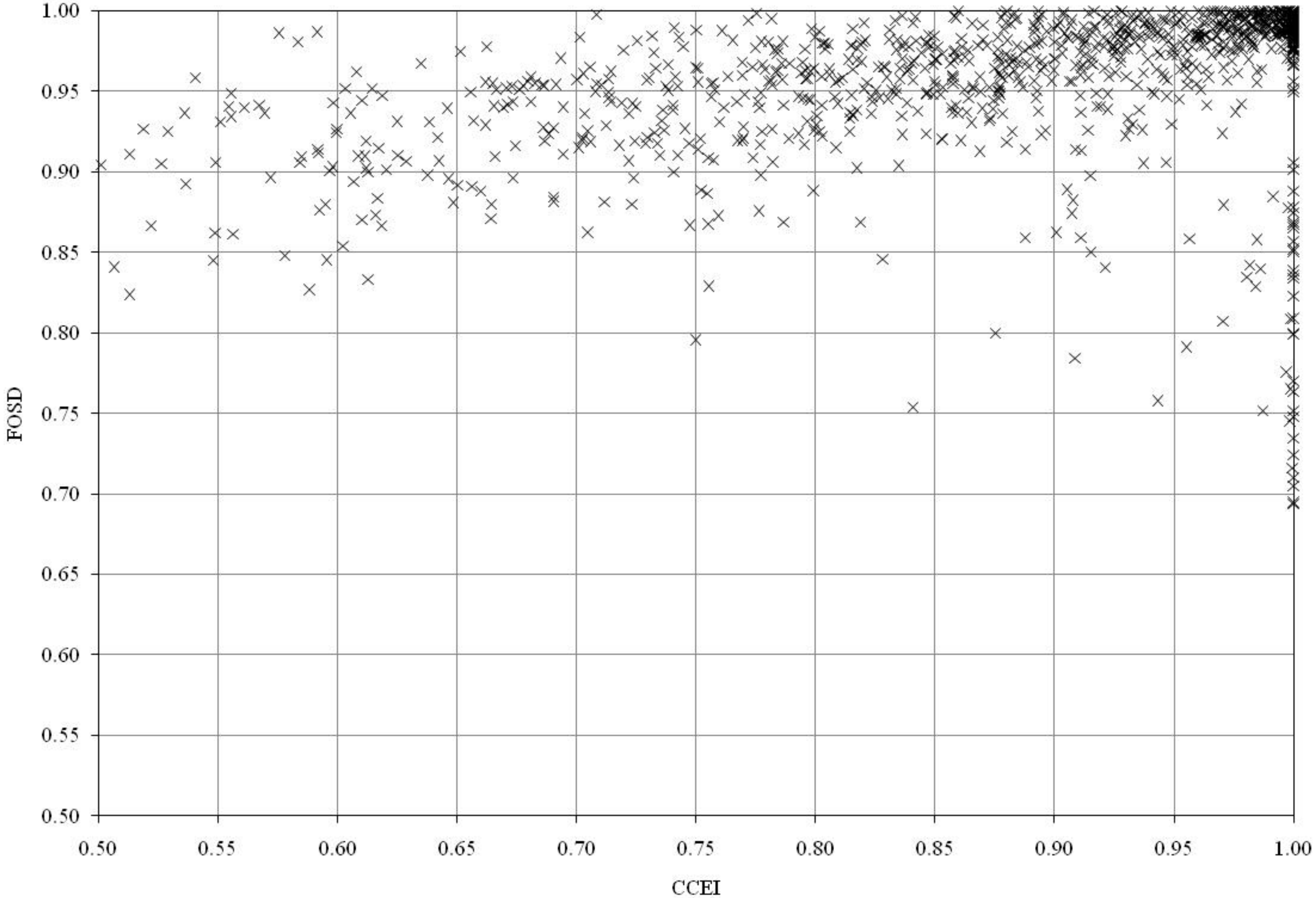
- In addition, we can impose the symmetry, generate the mirror-image data, and combine the actual and mirror-image data to conduct GARP analysis.

Figure 3. A violation of stochastic dominance



The individual can choose any allocation x' (position along CD) but prefers allocation x (position along AB) such that $F_{x'} < F_x$ where $F_{x'}$ and F_x are the resulting payoff distributions.

A scatterplot of CCEI and FOSD scores



Decision-making quality and wealth

- To the extent that rationality in simple experimental domain reflects a "trait", it may predict some imporant, real-life behavior.

- Particularly, if a measure of GARP violations proxies decision-making quality, it may correlate with economic well-being.

- Prior studies (e.g., Ameriks et al (2003)) indicate that decision-making quality matters in wealth accumulation.

- Is a measure of rationality in this narrow domain correlated with wealth?

Wealth measure in CentERpanel

- The CentERpanel collects information about wealth on an annual basis.

- All household members whose ages are above 16 respond to questions regarding assets and liabilities they hold alone.

- In addition, one member in the houshold, identified as a financial respondent, provides information about assets and liabilities that are jointly held.

- Our analysis focuses on household net worth, calculated by summing net worth over household members, as averaged over 2008 and 2009.

Table 6. Household 2008-2009 net worth summary statistics

(2008 Euros)

Mean		164,130
Std. Dev.		243,548
Max		3,984,151
Min		-180,700
Percentiles	1	-68,237
	5	-4,810
	10	0
	25	10,780
	50	92,979
	75	242,054
	90	412,494
	95	523,839
	99	955,599
# of obs.		703

Regression analysis

- (Benchmark) We regress the log of household wealth on demographic variables, log of household income, and measures of decision-making quality for financial respondent.

- We find economically large, significant relation between CCEI and household wealth: a standard deviation increase in CCEI is associated with 15% ~19% more household wealth.

Table 7. The relationship between households' net worth and CCEI scores

	(1)	(2)	(3)
CCEI	1.170**	1.425**	99933.2*
	(0.535)	(0.565)	(52656.0)
CCEI (combined dataset)			
Risk aversion			
Log 2008 household income	0.623***	0.601***	
	(0.123)	(0.127)	
2008 household income			1.74***
			(0.3)
Female	-0.275*	-0.228	-28223.9*
	(0.154)	(0.164)	(15906.3)
Age	0.004	-0.286	-33974.7
	(0.205)	(0.316)	(27100.3)
Age^2	0.002	0.006	726.5
	(0.004)	(0.005)	(471.1)
Age^3	0.000	0.000	-4.3
	(0.000)	(0.000)	(2.7)
Partner	0.623***	0.682***	48106.5***
	(0.173)	(0.183)	(16995.7)
# of children	0.125	0.103	14472.9*
	(0.086)	(0.092)	(8291.6)
Education			
Pre-vocational	0.242	0.267	13056.4
	(0.459)	(0.459)	(43981.0)
Pre-university	0.528	0.600	57288.3
	(0.474)	(0.476)	(45189.8)
Senior vocational training	0.407	0.403	27365.6
	(0.465)	(0.469)	(42967.4)
Vocational college	0.485	0.448	27964.9
	(0.450)	(0.452)	(42704.3)
University	0.637	0.679	73733.5
	(0.463)	(0.470)	(48008.2)
Constant	0.229	5.932	335793.4
	(3.554)	(5.862)	(5.0E+05)
R^2	0.217	0.179	0.191
# of obs.	566	517	568

Table7.

(Continued)

	(4)	(5)	(6)	(7)
CCEI	1.490***	1.348*	1.545***	1.563**
	(0.574)	(0.714)	(0.591)	(0.735)
CCEI (combined dataset)		0.078		-0.018
		(0.381)		(0.373)
Risk aversion			-1.166	-1.165
			(0.828)	(0.829)
Log 2008 household income	0.629***	0.602***	0.595***	0.595***
	(0.124)	(0.127)	(0.128)	(0.129)
2008 household income				
Female	-0.258	-0.229	-0.232	-0.232
	(0.162)	(0.164)	(0.166)	(0.166)
Age	-0.277	-0.284	-0.307	-0.308
	(0.318)	(0.316)	(0.313)	(0.315)
Age^2	0.006	0.006	0.007	0.007
	(0.005)	(0.005)	(0.005)	(0.005)
Age^3	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Partner	0.683***	0.682***	0.726***	0.725***
	(0.184)	(0.183)	(0.187)	(0.188)
# of children	0.106	0.103	0.092	0.092
	(0.093)	(0.093)	(0.094)	(0.095)
Education				
Pre-vocational		0.264	0.331	0.331
		(0.461)	(0.483)	(0.484)
Pre-university		0.596	0.676	0.677
		(0.486)	(0.498)	(0.498)
Senior vocational training		0.403	0.480	0.481
		(0.469)	(0.493)	(0.494)
Vocational college		0.443	0.549	0.550
		(0.452)	(0.475)	(0.480)
University		0.672	0.745	0.746
		(0.474)	(0.498)	(0.502)
Constant	5.451	5.888	6.938	6.947
	(6.110)	(5.879)	(5.786)	(5.812)
R^2	0.170	0.178	0.186	0.184
# of obs.	517	517	507	507

Summary

- We have examined the experimental data generated by Choi et al (2007b) and Choi et al (2010) to address the question of consistency.

- CCEI, as a measure of GARP violations, provides a useful way of measuring the quality of decision-making.

- The experimental measurement using the convex budget set design has such a high relevance that there is an economically significant relation between CCEI and household wealth.

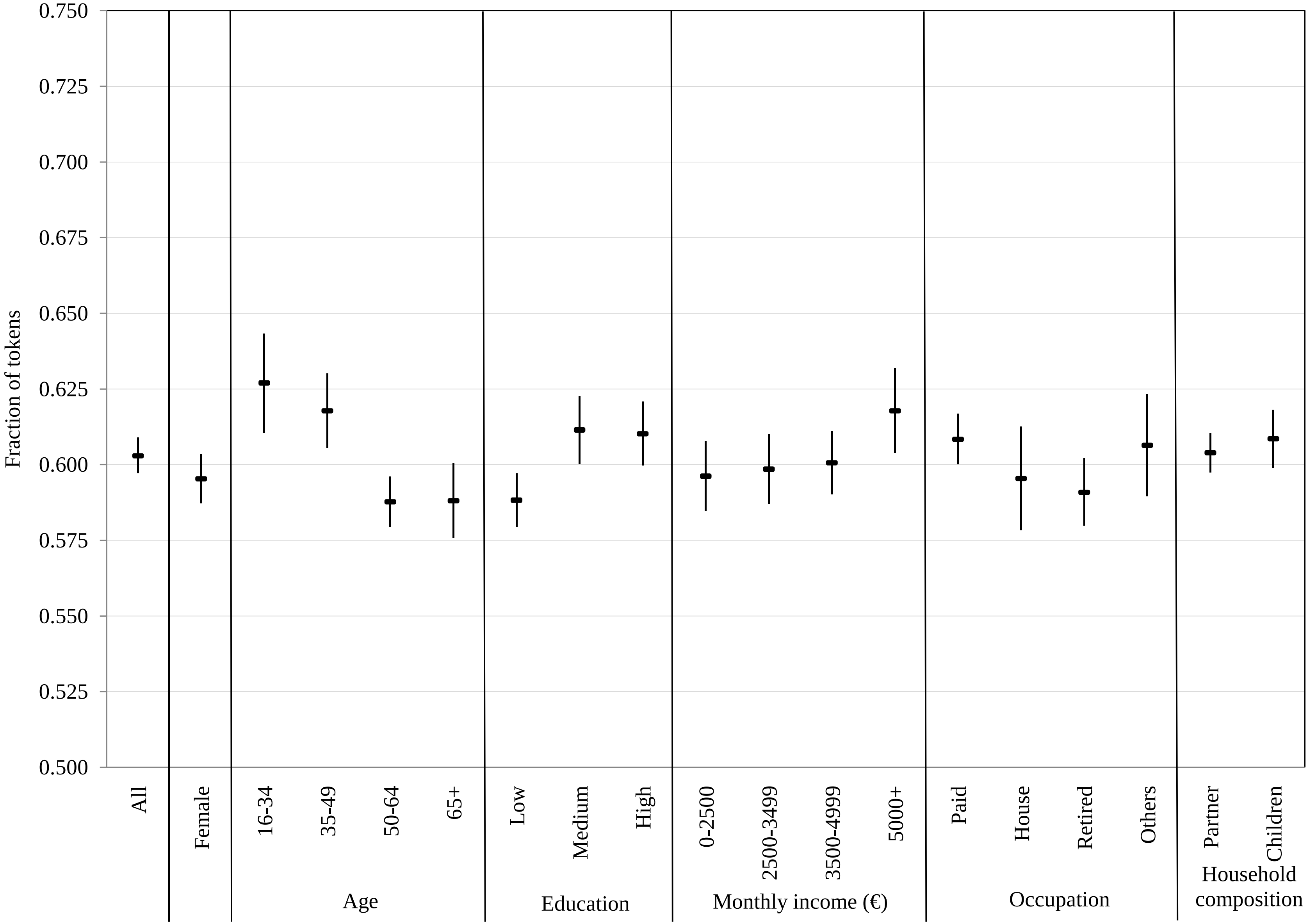
Heterogeneity of demand behavior

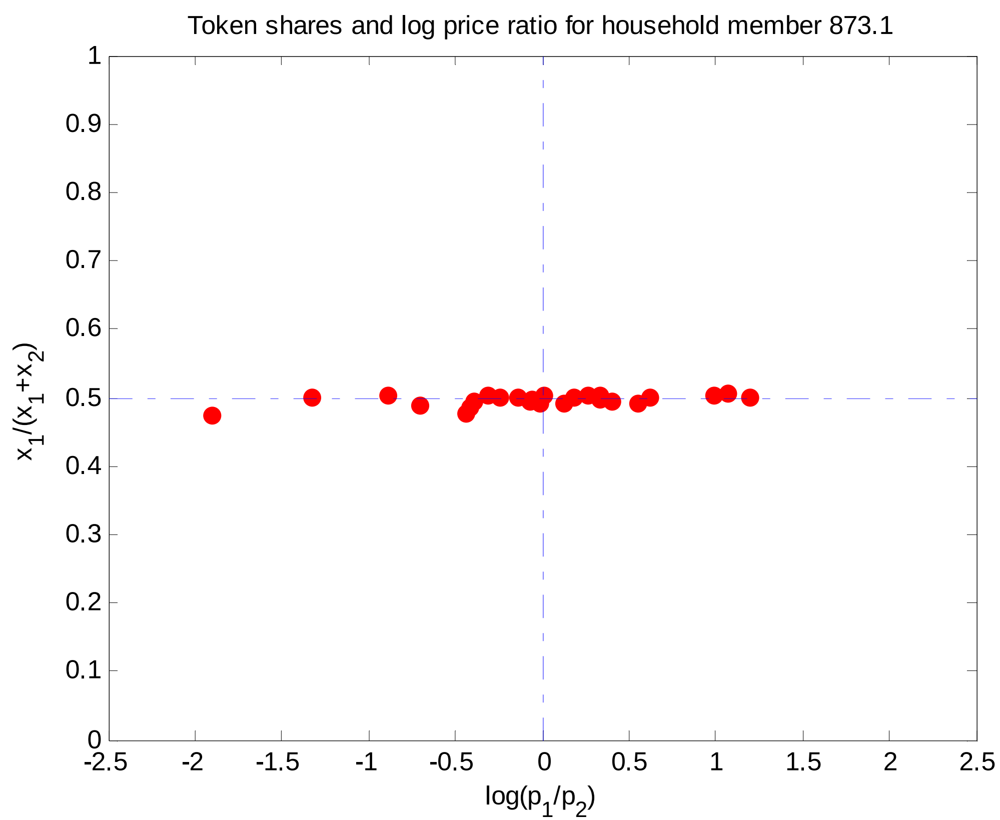
- The experimental data reveal rich information on individual-level risk attitudes.

- One easy way of looking at the demand behavior is to compute average token shares for cheaper asset: $x_{cheaper}/(x_1 + x_2)$.

- Moreover, the scatter plots between $\ln(p_1/p_2)$ and $x_1/(x_1 + x_2)$ for some individuals gives us a sense of the richness of choice data.

Figure 3. The average fraction of tokens allocated to the cheaper asset



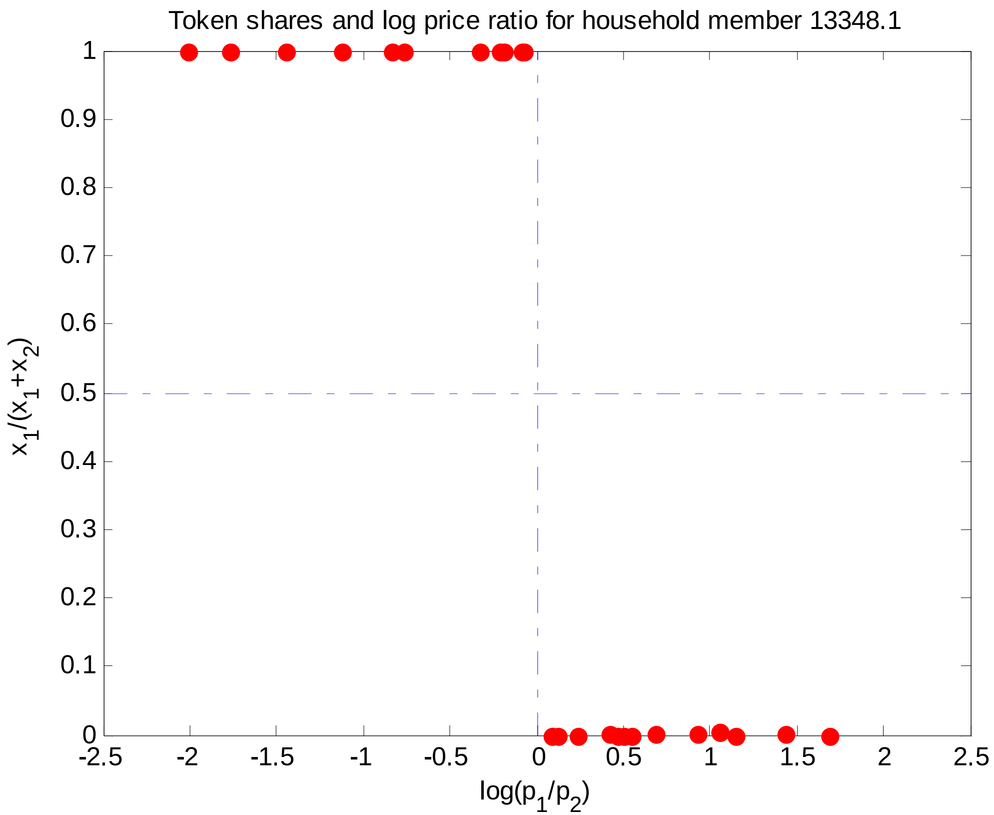


CCEI = 1; Male; 51 years old

Paid work; Mid education

HH income = €2600

# of HH members = 4

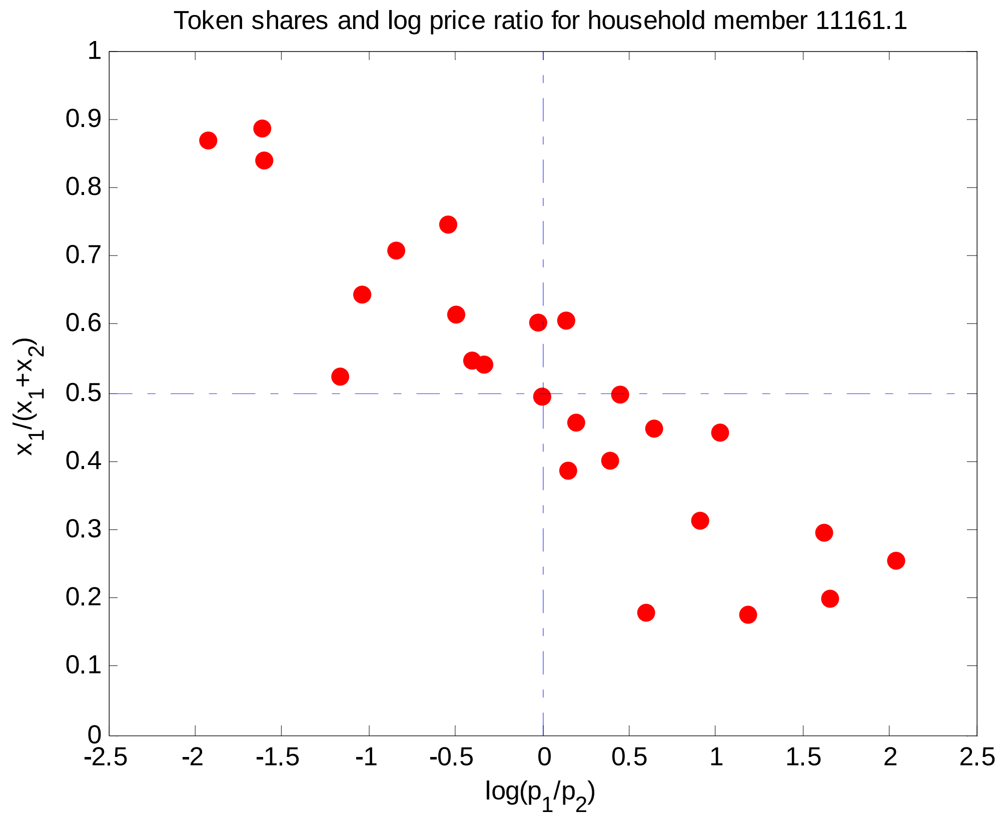


CCEI = 1; Male; 39 years old

Paid work; High education

HH income = €3500

# of HH members = 1

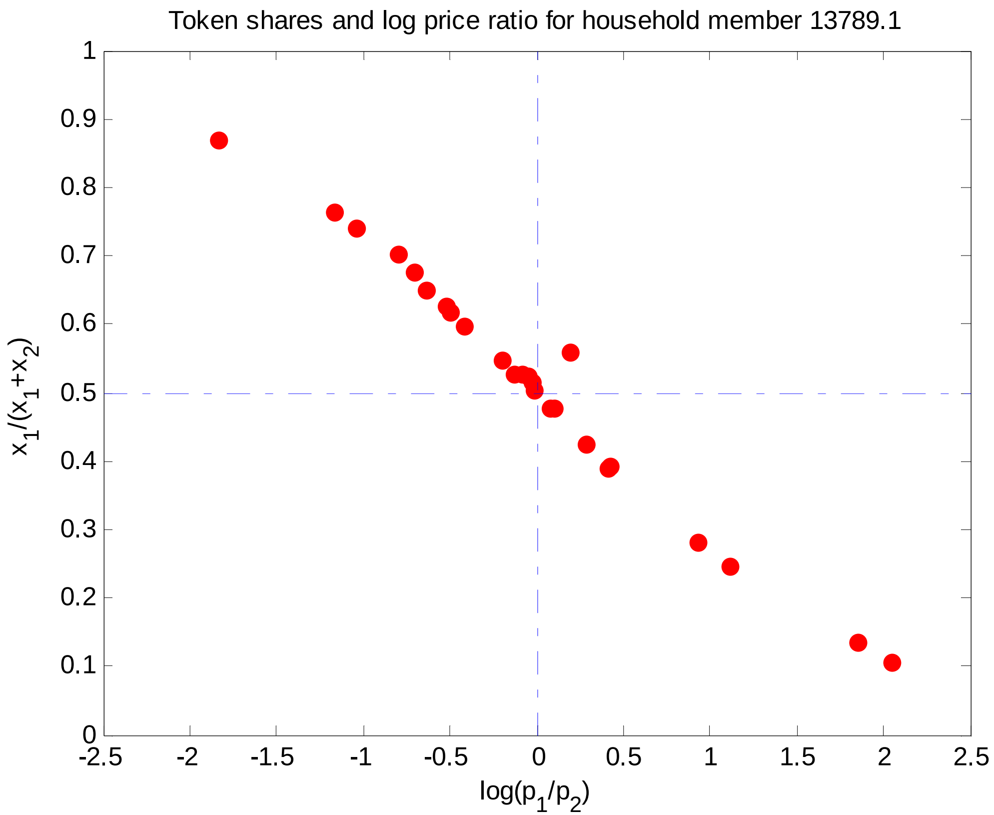


CCEI = 1; Female; 47 years old

Paid work; High education

HH income = €5164

# of HH members = 5

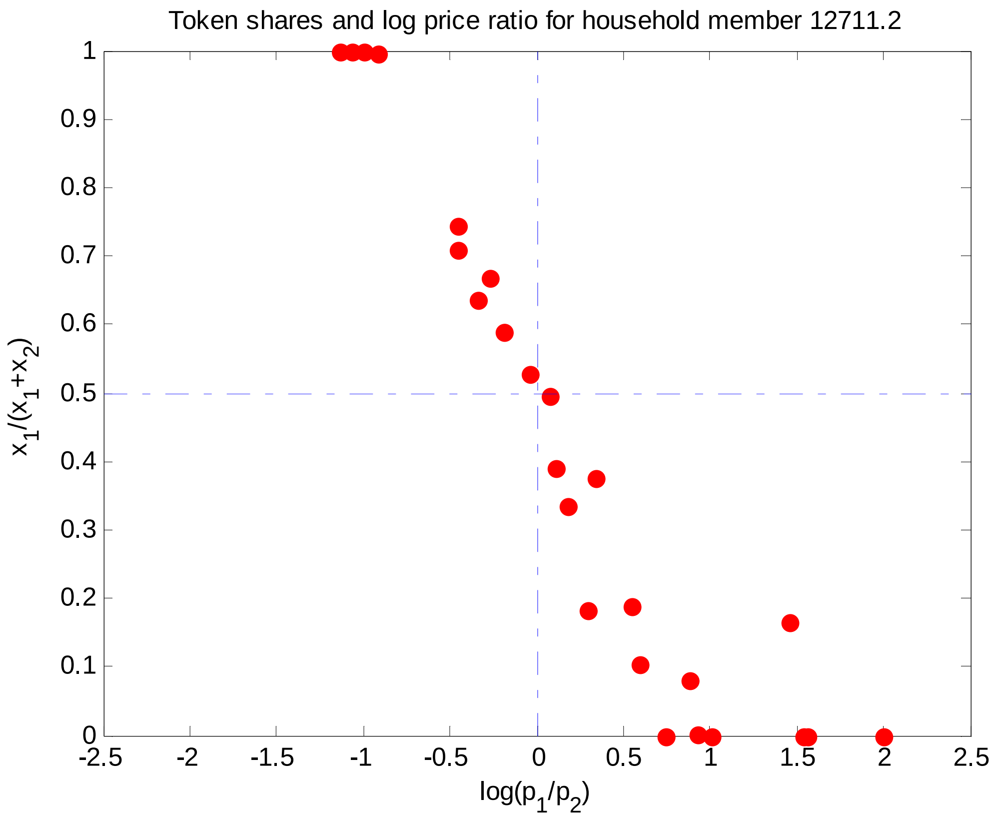


CCEI = 1; Male; 57 years old

Else; Mid education

HH income = €2500

# of HH members = 1

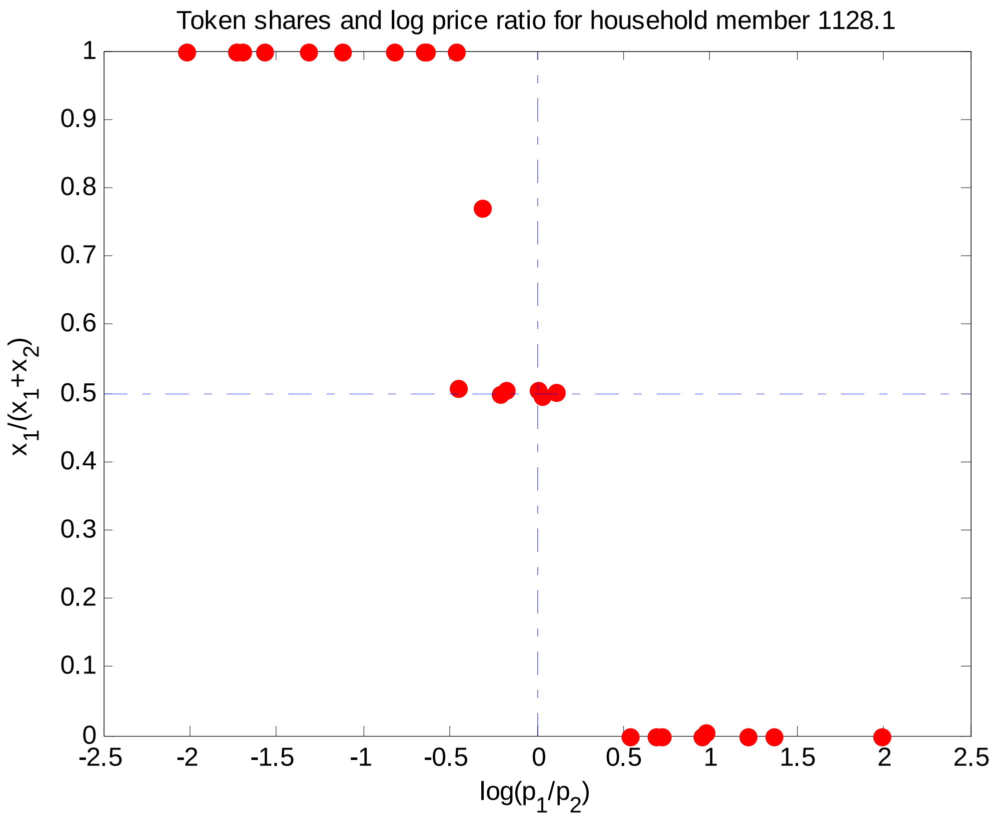


CCEI = 1; Female; 39 years old

Paid work; High education

HH income = €5432

# of HH members = 2

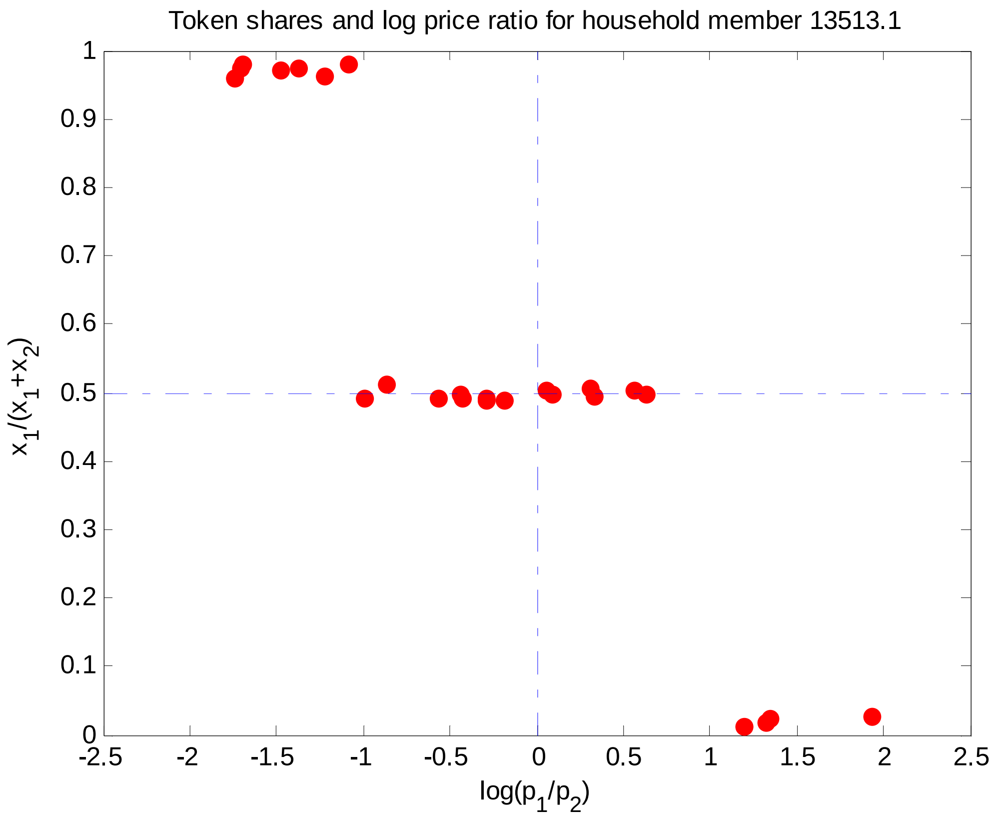


CCEI = 1; Male; 49 years old

Paid work; High education

HH income = €2860

# of HH members = 1



CCEI = 0.978; Male; 42 years old

Paid work; High education

HH income = €4700

# of HH members = 1

Parametric Specification for Preferences

- Because of the patterns of clustering at the safe and boundary portfolios, EUT cannot provide a plausible fit for the data at the individual level.

- Choi et al (2007b) propose a two-parameter utility function based on the loss/disappointment aversion model of Gul (1991), where the safe portfolio is taken to be the reference point.

- Specifically, the utility function over portfolios (x_1, x_2) takes the form: for $\alpha \geq 1$,

$$\min \{\alpha u(x_1) + u(x_2), u(x_1) + \alpha u(x_2)\},$$

where

$$u(x) = \frac{x^{1-\rho}}{1-\rho} \text{ or } -e^{-Ax}.$$

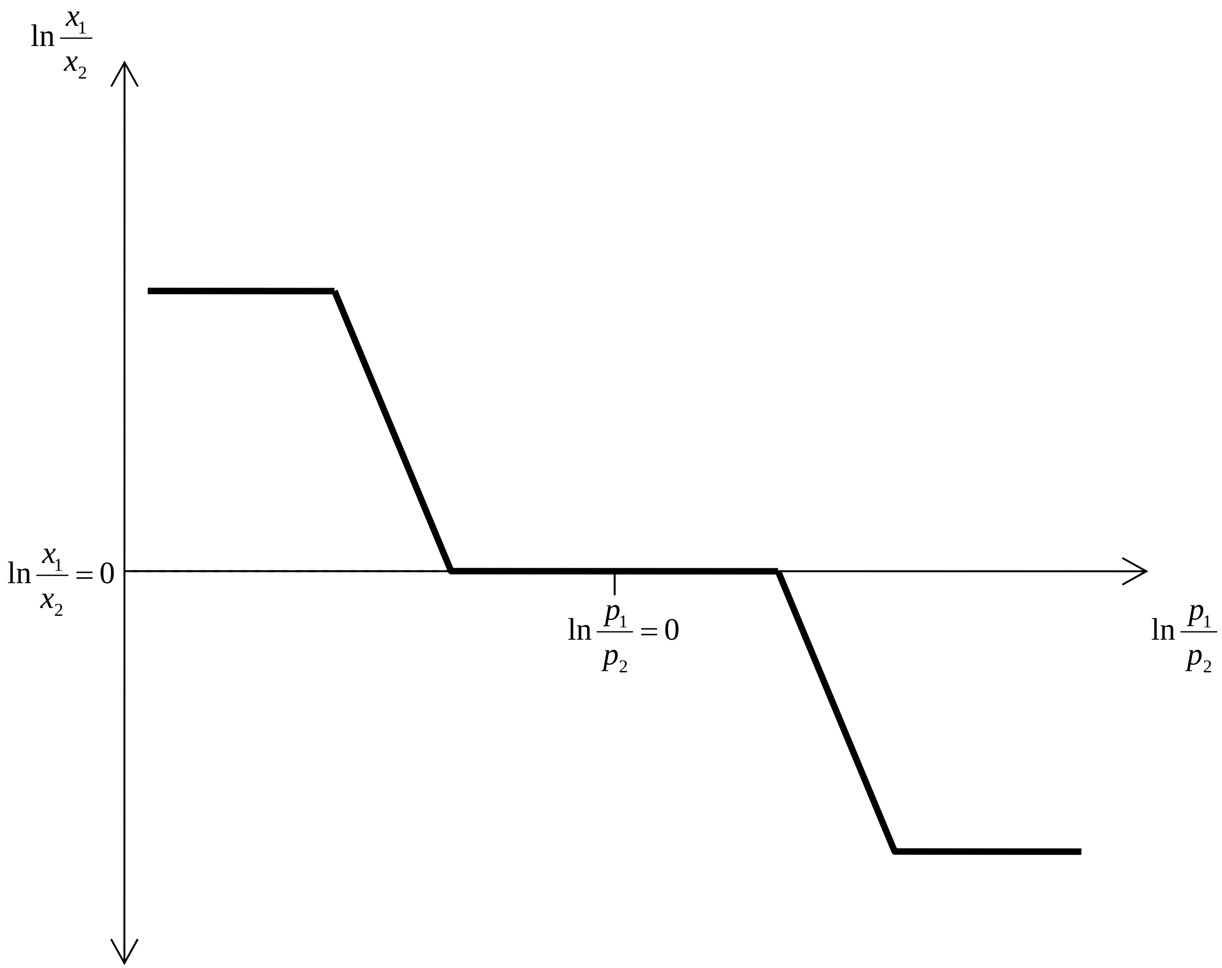
- If $\alpha = 1$, this amounts to the standard EUT representation. If $\alpha > 1$, there is a kink in an indifference curve along 45 degree line.

- Each utility specification represents a different relationship between portfolio choices $\left(\ln\left(\frac{x_1}{x_2}\right) \text{ or } (x_2 - x_2)\right)$ and log price ratios.

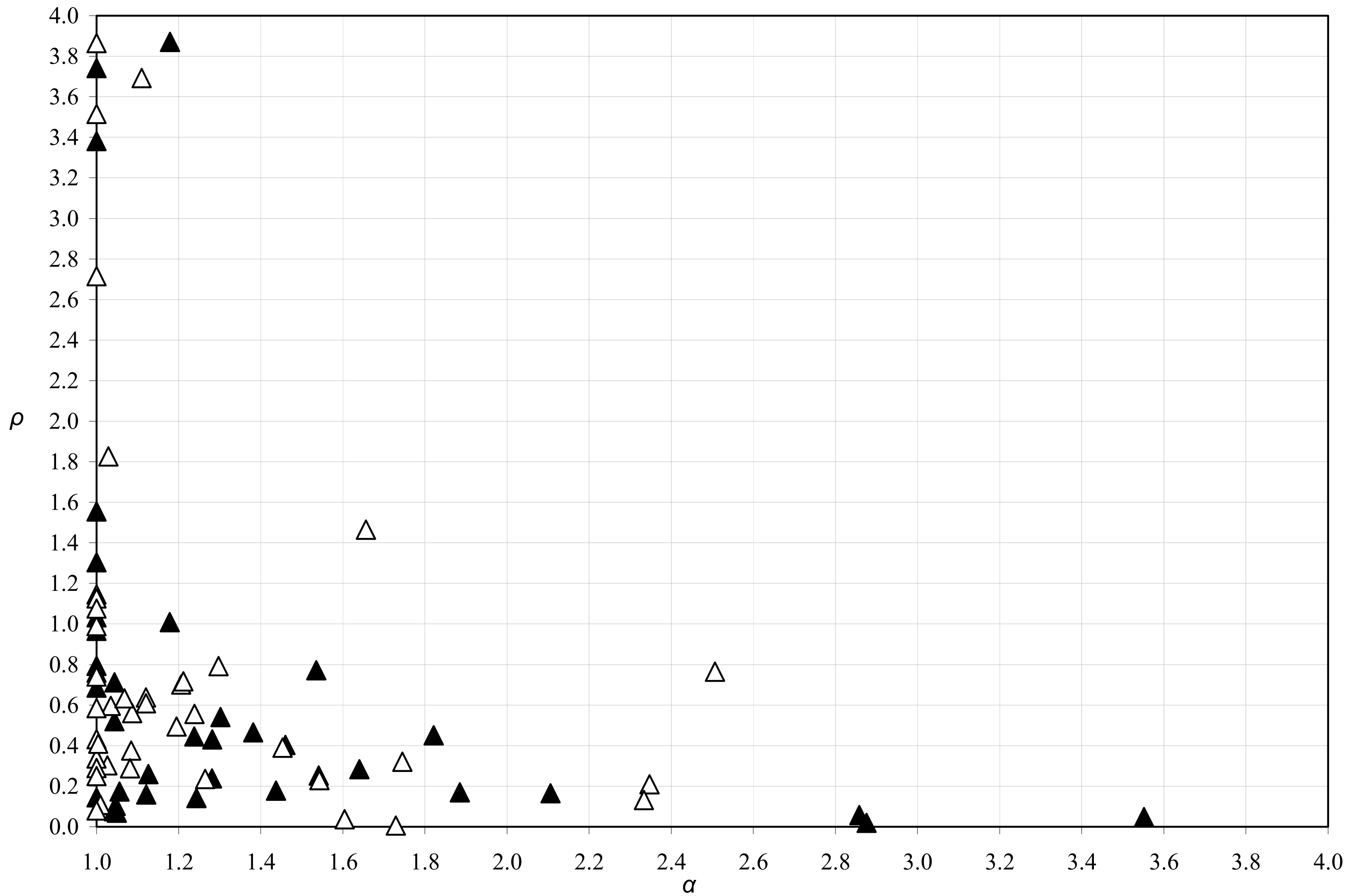
From Constant Relative Risk Aversion

$$\ln\left(\frac{x_1^*}{x_2^*}\right) = \begin{cases} \ln\omega & \text{if} \quad \ln\left(\frac{p_1}{p_2}\right) \geq \ln\alpha - \rho\ln\omega \\ -\frac{1}{\rho}\left[\ln\left(\frac{p_1}{p_2}\right) - \ln\alpha\right] & \text{if} \quad \ln\alpha < \ln\left(\frac{p_1}{p_2}\right) < \ln\alpha - \rho\ln\omega \\ 0 & \text{if} \quad -\ln\alpha \leq \ln\left(\frac{p_1}{p_2}\right) \leq \ln\alpha \\ -\frac{1}{\rho}\left[\ln\left(\frac{p_1}{p_2}\right) + \ln\alpha\right] & \text{if} \quad -\ln\alpha + \rho\ln\omega < \ln\left(\frac{p_1}{p_2}\right) < -\ln\alpha \\ -\ln\omega & \text{if} \quad \ln\left(\frac{p_1}{p_2}\right) \leq -\ln\alpha + \rho\ln\omega \end{cases}$$

An illustration of the relationship between $\ln(p_1/p_2)$ and $\ln(x_1/x_2)$ from CRRA function



Scatterplot of the estimated CRRA parameters $\hat{\alpha}_n$ and $\hat{\rho}_n$



A Univariate Measure of Risk Aversion: Risk Premium

- Consider a gamble which offers $50-50$ odds of winning or losing some fraction $0 < h < 1$ of the wealth level, ω_0.

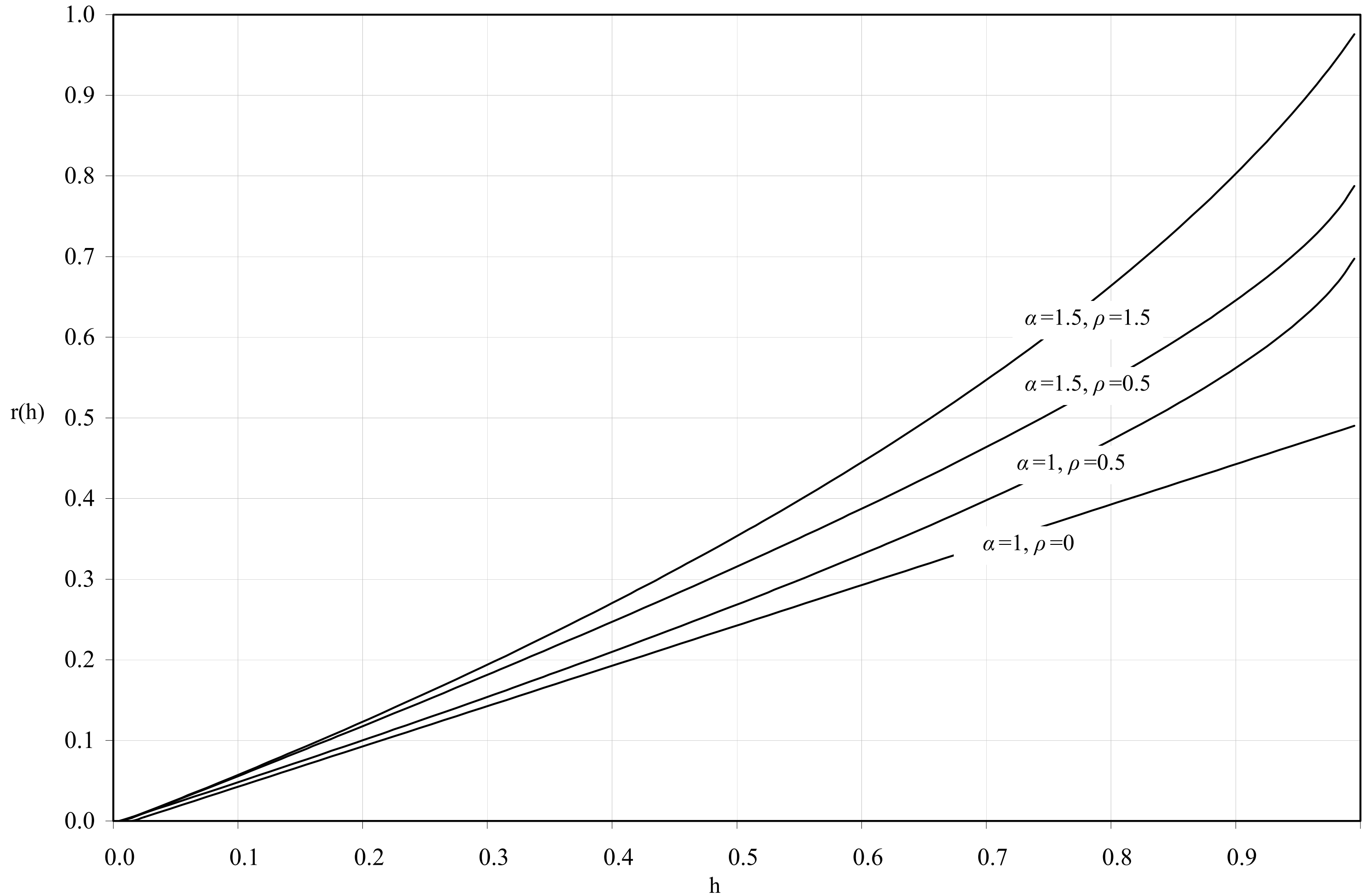
- The risk premium for a gamble h is the fraction of wealth $r(h)$ that satisfies the certainty equivalence relationship:

$$(1+\alpha)\,u\left(\omega_0\left(1-r\left(h\right)\right)\right) = \alpha u\left(\omega_0\left(1-h\right)\right) + u\left(\omega_0\left(1+h\right)\right).$$

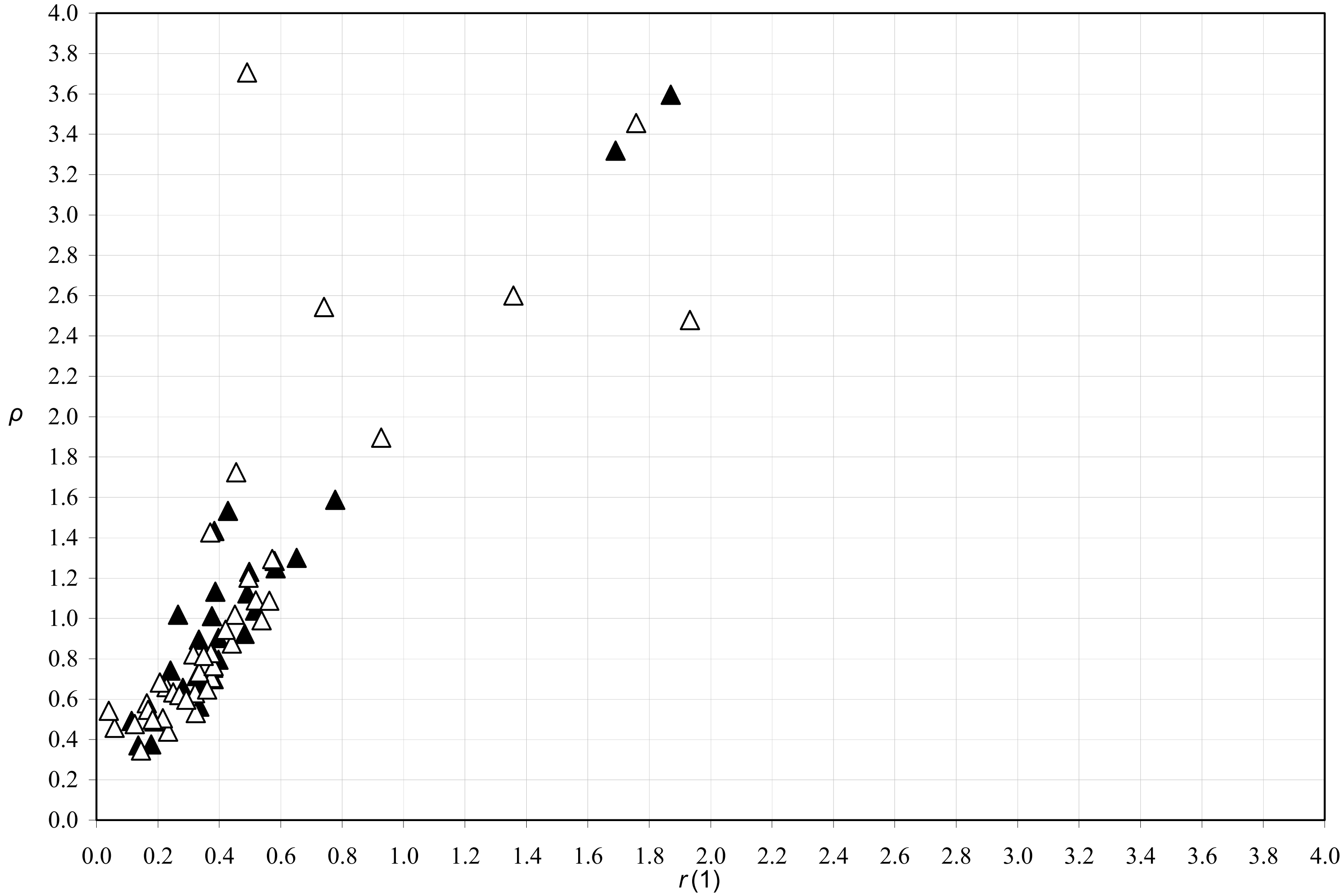
- α has a first-order effect on the risk premium, while ρ has a second-order effect.

$$r\left(h\right) \approx 0 + \frac{\alpha-1}{\alpha+1}h + \rho\frac{2\alpha}{\left(\alpha+1\right)^2}h^2.$$

The risk premium $r(h)$ for different values of α and ρ



Scatterplot of the risk measures $\hat{r}_n$ and values $\hat{\rho}_n$ derived from the simple OLS estimation



Regression analysis

- The simple regression of average token shares for cheaper assets on socioeconomic variables indicates the gender, age, and education effects.

- Because the average token shares contain both effects of risk aversion and loss aversion, we will disentangle those effects using individual-level estimates.

The correlation of average token shares of cheaper asset and subjects' individual characteristics

Variable	All samples	CCEI ≥ 0.95	CCEI ≥ 0.9	CCEI ≥ 0.8
Constant	.632***	.648***	.645***	.644***
	(.015)	(.027)	(.023)	(.019)
Female	-.020***	-.034***	-.026***	-.021***
	(.007)	(.012)	(.010)	(.008)
Age				
Age 35 - 49	-.010	-.030*	-.019	-.011
	(.011)	(.016)	(.014)	(.012)
Age 50 - 64	-.045***	-.066***	-.054***	-.048***
	(.010)	(.016)	(.013)	(.011)
Age ≥ 65	-.052***	-.076***	-.067***	-.054***
	(.014)	(.024)	(.021)	(.018)
Education				
Medium	.018**	.027*	.025**	.018*
	(.008)	(.014)	(.012)	(.009)
High	.015**	.036***	.026**	.016
	(.008)	(.013)	(.012)	(.009)
Income				
EUR 2500 - 3499	-.002	-.007	-.007	-.005
	(.008)	(.016)	(.013)	(.011)
EUR 3500 - 4999	-.003	-.008	-.006	-.008
	(.009)	(.018)	(.014)	(.011)
EUR 5000 +	.013	.006	.003	.009
	(.011)	(.020)	(.016)	(.013)
Occupation				
Paid work	-.006	-.013	-.014	-.009
	(.011)	(.020)	(.017)	(.014)
House work	.011	.003	.006	.007
	(.013)	(.021)	(.020)	(.017)
Others	.003	-.018	-.010	-.006
	(.012)	(.023)	(.020)	(.016)
Household composition				
Partner	.004	.010	.006	.007
	(.009)	(.015)	(.013)	(.010)
# of kids	-.007	-.006	-.004	-.005
	(.003)	(.005)	(.005)	(.004)
R-squared	0.048	0.071	0.054	0.045
# of observations	1182	534	681	901

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Ambiguity Aversion

Ellsberg experiment

- An urn contains 90 balls; 30 balls are red-colored and the colors of 60 balls are either black or white.
  - $\#(R) = 30$, $\#(B) + \#(W) = 60$.
- For decisions over securities (or acts) (x_R, x_B, x_W), the modal response in experiments is
  - $(100, 0, 0) \succ (0, 100, 0)$ and
  - $(100, 0, 100) \prec (0, 100, 100)$.

- Ellsberg experiments provide empirical evidence of ambiguity aversion in the form of the violation of the *sure-thing principle* of Savage (1954).

- Subsequent experimental work has repeatedly confirmed Ellsberg's conjecture.

- A theoretical literature has developed a variety of models consistent with this behavior.

- They all give rise to one of two main specifications with regard to (non-)differentiability.

An overview of theoretical literature

Kinked specification

– Maxmin Expected Utility (MEU) of Gilboa and Schmeidler (1989)

$$\min_{\pi \in \Pi} \int_S u(x_s)\, d\pi(s)$$

evaluates a portfolio by its minimal expected utility over a set of subjective beliefs.

– Choquet Expected Utility (CEU) of Schmeidler (1989)

$$\int_S u(x_s)\, d\nu(s)$$

uses a nonadditive capacity over the state space; the convexity of the capacity captures ambiguity aversion.

– Contraction model of Gajdos et al. (2008)

$$\min_{\pi \in (1-\epsilon)\{s(\Pi)\}+\epsilon\Pi} \int_S u(x_s)\, d\pi(s)$$

incorporates objective information about the set of possible distributions over states.

– α-Maxmin Expected Utility (α-MEU) of Ghirardato et al. (2004)

$$\alpha \min_{\pi \in \Pi} \int_S u(x_s)\, d\pi(s) + (1-\alpha) \max_{\pi \in \Pi} \int_S u(x_s)\, d\pi(s)$$

evaluates a portfolio by a convex combination of its minimal and maximal expected utilities over a set of subjective beliefs.

Smooth specification

– Recursive Expected Utility (REU) of Klibanoff et al. (2005)

$$\int_{\Delta S} \varphi \left(\int_S u(x_s)\, d\pi(s) \right) d\mu(\pi)$$

assumes that the agent has a subjective distribution μ over the possible (first-order) beliefs π over states.

– Unsure of which of the possible first-order beliefs actually governs the states, the agent transforms the expected utilities for all prior beliefs π by a (concave) function φ before integrating these utilities with respect to his second-order distribution μ

– A distinct feature of this specification is that it is differentiable everywhere.

A variant of Ellsberg experiment

- Halevy (2007) consider an extension of Ellsberg experiment to compare the performance of competing theories, with regard to (i) attitudes toward ambiguity; and (ii) the reduction of compound lotters (ROCL).

- There are four urns, each of which contains 10 balls (red or black).
  - *Urn 1*: 5 red & 5 black; *Urn 2*: unknown composition;
  - *Urn 3*: # of red balls is uniformly distributed between 0 and 10;
  - *Urn 4*: either 10 red or 10 black balls with equal probability.

- Each subject was asked to bet on a color in each urn. Then, a reservation price for each urn was elicited.

- Different models generate different predictions about how the valuations of urns will be ordered.

- For each subject, there will be a unique model that predicts the subject's reservation values.

	ROCL	
Ambiguity Neutral	No	Yes
No	113	1
Yes	6	22

Limitations

- Ellsberg-type experiments generate just enough data to *classify* subjects' preferences, but not enough to *violate* any of theories of interests.

- Thus, such experiments are usually incapable of testing the predictive power of theories or measuring the degrees of ambiguity aversion.

- The exposure to ambiguity is fixed by the experimenter, which also limits in understanding forms of ambiguity aversion.

A portfolio choice experiment

- Ahn et al (2010) utilize the convex budget set design in the context of decision making under ambiguity.

- There are three states of nature, $s = 1, 2, 3$, whose probabilities are only known as follows:

  - $\pi_2 = 1/3$ and $\pi_1 + \pi_3 = 2/3$.

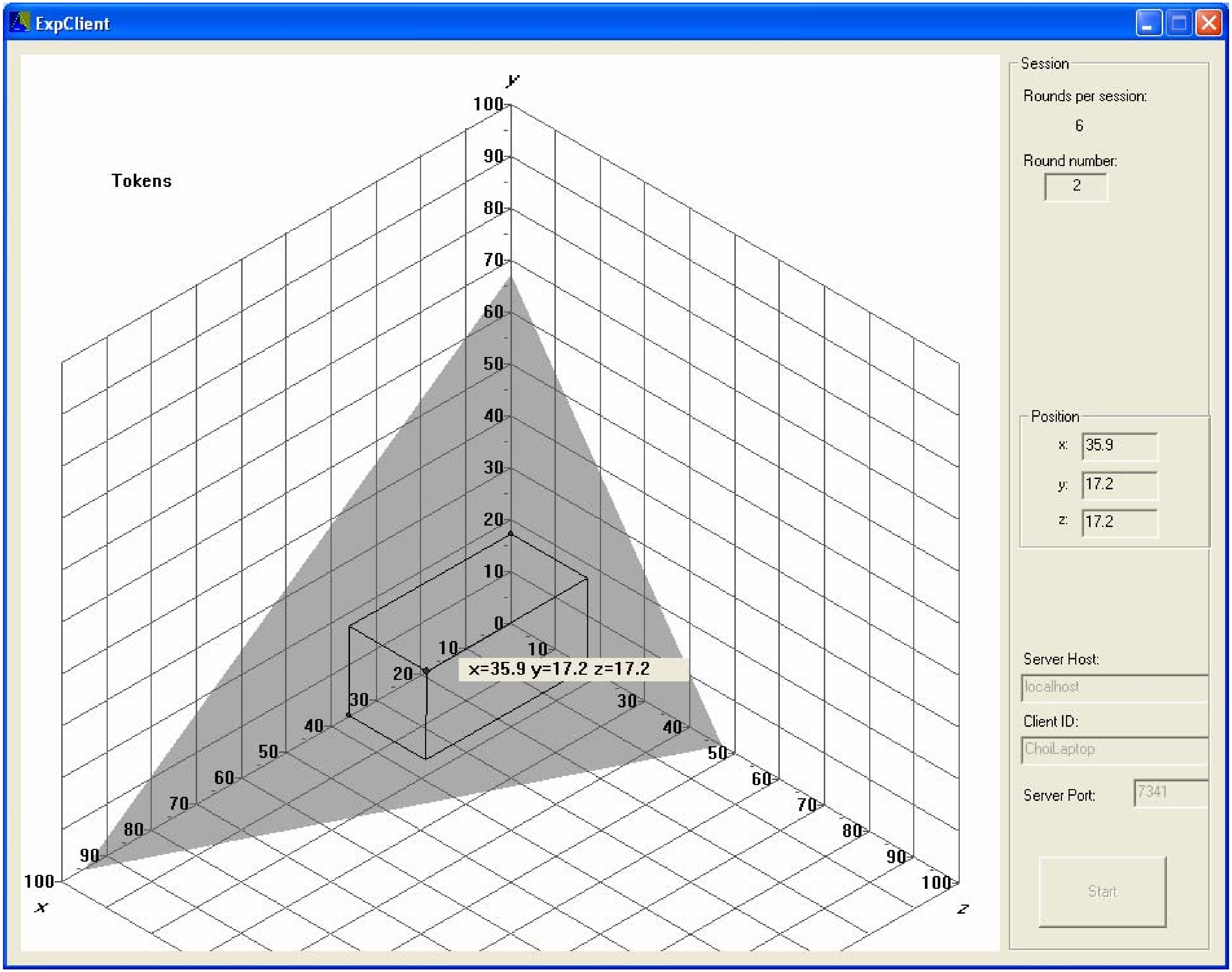
- There are three Arrow securities corresponding to each of the three states, whose prices are given by $p = (p_1, p_2, p_3)$.

- Subjects are allowed to choose any non-negative portfolio $x = (x_1, x_2, x_3)$ satisfying the budget constraint

$$p \cdot x = 1.$$

- Unlike Ellsberg-type experiments, subjects can reduce their exposure to ambiguity by choosing particular portfolios.
  - When $x_1 = x_3$, there is no effective exposure to ambiguity.

- By introducing enough variations in prices, we can detect how prevalent such behavior is in the experimental data.


ExpClient
Tokens
y
x
z
x=35.9 y=17.2 z=17.2
Session
Rounds per session:
6
Round number:
2
Position
x: 35.9
y: 17.2
z: 17.2
Server Host:
localhost
Client ID:
ChoiLaptop
Server Port:
7341
Start

Aggregate behavior

- An analysis of aggregate behavior reveals the stronger tendency to equalize between two ambiguous assets, x_1 and x_3.

- We compare the densities of relative demand between two ambiguous assets, $x_1/(x_1 + x_3)$, and that between one risky and one ambiguous assets, $x_1/(x_1 + x_2)$.
  - Choosing x_1 closer to x_3 reduces exposure to ambiguity;
  - Risk aversion will lead to a symmetric response across the three states.

Figure 1: The distribution of relative demands
(Kernel density estimates)

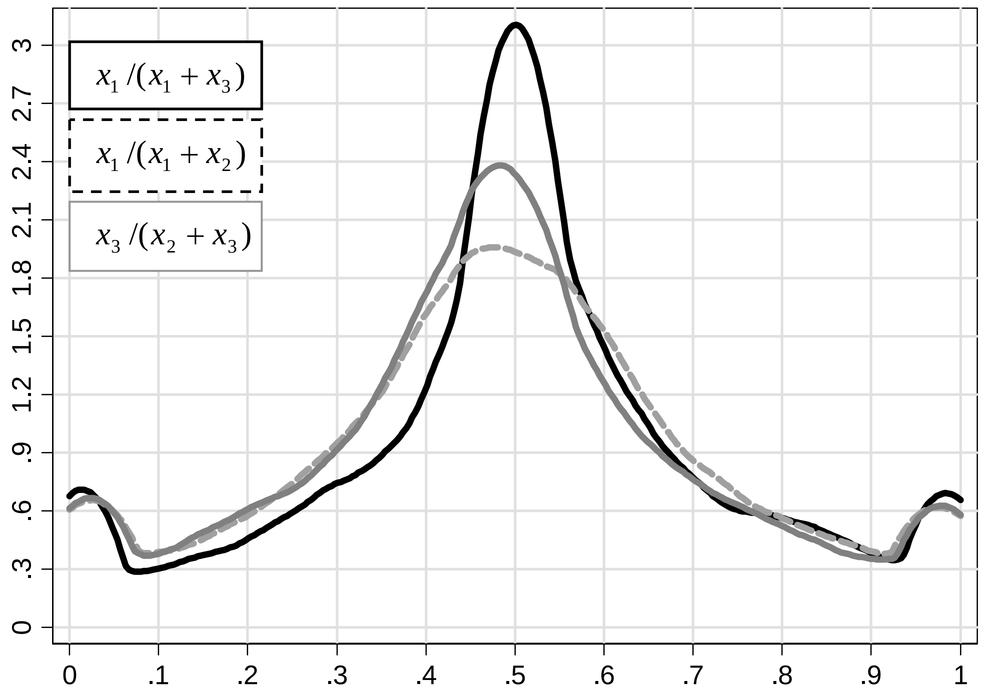
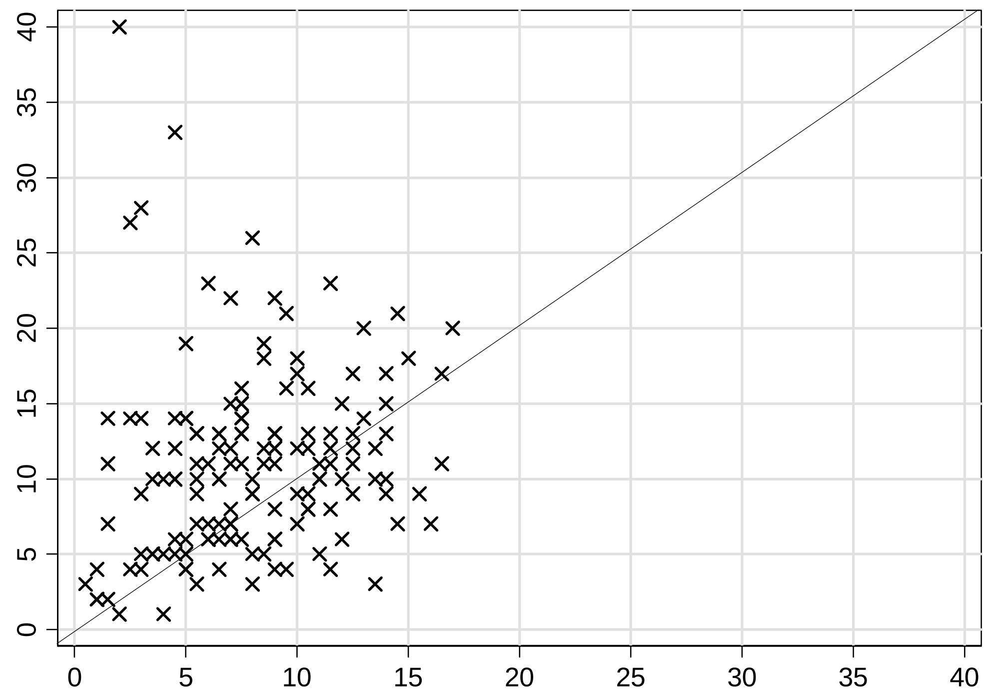


Figure 2: The number of diagonal portfolios by subject

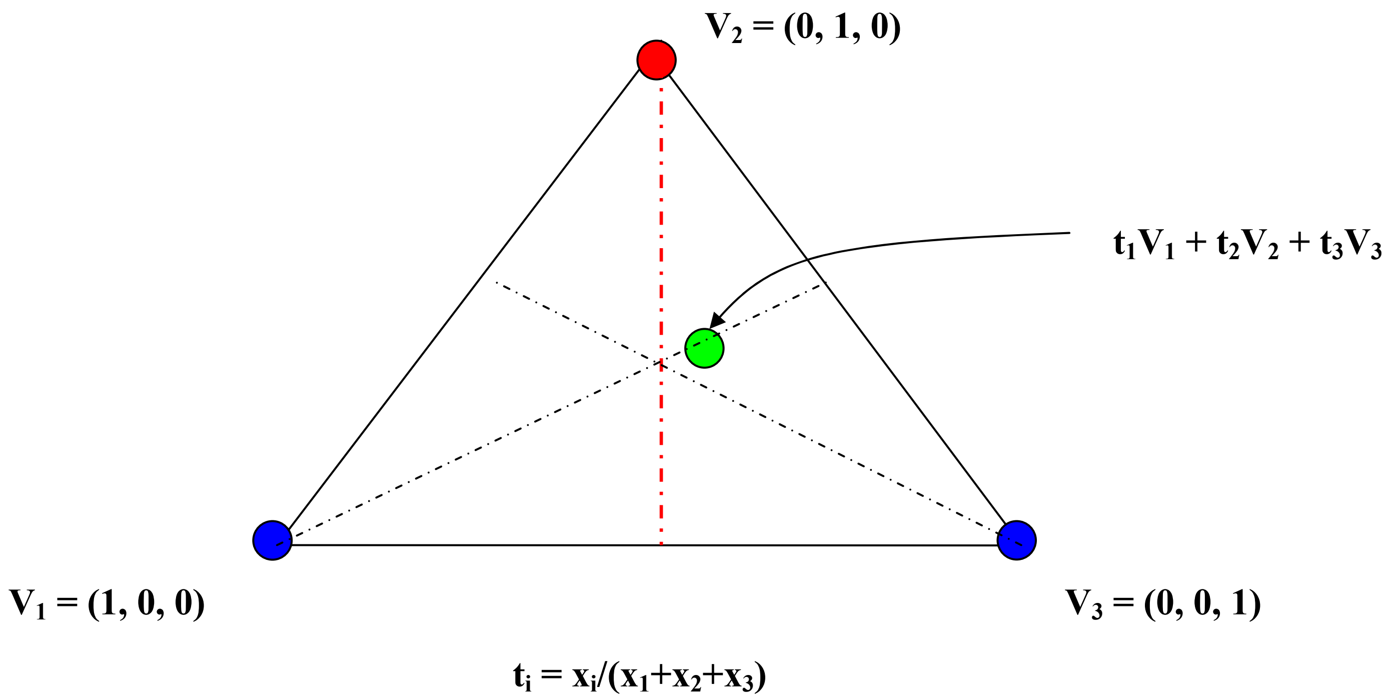


Vertical axis: the number of unambiguous portfolios for which $0.45 \leq x_1/(x_1+x_3) \leq 0.55$. Horizontal axis: the average number of portfolios for which $x_1/(x_1+x_2)$ or $x_2/(x_2+x_3)$ lies between these bounds. The numbers are calculated after screening out safe and boundary portfolios using a narrow confidence interval of two tokens.

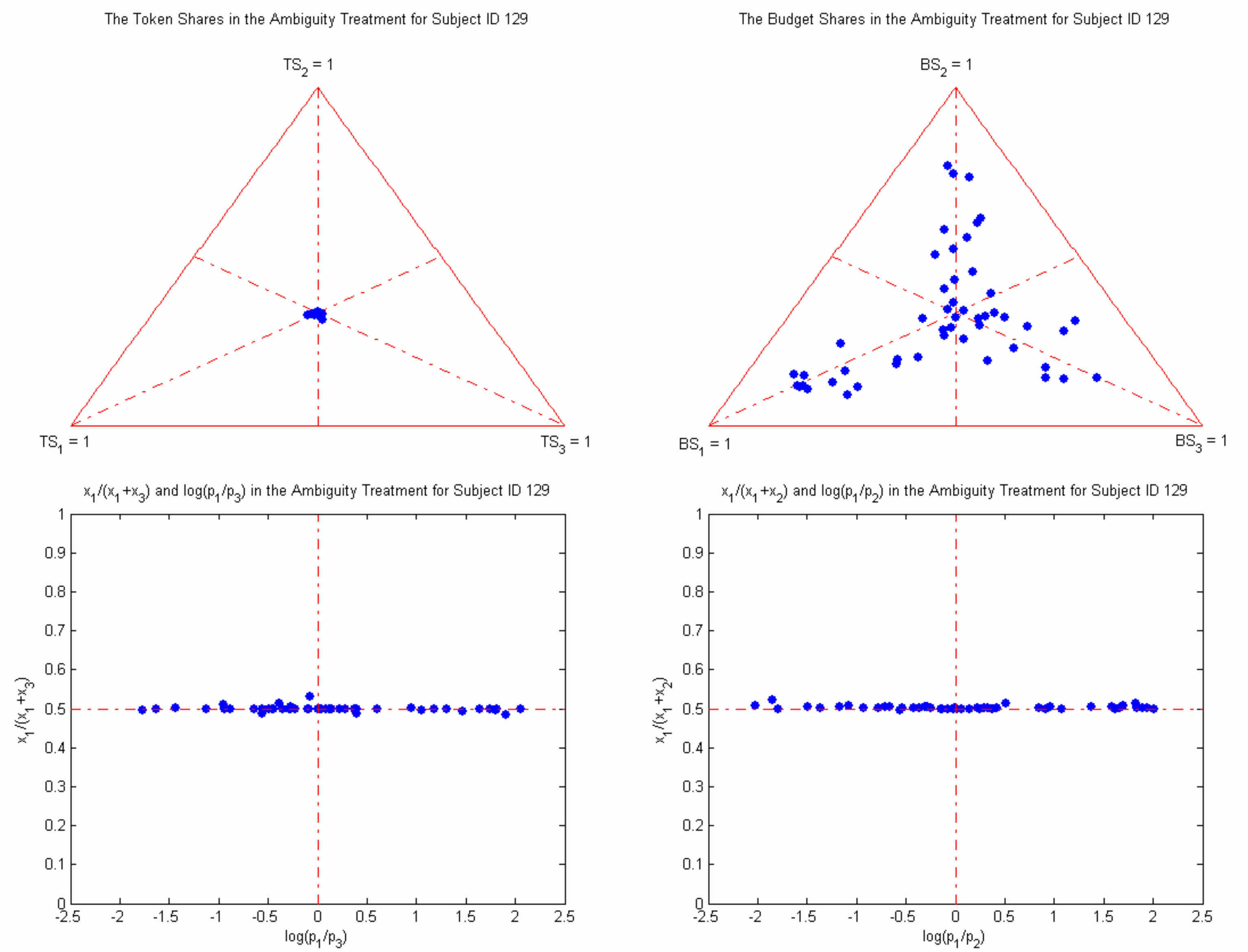
Individual behavior

- A casual inspection of scatterplots provides some hints of the degree of individual heterogeneity with respect to attitudes toward risk and ambiguity.
  - triangle simplexes for token shares, $x_i/(x_1 + x_2 + x_3)$, and expenditure shares, $p_i x_i$, for $i = 1, 2, 3$;
  - the relation between log price ratio and relative demand.

Token Share Simplex



Subject ID 129



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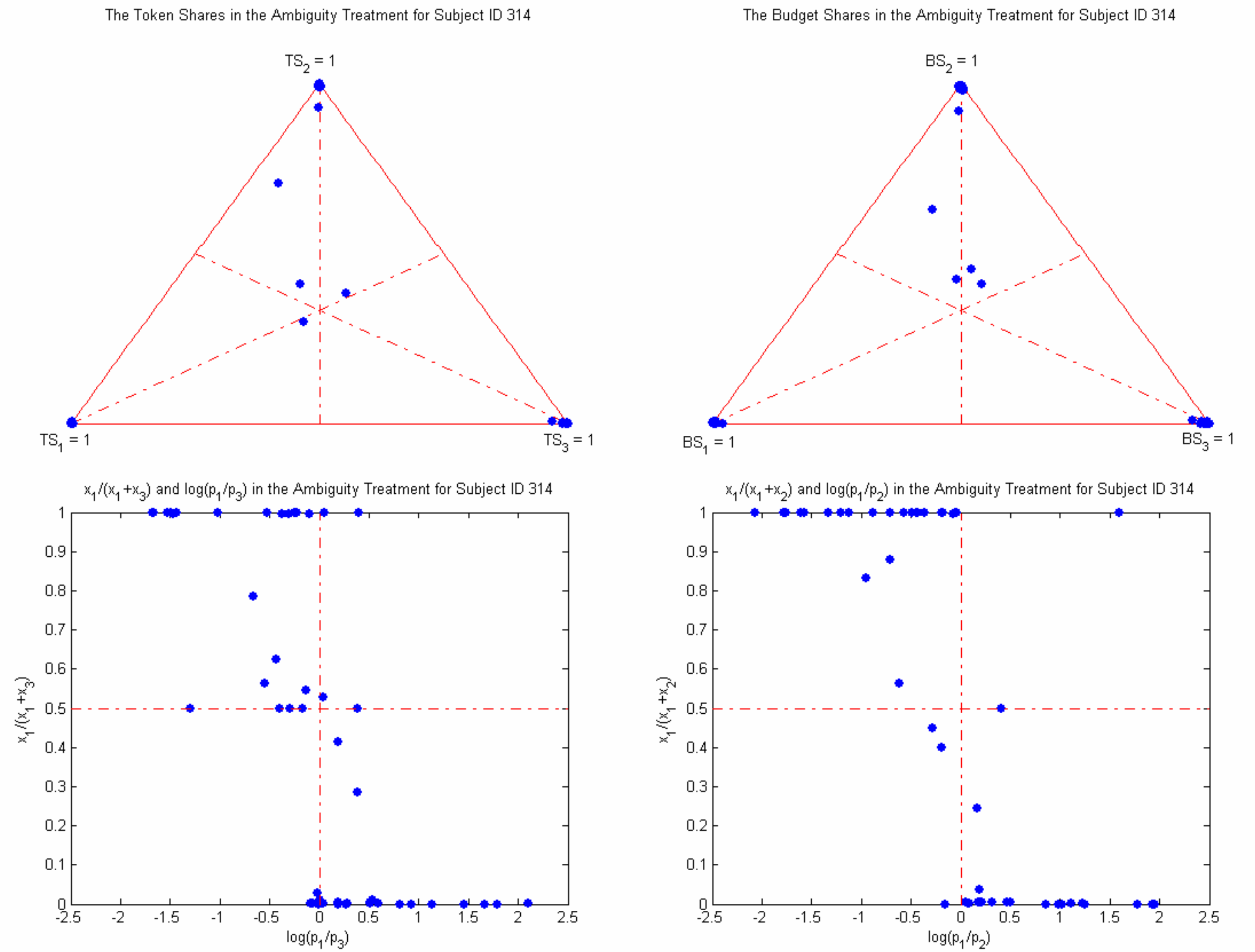
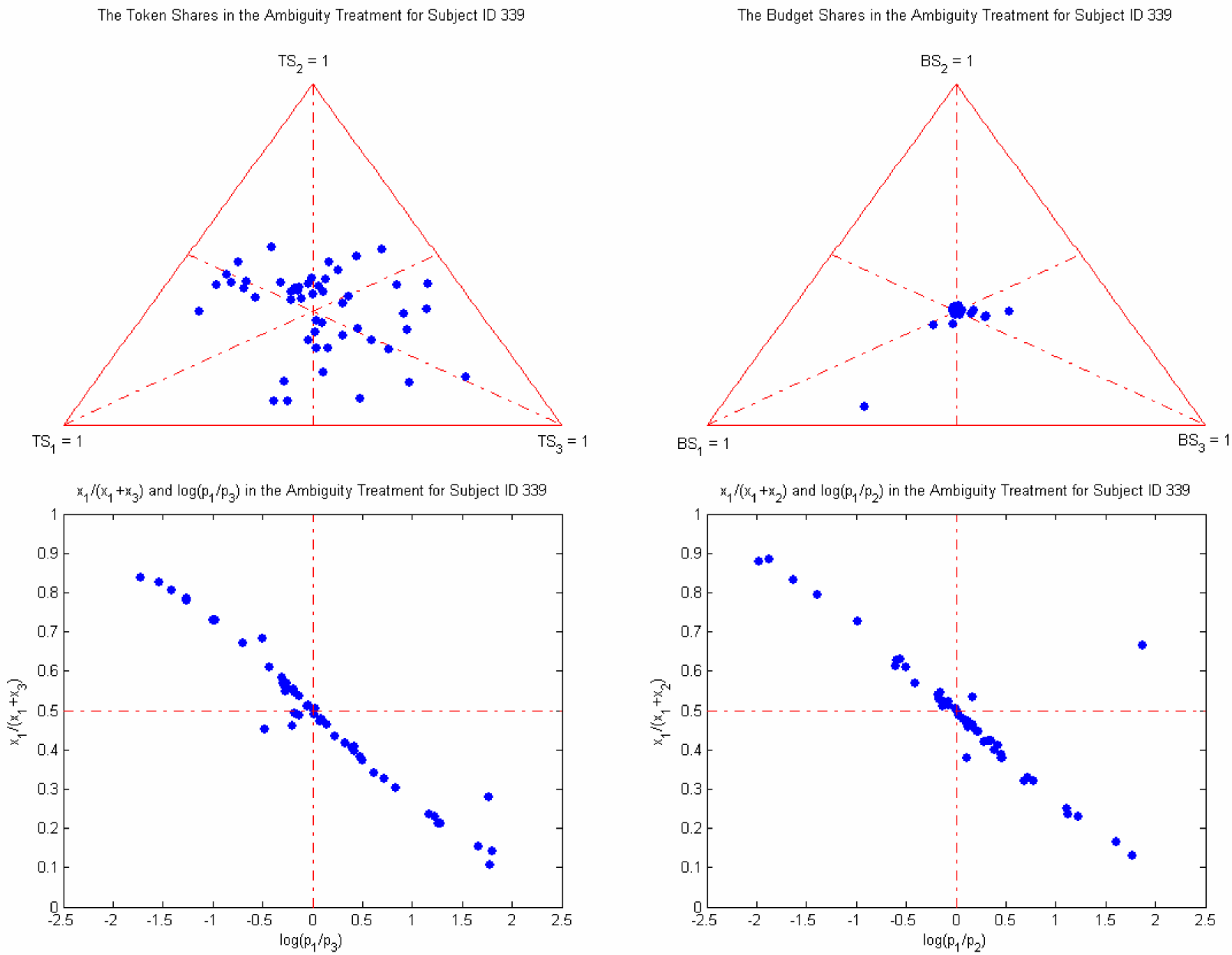


Subject ID 339



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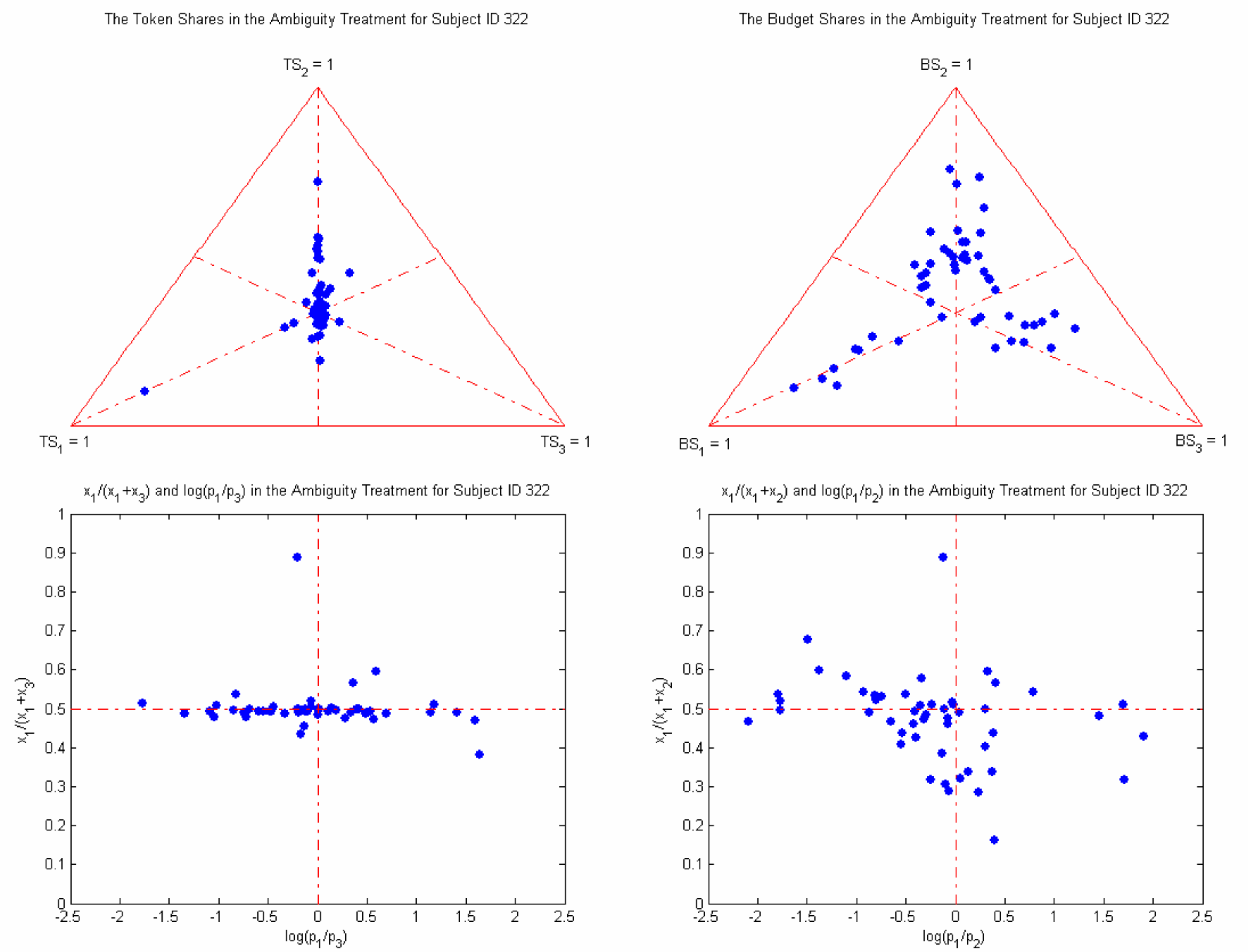

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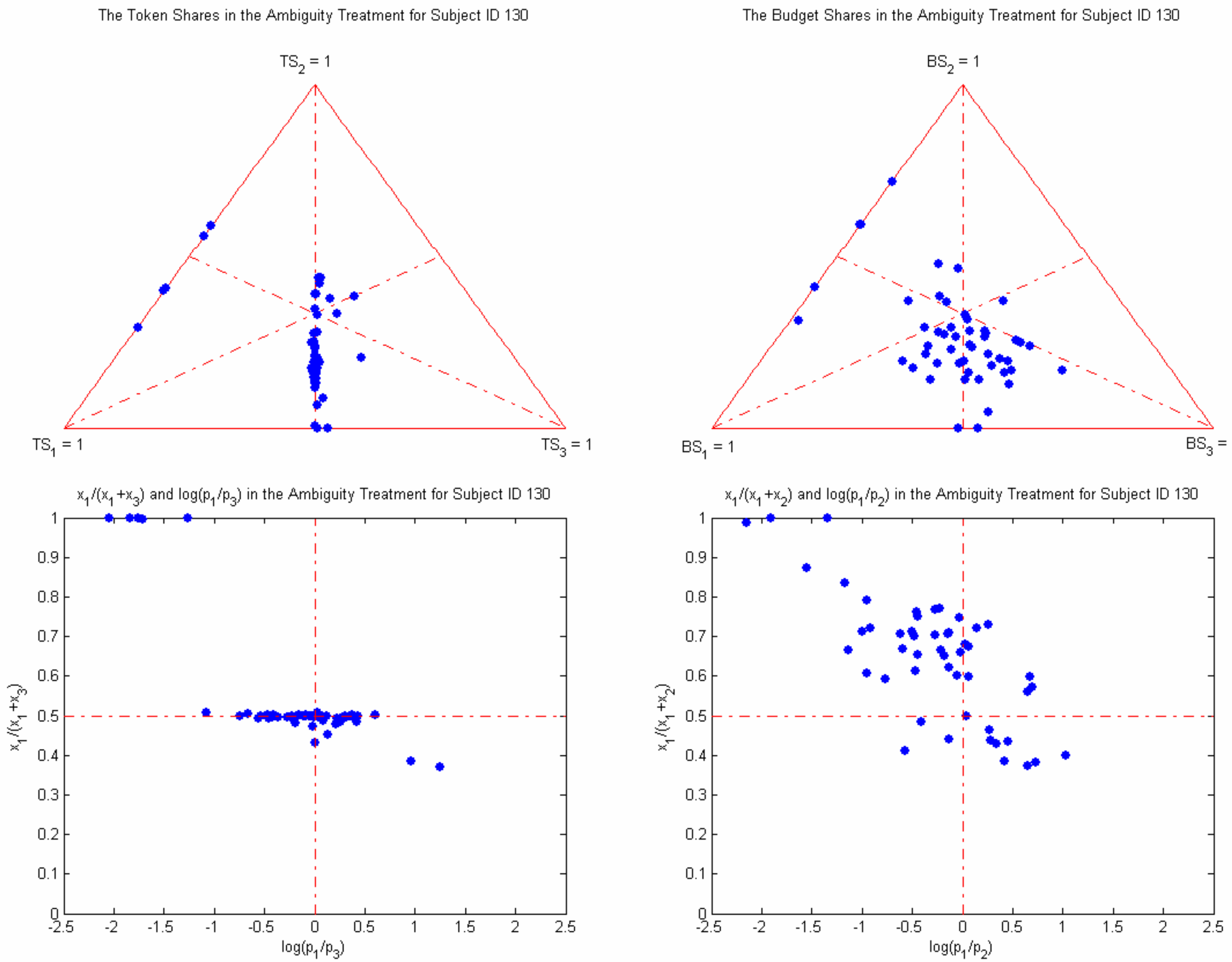

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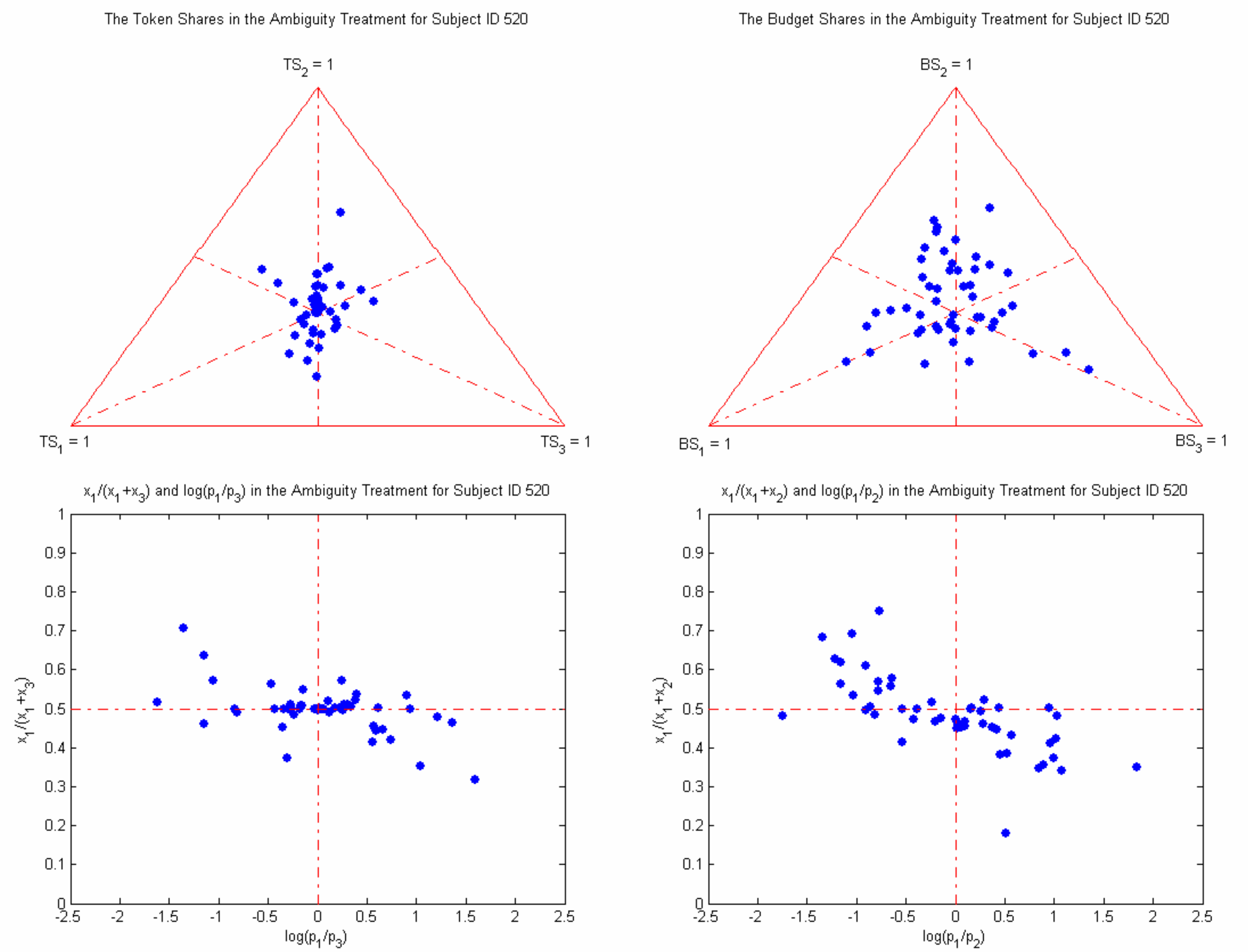
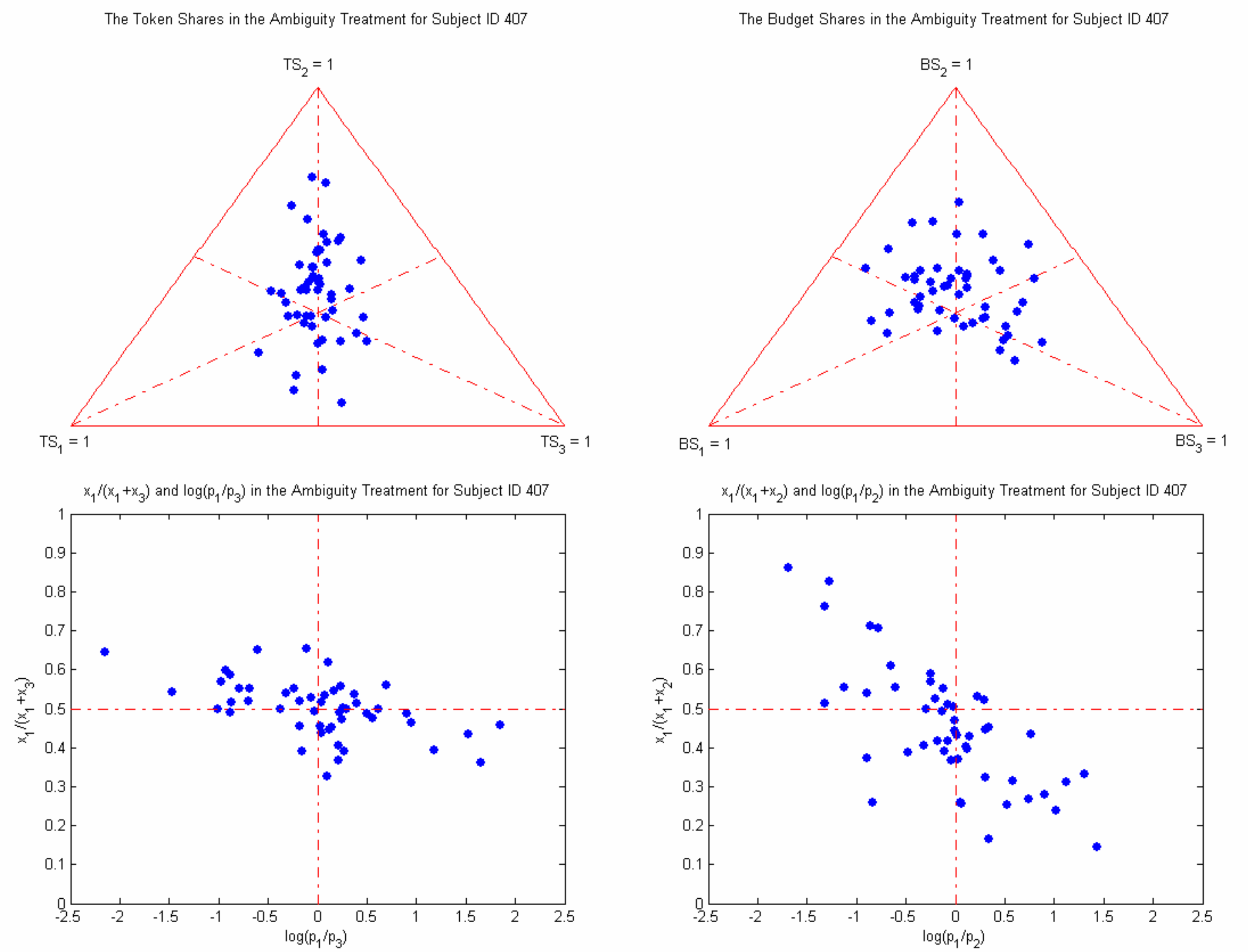


Subject ID 407



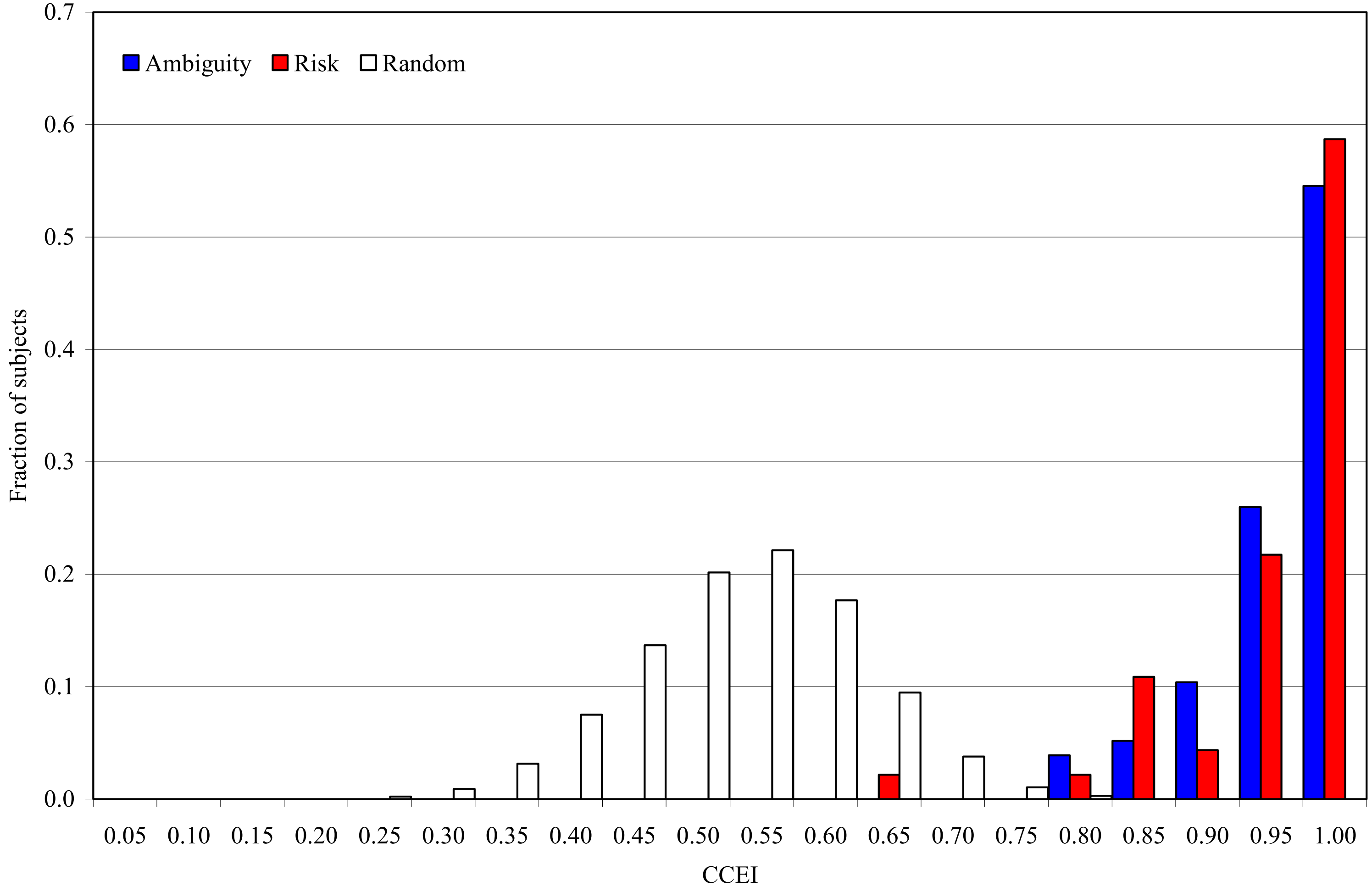
Revealed Preference

- Behavior exhibiting ambiguity aversion may be perfectly rational, in the sense of being consistent with a complete and transitive preference ordering.

- In practice, however, one might suspect that individuals exhibiting ambiguity aversion are more likely to violate the axioms of rational behavior.

- For the purpose of comparison, we borrow data in a concurrent experiment (Choi, Fisman, Gale and Kariv, in progress) that is identical except for $\pi_1 = \pi_3 = 1/3$.

The distribution of CCEI scores



Parametric specifications

- The near consistency of subjects' choices suggests that there exists a well-behaved utility function that rationalizes most of the data.

- Because of the different forms of ambiguity aversion, we consider two distinct specifications of ambiguity attitudes: *kinked* vs. *smooth*.

- Throughout, we assume that cardinal utility over monetary payoffs exhibits constant absolute risk aversion (CARA):

$$u(y;\rho) = -\frac{\exp(-\rho y)}{\rho}.$$

Kinked specification

- We consider the following functional form:

$$\begin{aligned} U_K(x;\alpha,\rho) &= \alpha\left\{\frac{2}{3}u\left(\min\{x_1,x_3\};\rho\right)+\frac{1}{3}u\left(x_2;\rho\right)\right\} \\ &\quad+(1-\alpha)\left\{\frac{2}{3}u\left(\max\{x_1,x_3\};\rho\right)+\frac{1}{3}u\left(x_2;\rho\right)\right\}. \end{aligned}$$

- A distinct feature is its dependence on the minimal and maximal allocations between two ambiguous assets, which induces indifference curves that are kinked at points where $x_1 = x_3$.

- A variety of models, such as MEU and CEU, we considered can lead to this specification.

Smooth specification.

- The smooth specification we consider is given by

$$U_S(x;\alpha,\rho) = \int_0^{\frac{2}{3}} -\frac{1}{\alpha}\exp\left[-\alpha\left\{\begin{array}{c}\pi_1 u(x_1;\rho)+\frac{1}{3}u(x_2;\rho)\\ +\left(\frac{2}{3}-\pi_1\right)u(x_3;\rho)\end{array}\right\}\right]d\pi_1$$

- This specification is differentiable everywhere and involves two iterated integrals: (i) the expected value of cardinal utility of portfolio given π_1; and (ii) the integration of these expected utilities with respect to uniform distribution for π_1.

- One crucial feature is its reliance on a cardinal utility and thus is not independent of a change in the scale of utility.

Generalized kinked specification

- In addition to the tendency of equating the demand between x_1 and x_3, there is similar (although weaker) tendency between the risky and one ambiguous assets, x_1 and x_2 or x_2 and x_3.

- The tendency to equate the demand for all pairs of assets suggest a loss aversion.

- To disentangle the effects of ambiguity aversion and loss aversion, we make use of the RDU model proposed by Quiggin (1982).

- Let $x_{\text{max}} = \max\{x_1, x_3\}$ and $x_{\text{min}} = \min\{x_1, x_3\}$.

I. $x_2 \leq x_{\text{min}}$,

$$\beta_1 u(x_2) + (\beta_2 - \beta_1) u(x_{\text{min}}) + (1 - \beta_2) u(x_{\text{max}});$$

II. $x_{\text{min}} \leq x_2 \leq x_{\text{max}}$,

$$\beta_3 u(x_{\text{min}}) + (\beta_2 - \beta_3) u(x_2) + (1 - \beta_2) u(x_{\text{max}});$$

III. $x_{\text{max}} \leq x_2$,

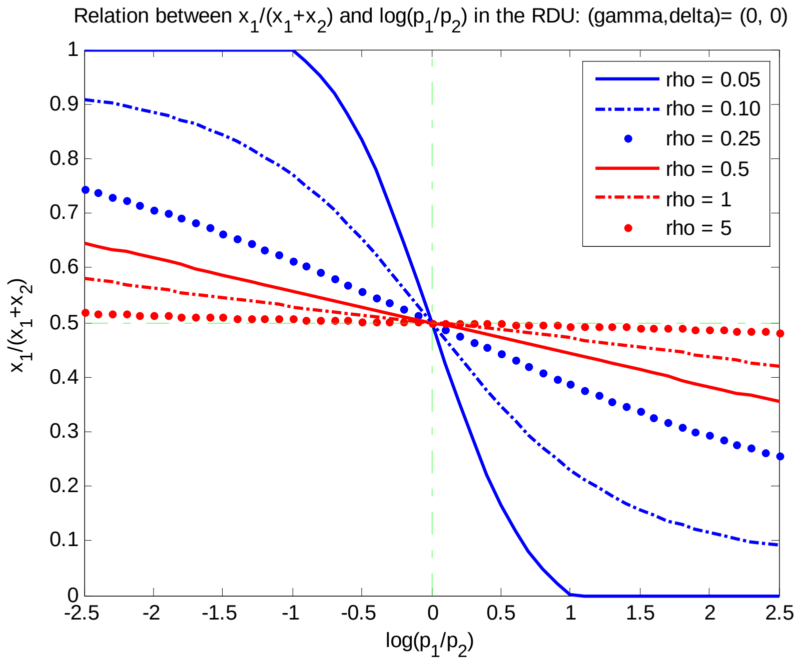
$$\beta_3 u(x_{\text{min}}) + (\beta_4 - \beta_3) u(x_{\text{max}}) + (1 - \beta_4) u(x_2),$$

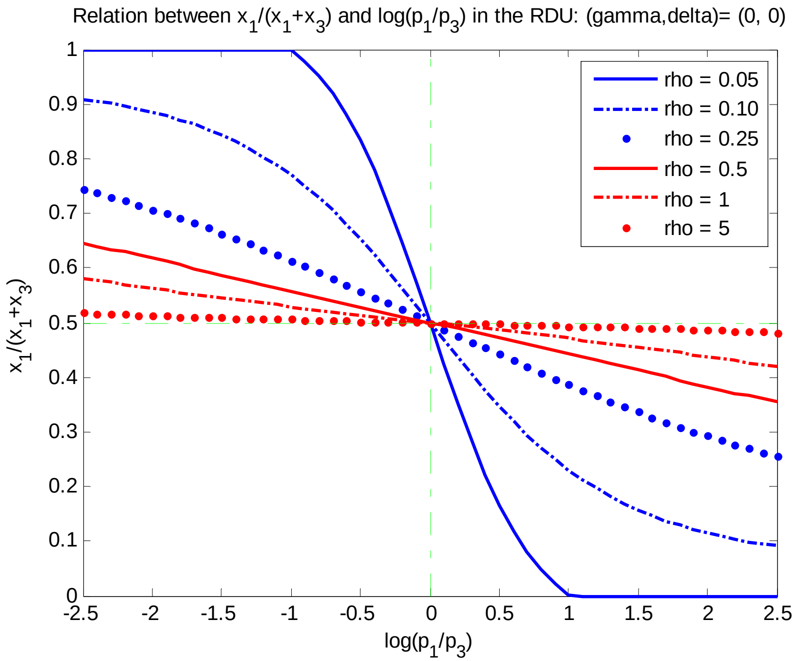
where $\beta_1 = \frac{1}{3} + \gamma$, $\beta_2 = \frac{2}{3} + \gamma + \delta$, $\beta_3 = \frac{1}{3} + \gamma + \delta$, and $\beta_4 = \frac{2}{3} + \gamma$.

- This specification is general enough to incorporate:
  - the kinked specification when $\delta \geq 0$ and $\gamma = 0$;
  - the loss/disappointment aversion model of Gul (1991) when $\delta = 0$ and $\gamma \geq 0$;
  - the standard SEU specification when $\delta = 0$ and $\gamma = 0$.
- Thus, δ measures ambiguity aversion and γ is a measure of loss aversion.

Simulation of Rank Dependent Utility Model

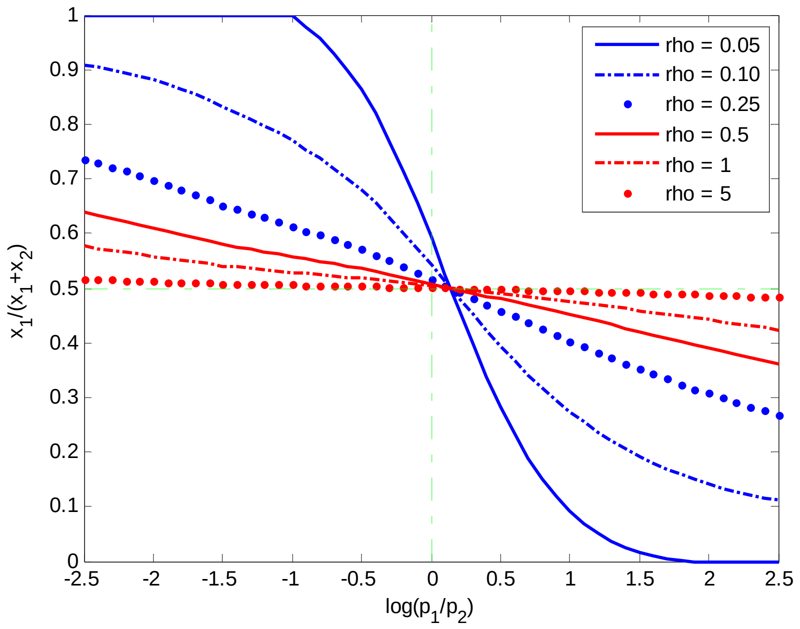
Case 1 (loss-neutral and ambiguity-neutral): $\gamma = 0$, $\delta = 0$



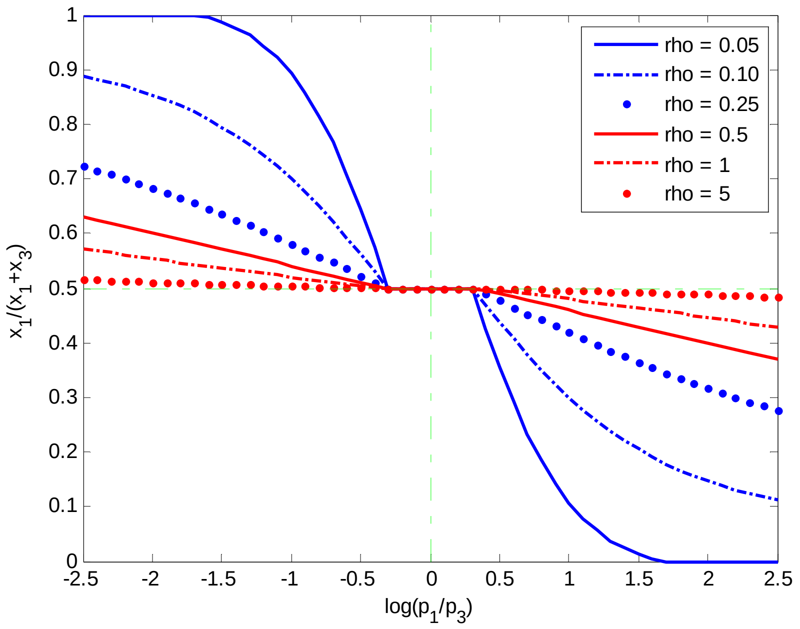


Case 2-1 (loss-neutral & ambiguity-averse): γ = 0, δ = 0.05

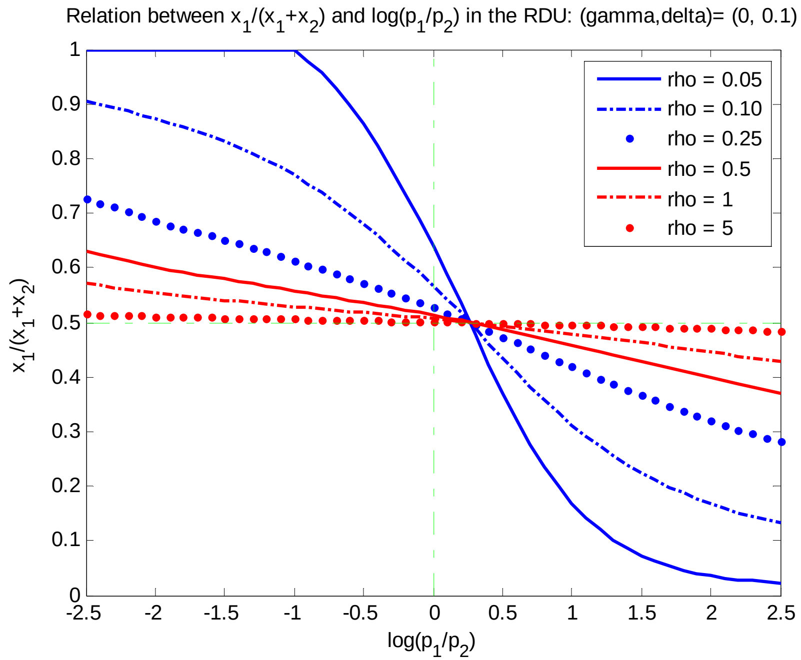
Relation between $x_1/(x_1+x_2)$ and $\log(p_1/p_2)$ in the RDU: (gamma,delta)= (0, 0.05)

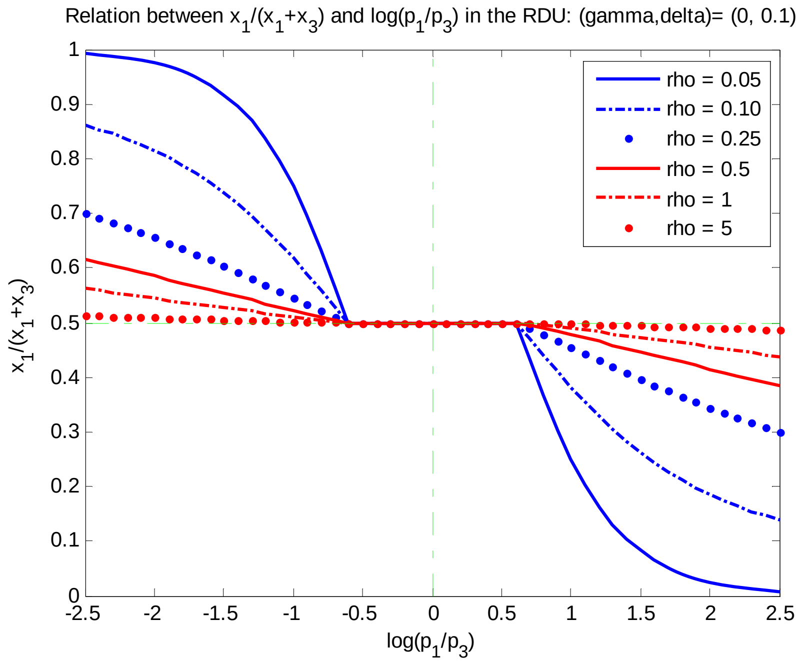


Relation between $x_1/(x_1+x_3)$ and $\log(p_1/p_3)$ in the RDU: (gamma,delta)= (0, 0.05)

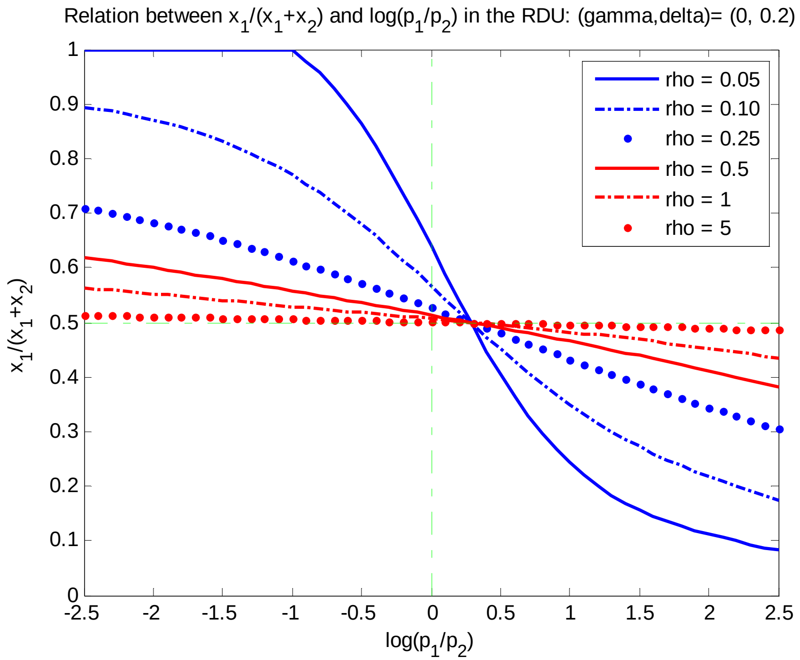


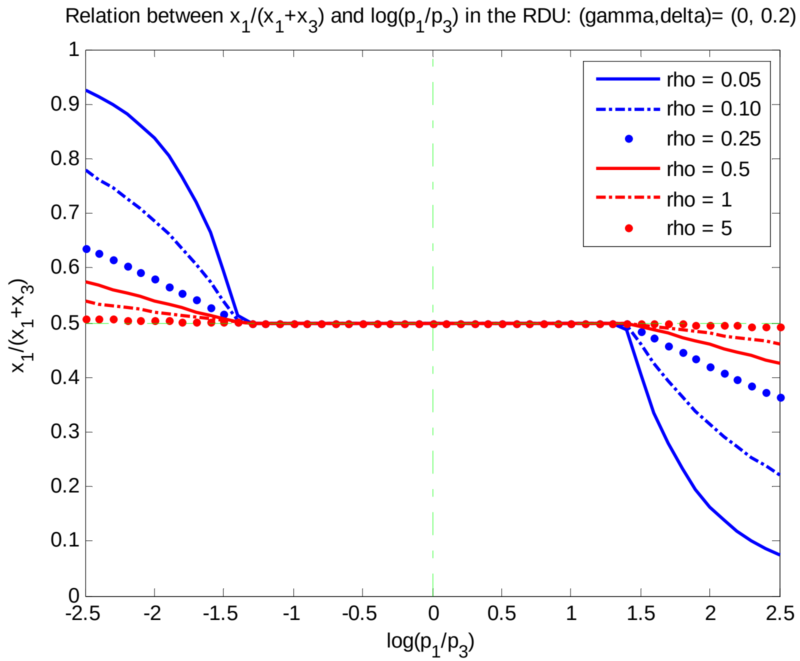
Case 2-2 (loss-neutral & ambiguity-averse): $\gamma = 0$, $\delta = 0.1$



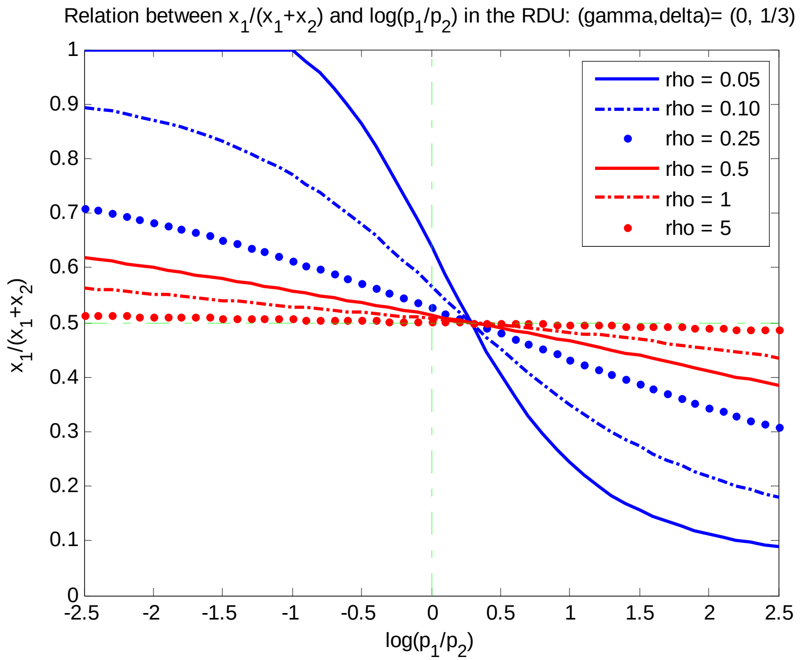


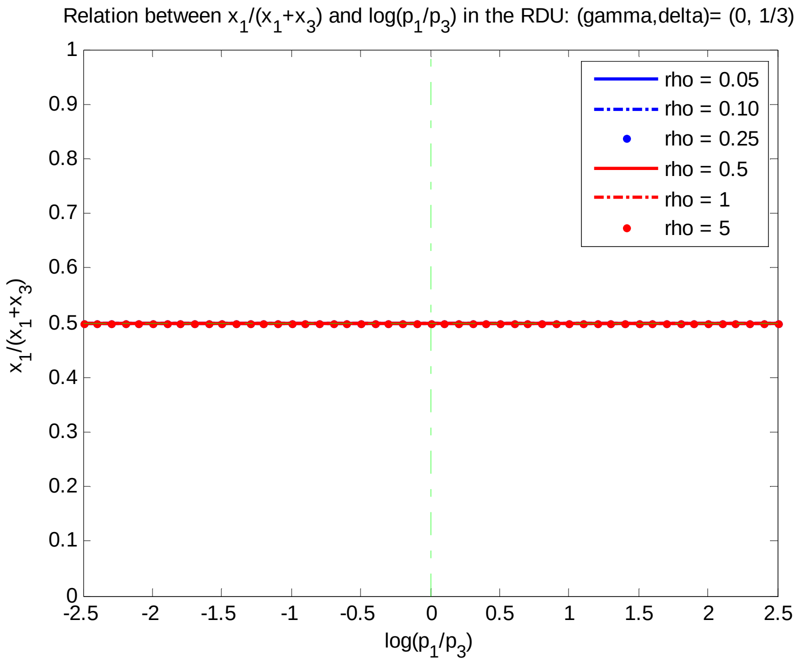
Case 2-3 (loss-neutral & ambiguity-averse): $\gamma = 0$, $\delta = 0.2$



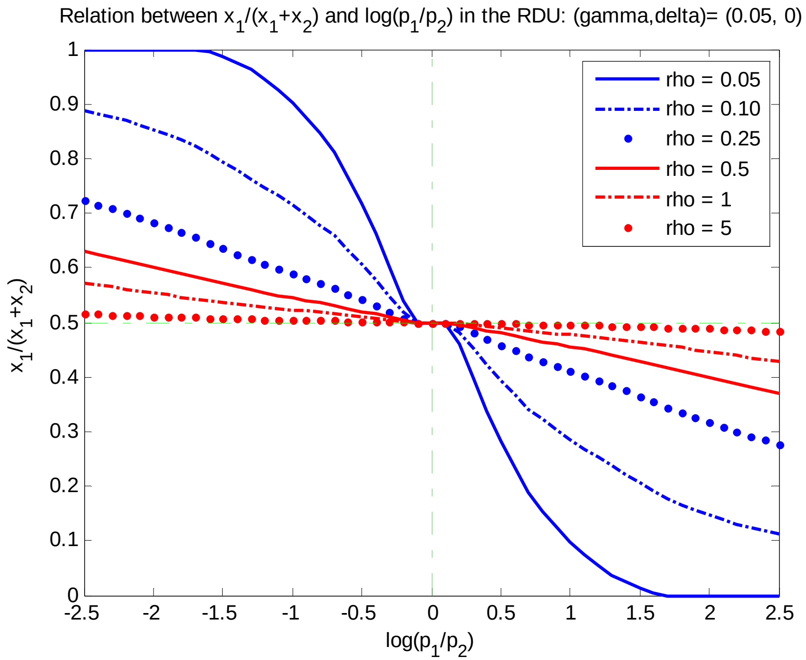


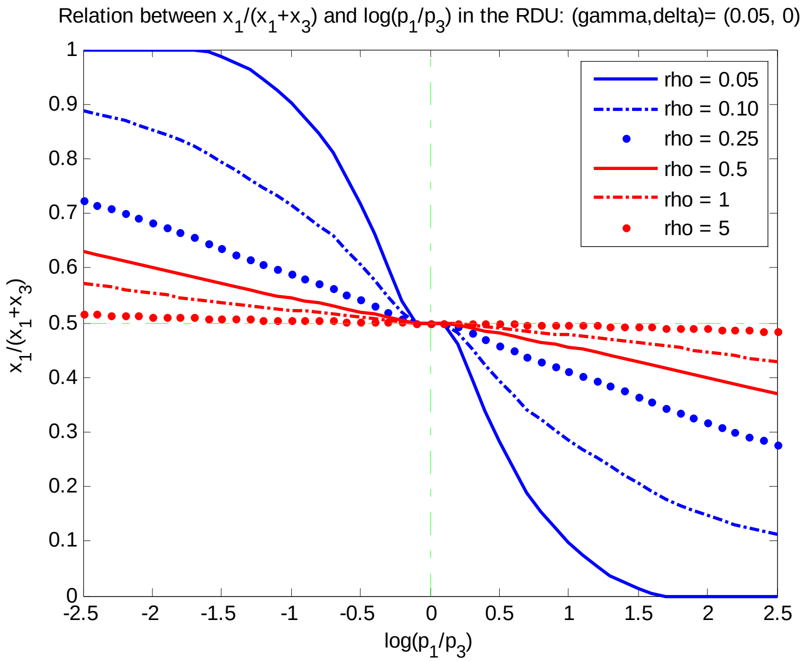
Case 2-4 (loss-neutral & ambiguity-averse): $\gamma = 0$, $\delta = 1/3$



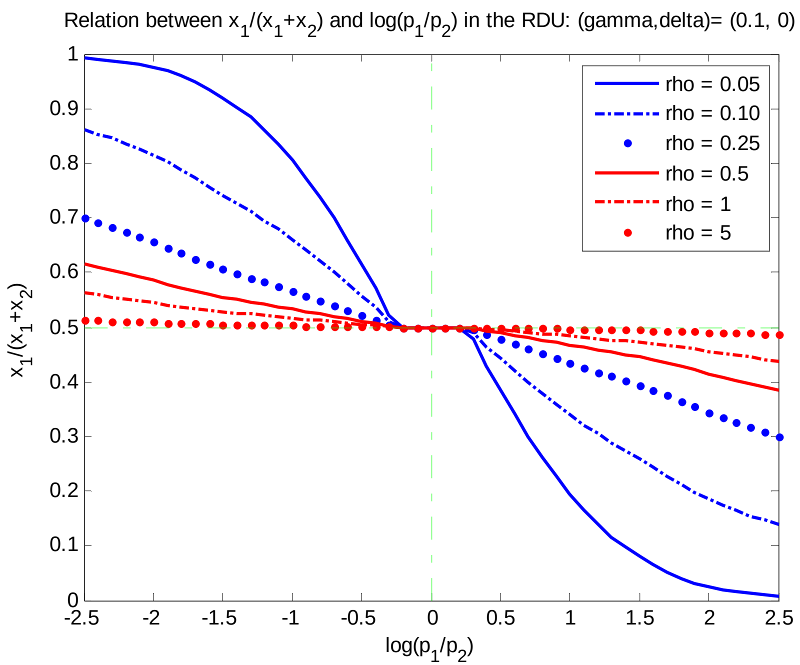


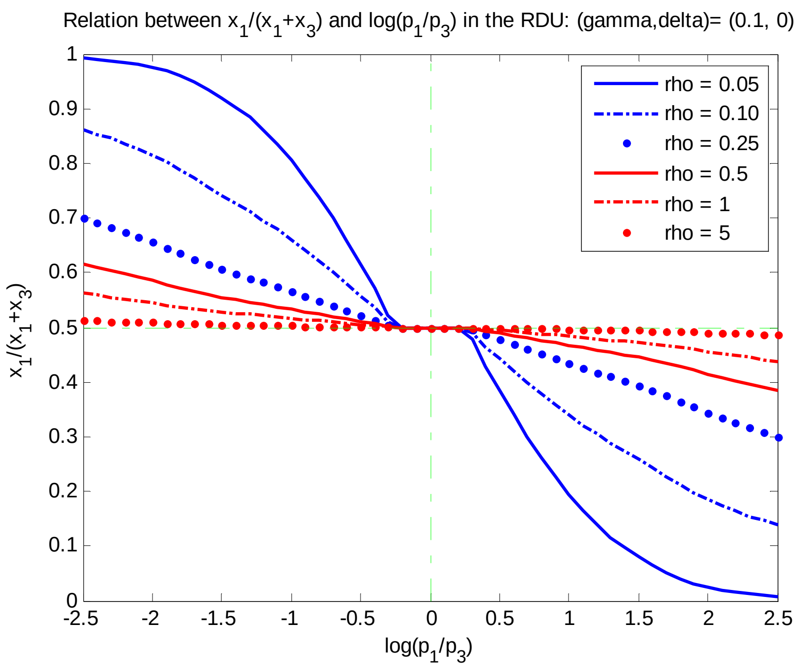
Case 3-1 (loss-averse & ambiguity-neutral): $\gamma = 0.05$, $\delta = 0$



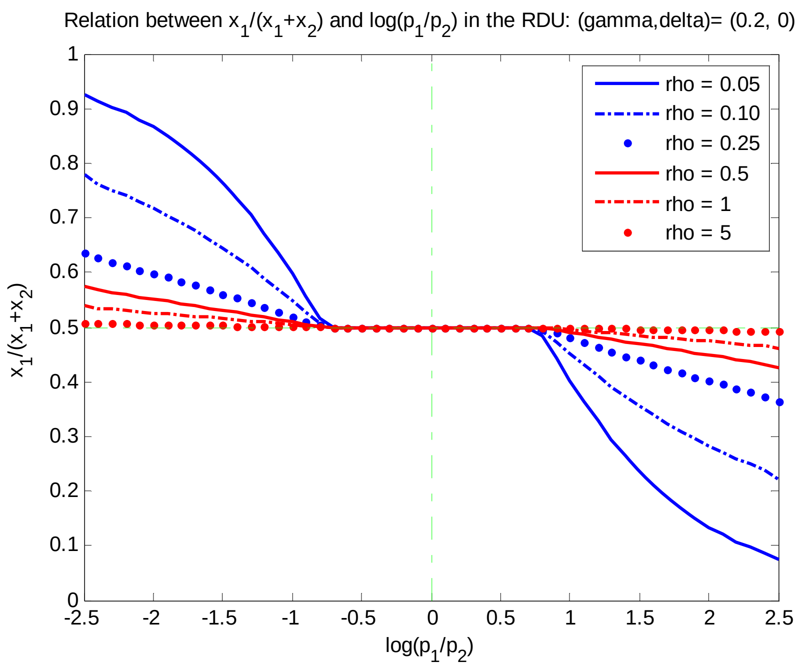


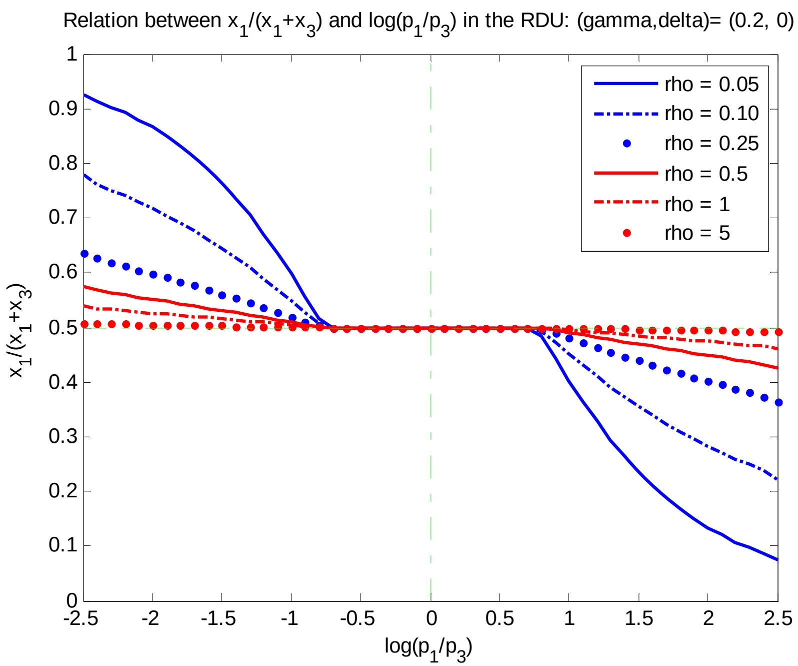
Case 3-2 (loss-averse & ambiguity-neutral): $\gamma = 0.1$, $\delta = 0$



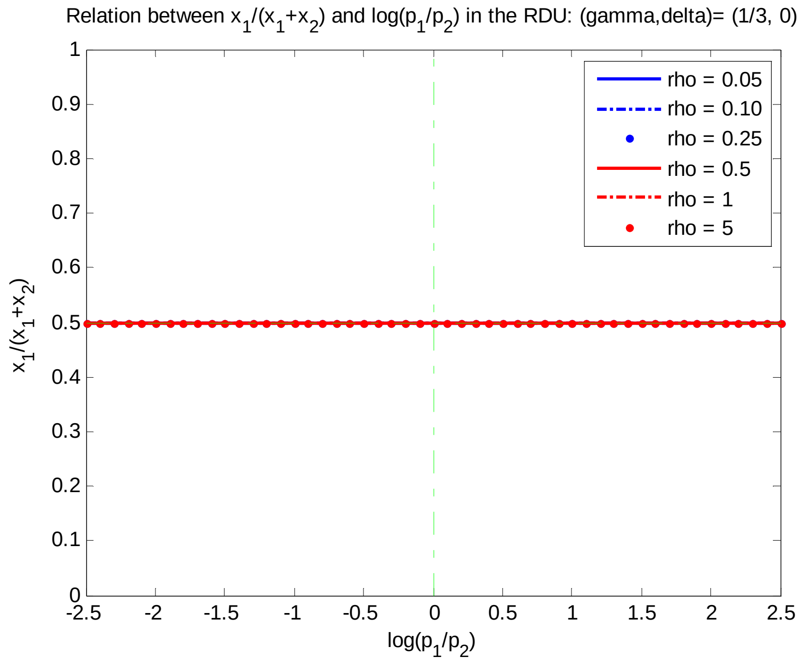


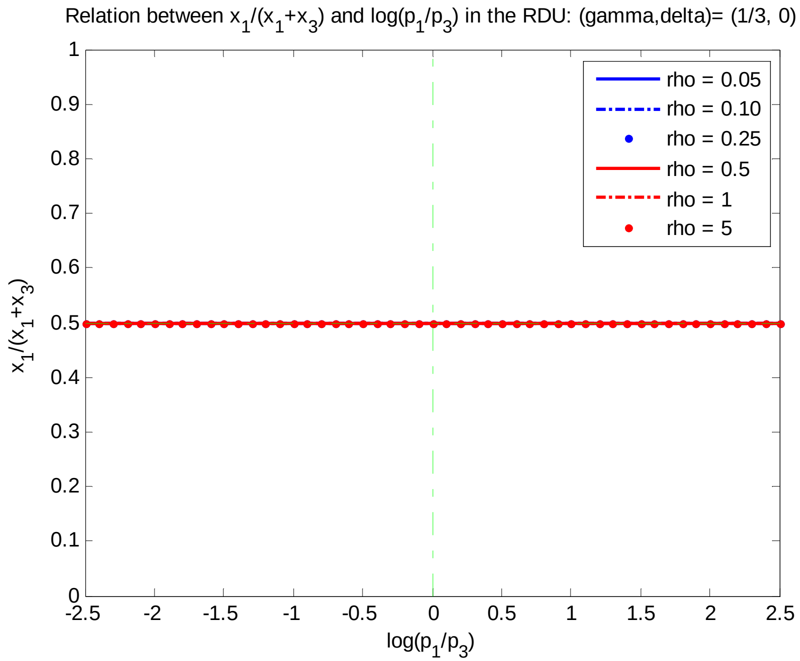
Case 3-3 (loss-averse & ambiguity-neutral): $\gamma = 0.2$, $\delta = 0$



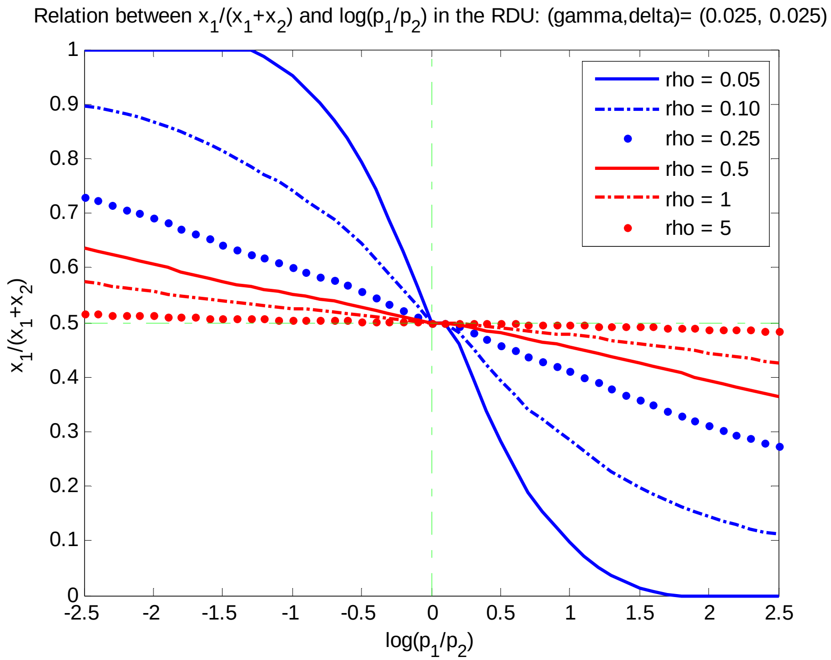


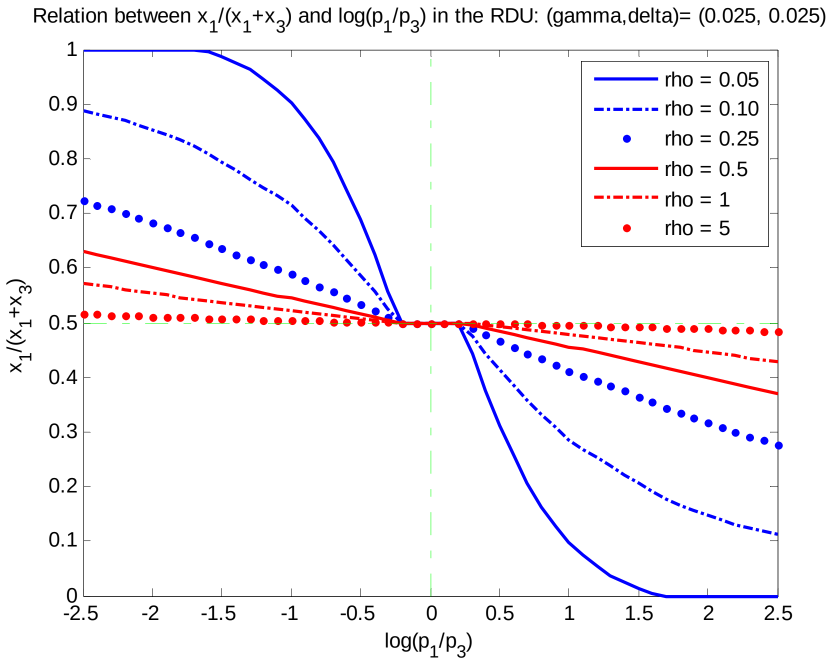
Case 3-4 (loss-averse & ambiguity-neutral): $\gamma = 1/3, \delta = 0$



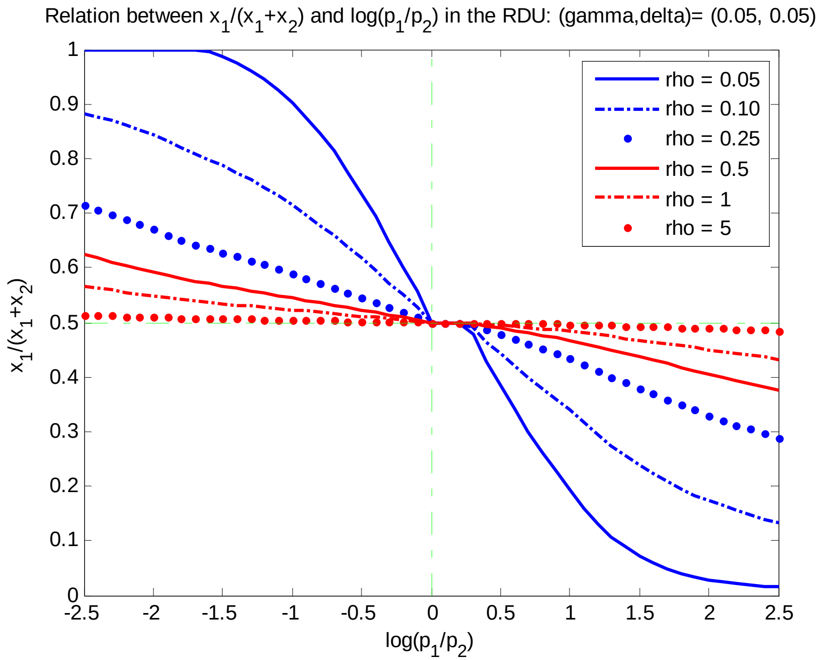


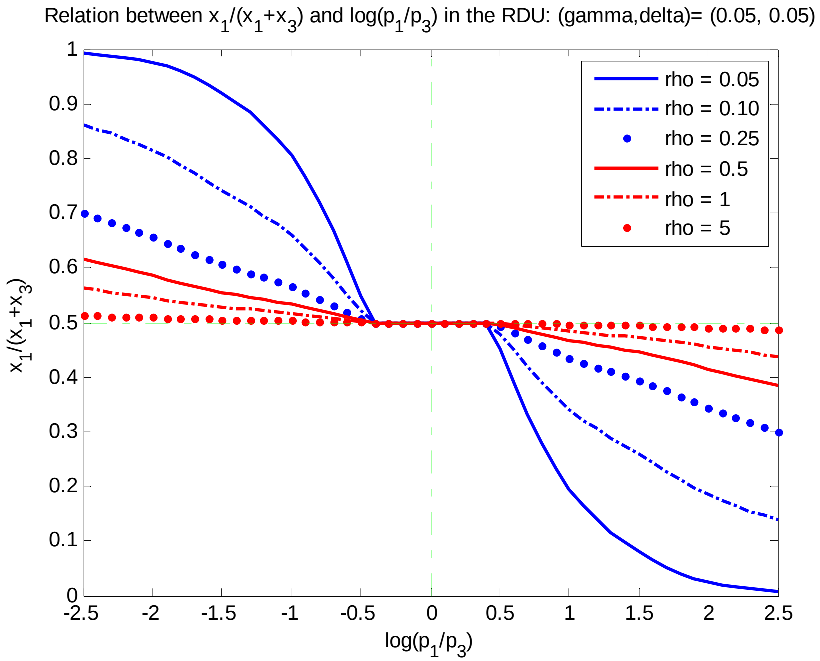
Case 4-1 (loss-averse & ambiguity-averse): γ = 0.025, δ = 0.025



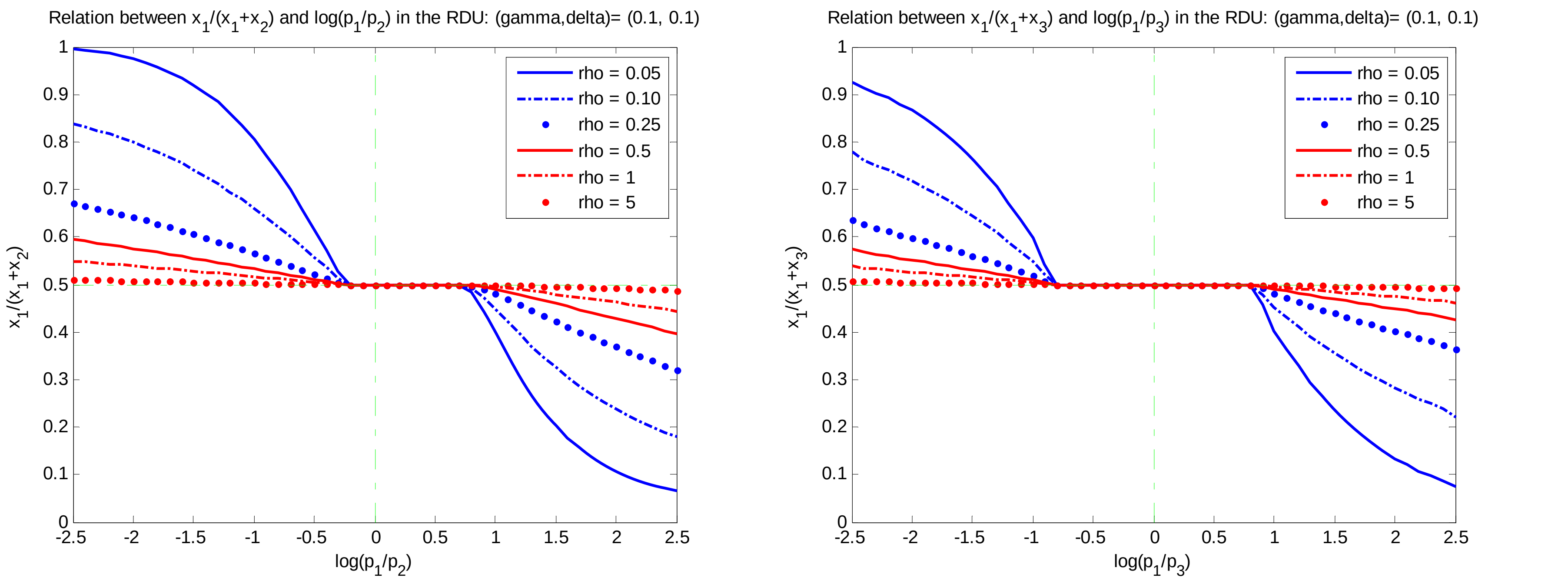


Case 4-2 (loss-averse & ambiguity-averse): $\gamma = 0.05$, $\delta = 0.05$

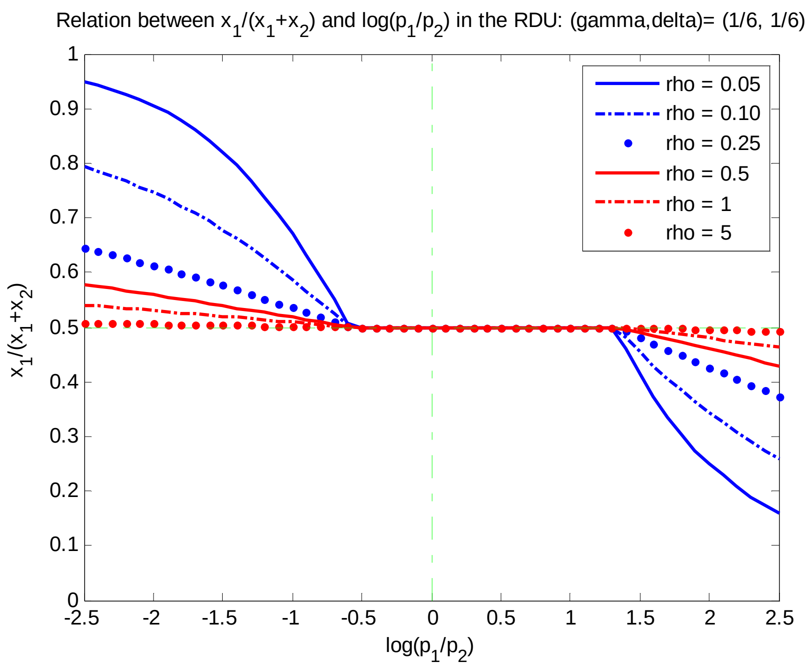


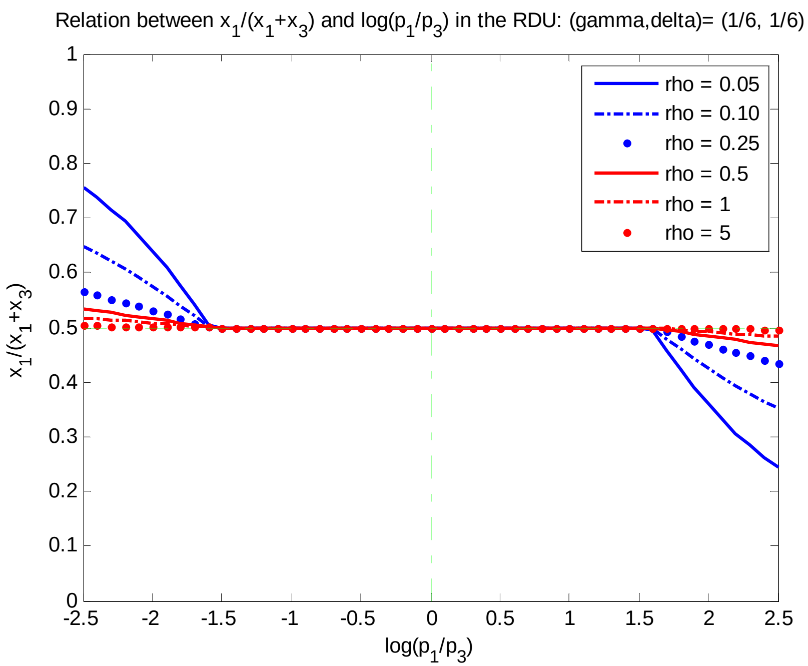


Case 4-3 (loss-averse & ambiguity-averse): $\gamma = 0.1$, $\delta = 0.1$



Case 4-4 (loss-averse & ambiguity-averse): $\gamma = 1/6$, $\delta = 1/6$





Summary of demand behavior and specifications

- There is the strong tendency of equating between two ambiguous assets, x_1 and x_3, which is better accommodated by the kinked specification than the smooth one.

- In addition, there is the (although weaker) tendency of equating between the risky and one ambiguous assets, which is hardly accommodated by ambiguity aversion alone.

- These lead to a conclusion that the generalized kinked specification may provide the best parsimonious way of organizing the data.

Estimation method and identification

- For each model, the individual-level parameter estimates θ are chosen to minimize

$$\sum_{i=1}^{50} \left\| x^i - x^* \left(p^i ; \widehat{\theta} \right) \right\| .$$

- Because of unidentifiability between ambiguity-(risk- / loss-) neutral and ambiguity-(risk- / loss-)loving behaviors, we restrict the coefficients
  - $0 \leq \rho \leq 2$ in all models; $0 \leq \alpha \leq 2$ in the smooth specification and $1/2 \leq \alpha \, (\leq 1)$ in the kinked one;
  - $0 \leq \delta, \gamma$ and $\delta + \gamma \leq \frac{1}{3}$ in the generalized kinked specification.

Summary of Individual-level estimates

- The generalized kinked specification captures the main patterns in the data, the presence of both ambiguity and loss aversion.
- The estimation results suggest that there is a large amount of heterogeneity.
- Singificance tests suggest that the majority of subjects are best described by the the loss- and ambiguity-neutral SEU model.

Subjects' ambiguity and loss classifications
(fractions of subjects)

		Ambiguity		
		Neutral	Averse	Total
Loss	Neutral	0.604	0.167	0.771
	Averse	0.181	0.049	0.229
	Total	0.785	0.215	1

Based on 144 subjects; used 5% significance level to classify individuals according to individual-level estimates.

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Time Preferences

Introduction

- Intertemporal decision problems have been at the centre of the hot debates surrounding traditional economics and behavioral economics.

- There is a huge literature in psychology and economics, documenting the measurement of time discounting and anomalies in intertemporal choices (Frederick et al., 2002).

- Experimental evidence in the literature is often based on some implicit assumptions, which makes the literature quite controversial.

Decision problems in conventional designs

- One common experimental method of eliciting time discount rates uses reward-time pairs (m, t):

  - (Choice task) Which do you prefer, ($\pounds$100, today) vs. ($\pounds$120, 1 year later)?

  - (Matching task) Which amount of x makes you indifferent between ($\pounds$100, today) and ($\pounds x$, 1 year later)?

- What is it supposed to measure? What (implicit) assumptions are made in the measurement?

An example

- Thaler (1981) asks subjects to state the amount of money they would require in (1 month / 1 year / 10 years) to make them indifferent with \$15 today.

- The median responses were \$20 in 1 month / \$50 in 1 year / \$100 in 10 years.

- By continuously compounding discount rates (e.g., $\$15 = \$50e^{-(1.20)(1)}$), he reported that the median responses imply the following annual discount rates of 345% over a one-month horizon / 120% over a one-year horizon / 19% over a ten-year horizon.

- What assumptions were implicitly made?

A theoretical framework

- Suppose an individual has the following intertemporal utility function over a consumption stream $(c_0, ..., C_T)$

$$U^0(c_0, ..., C_T) = \sum_{k=0}^{T} D(k)\, u(c_k).$$

  - exponential discounting model: $D(k) = \left(\frac{1}{1+\rho}\right)^k = \beta^k$ with $\rho \geq 0$ or $\beta \leq 1$;
  - hyperbolic discounting model: $D(k) = \frac{1}{1+\rho\tau}$, whose discount rate is given $\frac{\rho}{1+\rho\tau}$;

– quasi-hyperbolic discounting model:

$$D(k) = \begin{cases} 1 & \text{if } k = 0 \\ \alpha \left(\frac{1}{1+\rho}\right)^k & \text{otherwise} \end{cases}$$

If $\alpha < 1$, it is said to exhibit a present bias. The smaller α is, the larger the present bias is.

- Suppose an individual compares (m, t) and (m', t') with $t < t'$ and expresses his preference as $(m, t) \succsim (m', t')$:

$$\begin{aligned} &\iff U^0 (c_0, ...c_t + m, ..., c_{t'}, ..., C_T) \geq U^0 \left(c_0, ...c_t, ..., c_{t'} + m', ..., C_T\right) \\ &\iff D(t) [u (c_t + m) - u (c_t)] \geq D\left(t'\right) \left[u \left(c_{t'} + m'\right) - u (c_{t'})\right]. \end{aligned}$$

- The discounted increase in utility at time t by choosing (m, t) is at least as large as that at time t' by choosing (m', t').

Some assumptions in the example

- **Consumption reallocation**: assumes that subjects entirely "consume" the reward at the moment it is received.

- **Intertemporal arbitrage**: assumes that subjects either have no access to external capital markets or do not perceive the opportunity of intertemporal arbitrage using capital markets.

- **Linear utility**: assumes that the utility function is linear so that discount rates are solely determined by the ratios of two monetary rewards in different periods.

Some recent experiments

- There have been some efforts in addressing the issue of linear utility assumption.

- Andersen, et al. (2008) use the Multiple Price List (MPL) designs for risk aversion and time discount rate, separately.

- They find that joint elicitation of risk and time preferences results in significantly lower discount rates than separate elicitation of discount rates.

- Many subjects have concave utility functions, which makes the implied discount rates are lower than when one incorrectly assumes a linear utility function.

TABLE I

TYPICAL PAYOFF MATRIX IN THE RISK AVERSION EXPERIMENTS[a]

Lottery A				Lottery B							
p	DKK	p	DKK	p	DKK	p	DKK	EV^A (DKK)	EV^B (DKK)	Difference (DKK)	Open CRRA Interval if Subject Switches to Lottery B and $\omega = 0$
0.1	2000	0.9	1600	0.1	3850	0.9	100	1640	475	1165	$-\infty$, -1.71
0.2	2000	0.8	1600	0.2	3850	0.8	100	1680	850	830	-1.71, -0.95
0.3	2000	0.7	1600	0.3	3850	0.7	100	1720	1225	495	-0.95, -0.49
0.4	2000	0.6	1600	0.4	3850	0.6	100	1760	1600	160	-0.49, -0.15
0.5	2000	0.5	1600	0.5	3850	0.5	100	1800	1975	-175	-0.15, 0.14
0.6	2000	0.4	1600	0.6	3850	0.4	100	1840	2350	-510	0.14, 0.41
0.7	2000	0.3	1600	0.7	3850	0.3	100	1880	2725	-845	0.41, 0.68
0.8	2000	0.2	1600	0.8	3850	0.2	100	1920	3100	-1180	0.68, 0.97
0.9	2000	0.1	1600	0.9	3850	0.1	100	1960	3475	-1515	0.97, 1.37
1	2000	0	1600	1	3850	0	100	2000	3850	-1850	1.37, ∞

[a]The last four columns in this table, showing the expected values of the lotteries and the implied CRRA intervals, were not shown to subjects.

TABLE II

PAYOFF TABLE FOR 6 MONTH TIME HORIZON IN THE DISCOUNT RATE EXPERIMENTS

Payoff Alternative	Payment Option A (Pays amount below in 1 month)	Payment Option B (Pays amount below in 7 months)	Annual Interest Rate (AR, in percent)	Annual Effective Interest Rate (AER, in percent)	Preferred Payment Option (Circle A or B)	
1	3000 DKK	3075 DKK	5	5.09	A	B
2	3000 DKK	3152 DKK	10	10.38	A	B
3	3000 DKK	3229 DKK	15	15.87	A	B
4	3000 DKK	3308 DKK	20	21.55	A	B
5	3000 DKK	3387 DKK	25	27.44	A	B
6	3000 DKK	3467 DKK	30	33.55	A	B
7	3000 DKK	3548 DKK	35	39.87	A	B
8	3000 DKK	3630 DKK	40	46.41	A	B
9	3000 DKK	3713 DKK	45	53.18	A	B
10	3000 DKK	3797 DKK	50	60.18	A	B

TABLE III

ESTIMATES OF RISK AND TIME PREFERENCES ASSUMING EXPONENTIAL DISCOUNTING

Parameter	Estimate	Standard Error	Lower 95% Confidence Interval	Upper 95% Confidence Interval
	A. Allowing a Concave Utility Function (Risk Aversion)			
r	0.741	0.048	0.648	0.835
δ	0.101	0.008	0.084	0.117
μ (for RA)	0.086	0.015	0.056	0.116
ν (for DR)	0.023	0.005	0.012	0.034
	B. Assuming a Linear Utility Function (Risk Neutrality)			
δ	0.252	0.012	0.228	0.276
ν (for DR)	0.133	0.008	0.118	0.148

TABLE IV

ESTIMATES OF RISK AND TIME PREFERENCES ASSUMING HYPERBOLIC DISCOUNTING

Parameter	Estimate	Standard Error	Lower 95% Confidence Interval	Upper 95% Confidence Interval
	A. Allowing a Concave Utility Function (Risk Aversion)			
r	0.750	0.048	0.656	0.844
γ	0.103	0.009	0.085	0.120
μ (for RA)	0.084	0.015	0.054	0.113
ν (for DR)	0.022	0.005	0.012	0.033
	B. Assuming a Linear Utility Function (Risk Neutrality)			
γ	0.270	0.015	0.241	0.298
ν (for DR)	0.136	0.008	0.120	0.152

- Andreoni and Sprenger (2010) use a convex budget set design that allows joint elicitation of risk and time preferences.

- They also find similar results as Andersen, et al. (2008).

- In addition, they find no evidence of present bias.

Figure 1: Sample Decision Screen

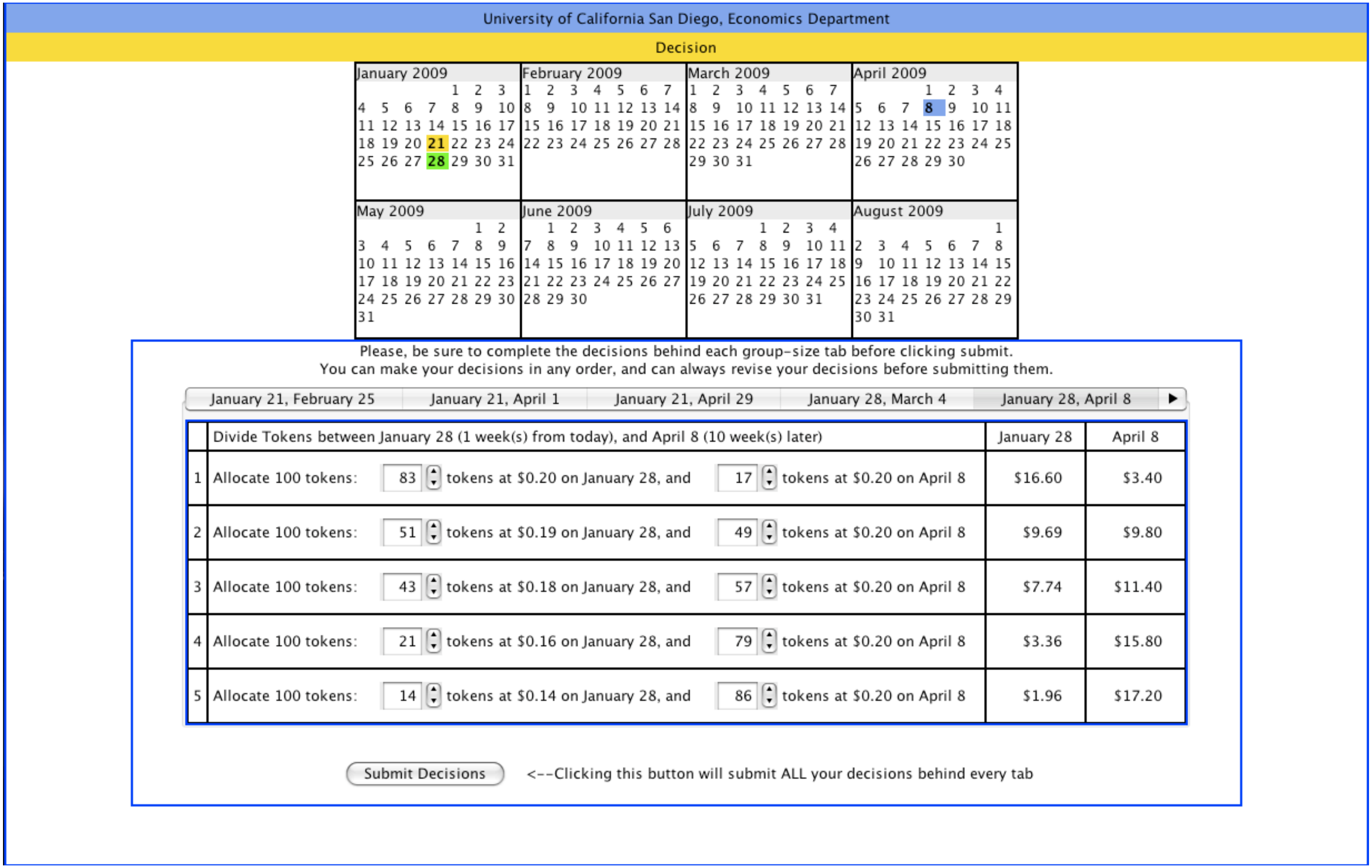
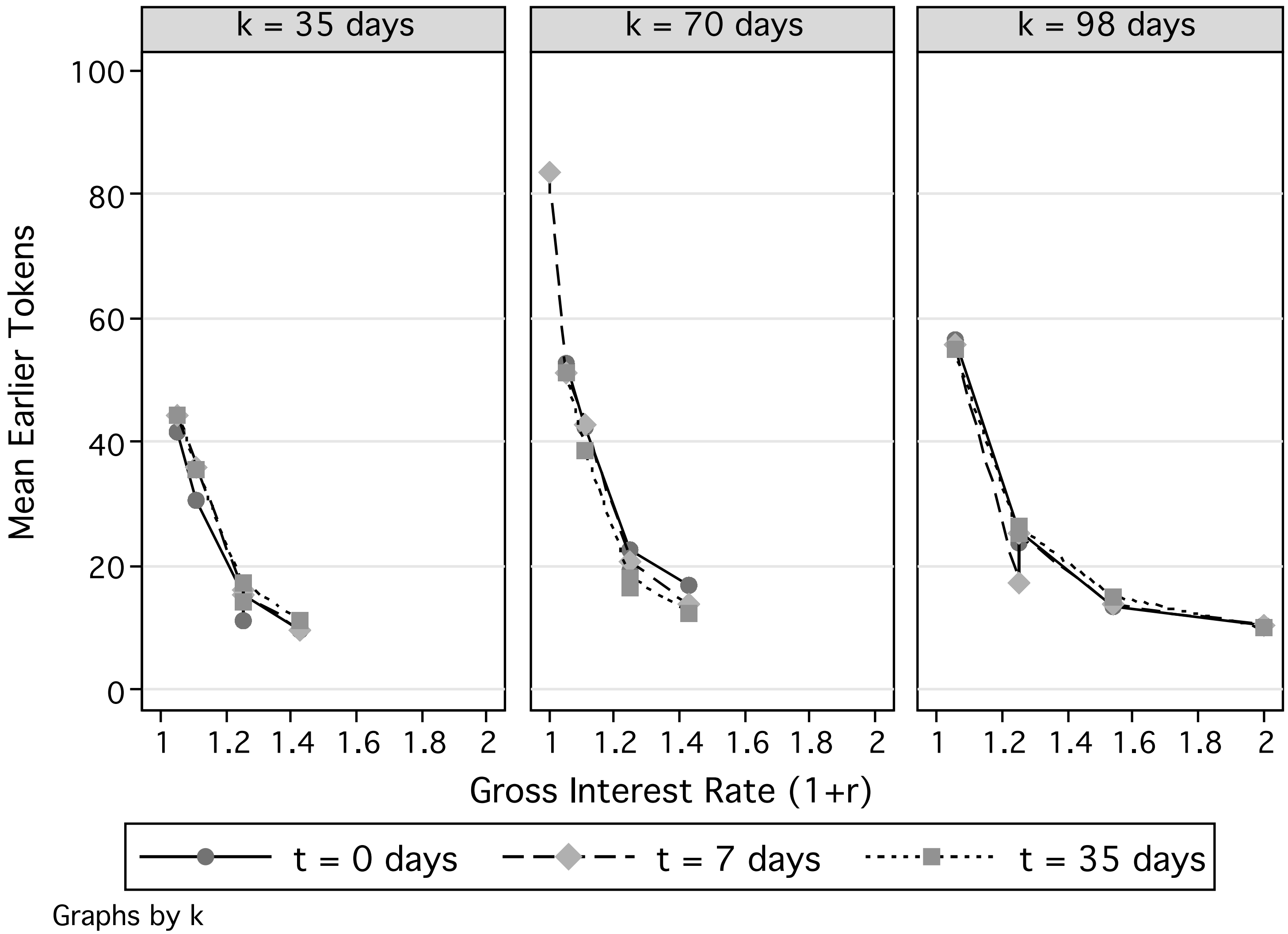


Figure 2: Mean Experimental Responses Over Time



Intertemporal arbitrage

- Cubitt and Read (2007) address theoretically the implications of intertemporal arbitrage in the elicitation of discount rates.

- When the opportunity of intertemporal arbitrage using external capital markets is allowed, the options in an experimental task are not consumption but rather opportunity sets from which consumption rescheduing may proceed.

- They reject both ideas: (i) experimental responses reveal subjects' preferences over consumption as if reward is consumed as it is received; and (ii) experimental tasks are wholly uninformative about preferences over the timing of consumption (Fisher(1930)).

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