Risk and ambiguity estimates from the field

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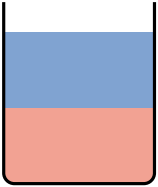
Risk and ambiguity

Define two acts:

- \$100 is paid if a red ball is randomly drawn from an urn.
- Act f: the urn contains 50 red and 50 blue balls.
- Act g: the urn contains 100 red and blue balls (unknown ratio).

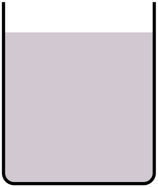
Act f



Risky act

risk aversion: $\$50 \succ f$

Act g



Ambiguous act

ambiguity aversion: $f \succ g$

Goals

Ambiguity is commonplace

- from the consequential: choosing a career, a life partner, an investment strategy;
- to the mundane: deciding what to wear, engaging in conversation.

High-stakes estimates of ambiguity attitudes are rare:

- it is difficult to separate ambiguity from ambiguity attitudes;
- experimental settings have limited budgets.

Goals of the paper:

- estimate attitudes to risk and ambiguity with large stakes;
- test between competing models of ambiguity attitudes;
- illustrate how to elicit ambiguity attitudes in strategic environments.

Context

Our laboratory is the Swiss version of *Deal or no Deal*.

- Each show contains:
  a) a game between 5 contestants $\rightarrow$ ambiguity attitudes;
  b) a sequence of dynamic lotteries $\rightarrow$ risk attitudes.
- Contestants can win up to 250 000 CHF.

Data:

- 1335 contestants in 267 episodes;
- 2362 strategic game decisions;
- 1304 non-strategic game decisions.

Approaches

Context:

- players interact once with strangers with unknown preferences;
- there is no opportunity for "cheap talk" to aid coordination;
- players have observed prior games.

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Context:

- players interact once with strangers with unknown preferences;
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- players have observed prior games.

Equilibrium with representative risk- and ambiguity-free agents:

- equilibrium presumes a mutual understanding of equilibrium strategies;
- this admits no role for ambiguity.

Approaches

Context:

- players interact once with strangers with unknown preferences;
- there is no opportunity for "cheap talk" to aid coordination;
- players have observed prior games.

Dynamic optimisation under ambiguity:

- solve each contestant's dynamic problem within a maximum likelihood estimation routine;
- unknown rival strategies induce strategic ambiguity;
- use the empirical distribution of decisions to define ambiguity.

Identification:

- risk attitudes: variation in the attractiveness of risky offers;
- ambiguity attitudes: variation in the sensitivity of the value of ambiguous acts to probability assessments.

Selective literature

If context is incomplete, decision makers face strategic ambiguity

- Aumann and Dreze (2008), Luce and Raiffa (1957)

Ambiguity aversion has been used to explain the equity premium puzzle, insurance and medical treatment choices.

- Gollier (2011), Ju and Miao (2012), Maenhout (2004), Alary et al. (2013), Snow (2011), Berger et al. (2013), Hoy et al. (2014)

Experimental tests of ambiguity models

- Hey et al. (2010), Ahn et al. (2014), Cubitt et al. (2020), many others
- surveys: Trautmann and van de Kuilen (2015), Wakker (2010)

Deal or no Deal and risk aversion:

- path dependence: Post, van den Assem, Baltussen, Thaler (2008);
- risk aversion and heterogeneity: de Roos and Sarafidis (2010), Bombardini and Trebbi (2012), many others.

Outline

Models of ambiguity attitudes

The non-strategic game

The strategic game

Data

Symmetric risk-neutral equilibrium

Risk and ambiguity

Summary

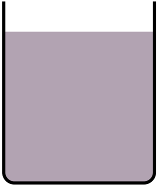
Ambiguity attitudes

Subjective expected utility (Savage, 1954)

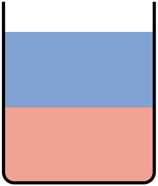
Agents behave as if they have a single subjective probability measure:

$$U(f, p) = \sum_{\omega \in \Omega} u(f(\omega))p(\omega).$$

Ambiguous act



Attitude



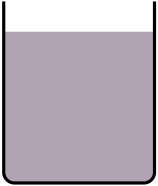
Ambiguity attitudes

Maxmin expected utility (Wald, 1950; Gilboa and Schmeidler, 1989)

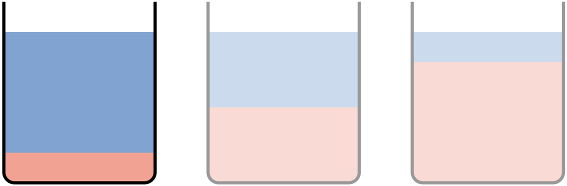
Agents adopt the most pessimistic rationalisable probability measure:

$$V(f) = \min_{p \in P} U(f, p).$$

Ambiguous act



Attitude



Ambiguity attitudes

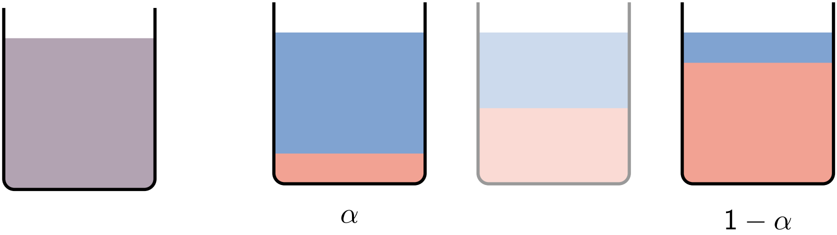
α-Maxmin expected utility (Hurwicz, 1951; Ghirardato et al., 2004)

Weighted average of most pessimistic and optimistic probability measures:

$$V(f) = \alpha \min_{p \in P} U(f,p) + (1-\alpha) \max_{p \in P} U(f,p).$$

Ambiguous act

Attitude



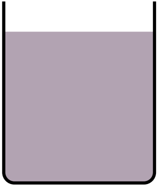
Ambiguity attitudes

Relative entropy (Hansen and Sargent, 2001; Strzalecki, 2011)

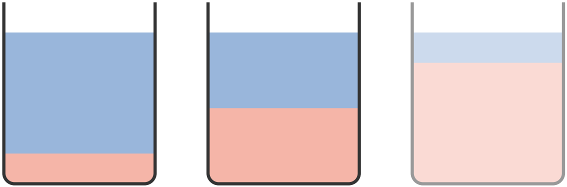
Preferences account for the distance from a focal probability measure, q:

$$V(f) = \min_{p \in P} U(f, p) + \alpha D(p||q).$$

Ambiguous act



Attitude

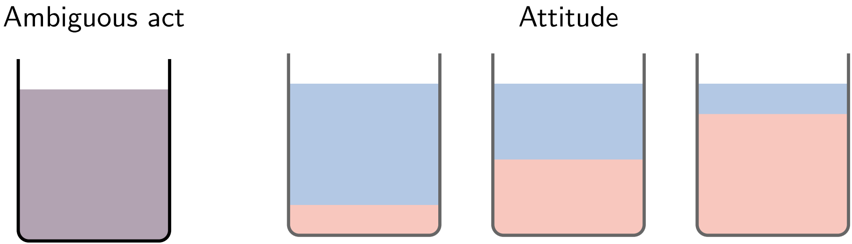


Ambiguity attitudes

Recursive expected utility – "smooth model" (Klibanoff et al., 2005)

Curvature over utility and probability measures:

$$V(f) = \sum_{p \in P} \phi(U(f,p))\,\mu(p).$$



Outline

Timeline

Preliminary task:
26 player general knowledge quiz;
5 players selected.

↓

Strategic game:
5 player elimination tournament;
one player selected.

↓

Non-strategic game:
One player faces a sequence of binary choices under risk.

0.05	0.5
1	2
5	10
20	50
100	150
250	500
750	1000
1500	2500
5000	7500
10000	15000
30000	50000
75000	100000
150000	250000

Non-strategic game

Round 1: remove 6 cases

▸ Model

0.05	0.5
1	2
5	10
	50
100	150
250	
750	
5000	7500
10000	15000
30000	50000
75000	100000
150000	

Non-strategic game

Round 1: remove 6 cases

▸ Model

0.05	0.5
1	2
5	10
	50
100	150
250	
750	
5000	7500
10000	15000
30000	50000
75000	100000
150000	

Non-strategic game

Bank offer:
1300

Deal or no deal?

Model

0.05	0.5
1	2
5	10
	50
100	150
250	
750	
5000	7500
10000	15000
30000	50000
75000	100000
150000	

Non-strategic game

Round 2: remove 5 cases

▸ Model

0.05	0.5
1	
5	10
	50
100	150
750	
5000	
	15000
30000	
75000	100000
150000	

Non-strategic game

Round 2: remove 5 cases

▸ Model

0.05	0.5
1	
5	10
	50
100	150
750	
5000	
	15000
30000	
75000	100000
150000	

Non-strategic game

Bank offer:
4800

Deal or no deal?

▸ Model

0.05	0.5
1	
5	10
	50
100	150
750	
5000	
	15000
30000	
75000	100000
150000	

Non-strategic game

Round 3: remove 4 cases

▸ Model

Non-strategic game

Round 3: remove 4 cases

	0.5
5	10
	50
100	
750	
5000	
	15000
30000	
75000	
150000	

▸ Model

0.5

5

10

50

100

750

5000

15000

30000

75000

150000

Non-strategic game

Bank offer:
6500

Deal or no deal?

Model

Non-strategic game

Round 4: remove 3 cases

0.5

5

10

50

100

750

5000

15000

30000

75000

150000

Model

0.5

10

50

100

5000

30000

75000

150000

Non-strategic game

Round 4: remove 3 cases

▸ Model

0.5

10

50

100

5000

30000

75000

150000

Non-strategic game

Bank offer:
17100

Deal or no deal?

▸ Model

0.5

10

50

100

5000

30000

75000

150000

Non-strategic game

Round 5: remove 2 cases

▸ Model

0.5

10

50

100

5000

30000

Non-strategic game

Round 5: remove 2 cases

▸ Model

0.5

10

50

100

5000

30000

Non-strategic game

Bank offer:
3900

Deal or no deal?

▸ Model

0.5

10

50

100

5000

30000

Non-strategic game

Round 6: remove 1 case

Model

Non-strategic game

0.5

10

50

100

30000

Round 6: remove 1 case

▸ Model

0.5

10

50

100

30000

Non-strategic game

Bank offer:
4100

Deal or no deal?

▸ Model

0.5

Non-strategic game

10

Round 7: remove 1 case

50

100

30000

Model

0.5

Non-strategic game

10

Round 7: remove 1 case

50

30000

Model

0.5

Non-strategic game

Bank offer:
5500

10

Deal or no deal?

50

30000

▸ Model

Non-strategic game

0.5

10

50

30000

Round 8: remove 1 case

▸ Model

0.5

Non-strategic game

Round 8: remove 1 case

50

30000

Model

0.5

Non-strategic game

Bank offer:
9000

Deal or no deal?

50

30000

Model

0.5

Non-strategic game

Bank offer:
9000

Deal or no deal?

50

DEAL!

30000

Model

0.5

Non-strategic game

Round 9: remove 1 case

50

30000

▸ Model

0.5

Non-strategic game

Round 9: remove 1 case

30000

Model

0.5

Non-strategic game

Bank offer:
15000

Deal or no deal?

30000

Model

The nonstrategic game

$$V_r(s, o; \theta) = \max\{o, V_{rc}(s; \theta)\},$$

$$V_{rc}(s; \theta) = \begin{cases} u^{-1}\left(\sum_{s'} p_r u\left(V_{r+1}\left(s', o\left(s'\right); \theta\right)\right)\right), & r < 9 \\ u^{-1}\left(\sum_{s'} p_r u(s')\right), & r = 9, \end{cases}$$

$$V(\theta) = u^{-1}\left(\sum_{s'} p_0 u\left(V_1\left(s', o\left(s'\right); \theta\right)\right)\right),$$

where

$$r = \text{current round of play;}$$

$$o; o(.) = \text{bank offer; bank offer function;}$$

$$s' \in S_r(s) \text{ (updated remaining cases);}$$

$$N(r) = \binom{|s|}{n(r)} \text{ (combinations of cases to be opened).}$$

Game

The bank offer function

$$\ln o_{ir} = \beta_{0r} + \beta_{1r} \ln EV_{ir} + \epsilon_{ir},$$

Round	9	8	7	6
Constant	-0.327	-0.275	-0.420	-0.649
	(0.064)	(0.038)	(0.058)	(0.058)
Exp. value	1.022	1.011	1.015	1.025
	(0.008)	(0.004)	(0.006)	(0.006)
Observations	120	167	214	244
R^2	0.993	0.997	0.992	0.991
$\overline{R}^2$	0.993	0.997	0.992	0.991

Notes: Standard errors are in parentheses ().

The bank offer function

$$\ln o_{ir} = \beta_{0r} + \beta_{1r} \ln EV_{ir} + \epsilon_{ir},$$

Round	5	4	3	2
Constant	-0.727	-0.871	-2.082	-3.215
	(0.075)	(0.108)	(0.218)	(0.277)
Exp. value	1.016	1.011	1.094	1.158
	(0.008)	(0.011)	(0.022)	(0.028)
Observations	256	261	261	261
R^2	0.986	0.970	0.906	0.872
$\overline{R}^2$	0.986	0.970	0.906	0.871

Notes: Standard errors are in parentheses ().

Outline

1	2
3	4
5	6
7	8
9	10
11	12
13	14
15	16
17	18
19	20
21	22
23	24
25	26

Strategic game

Winner: highest sum of cases

Round 1: privately reveal first case

Contestant 1

Contestant 2

Contestant 3

Contestant 4

Contestant 5

1	2
3	4
5	6
7	8
9	10
11	12
13	14
15	16
17	18
19	20
21	
23	24
25	26

Strategic game

Round 1: privately reveal first case

Contestant 1	22	
Contestant 2	24	
Contestant 3	5	
Contestant 4	16	
Contestant 5	26	

1	2
3	4
5	6
7	8
9	10
11	12
13	14
15	16
17	18
19	20
21	
23	24
25	26

Strategic game

Bank offer:
2500

Round 1: privately reveal first case

Contestant 1	22	
Contestant 2	24	
Contestant 3	5	
Contestant 4	16	
Contestant 5	26	

1	2
3	4
	6
7	8
9	10
11	12
13	14
15	16
	18
19	20
21	
23	24
25	26

Strategic game

Round 1: privately reveal first case

Contestant 1	22	1
Contestant 2	24	1
Contestant 3	5	17
Contestant 4	16	1
Contestant 5	26	1

1	2
3	4
	6
7	8
9	10
11	12
13	14
15	16
	18
19	20
21	
	24
25	26

Strategic game

Round 2: privately reveal second case

Contestant 1	22	23
Contestant 2	24	13
Contestant 3	5	17
Contestant 4	16	6
Contestant 5	26	1

1	2
3	4
	6
7	8
9	10
11	12
13	14
15	16
	18
19	20
21	
	24
25	26

Strategic game

Bank offer:
1500

Round 2: privately reveal second case

Contestant 1	22	23
Contestant 2	24	13
Contestant 3	5	17
Contestant 4	16	6
Contestant 5	26	1

1	2
3	4
	6
7	8
9	10
11	12
13	14
15	16
	18
19	20
21	
	24
25	26

Strategic game

Bank offer:
1500

Round 2: privately reveal second case

Contestant 1	22	23
Contestant 2	24	13
Contestant 3	5	17
Contestant 4	16	6
Contestant 5	26	1

The strategic game: overview

The probability of winning depends on:

- information revealed so far (own cases, and cases of exiting players) ;
- conjectures about rival strategies.

The premise is that contestants:

- understand the game and can calculate probabilities;
- do not know the strategies of their rivals $\rightarrow$ strategic ambiguity.

The approach:

- assume players adopt cut-off strategies;
- conjectures are based on the empirical distribution of strategies;
- integration over this distribution is contingent on the model of ambiguity.

The strategic game: strategies

Strategies map information to binary decisions, $\gamma = (\gamma_1, \gamma_2)$:

$$\gamma_{1i} : \mathcal{M}_0 = \{1, 2, \ldots, 26\} \to \{0, 1\},$$
$$\gamma_{2i} : \mathcal{M} \times \mathcal{Q} \to \{0, 1\},$$

Cut-off strategies: $\underline{\gamma}_i = (\underline{\gamma}_{1i}, \underline{\gamma}_{2i})$,

$$\underline{\gamma}_{1i} \in \{\gamma_{1i} : \gamma_{1i}(m_{1i}) = 0 \text{ iff } m_{1i} \geq \underline{m}_1\},$$
$$\underline{\gamma}_{2i} \in \{\gamma_{2i} : \gamma_{2i}(M_i, Q) = 0 \text{ iff } m_{1i} + m_{2i} \geq \underline{m}_2(Q)\}.$$

Notation:

- $\mathcal{M}$ is the feasible set of minicase pairs;
- $\mathcal{Q}$ is the feasible set of revealed cases by exiting rivals.

The strategic game: winning

A **state** $\omega \in \Omega$ is a feasible permutation of minicases:

$$\Omega = \{\{M_j\}_{j\in\mathcal{N}} : M_j \in \mathcal{M}, m_{jx} \neq m_{ky}, x, y \in \{1,2\}, j, k \in \mathcal{N}\}.$$

Player i dominates player j:

$$\begin{aligned} M_i \succ M_j \Leftrightarrow & (m_{i1} + m_{i2} > m_{j1} + m_{j2}) \\ & \text{or} \, (m_{i1} + m_{i2} = m_{j1} + m_{j2} \text{ and } m_{i2} > m_{j2}). \end{aligned}$$

Winning the strategic game:

$$f_i(\omega, \gamma_{-i}) = \prod_{j\in\mathcal{N}_1} (\gamma_{2j} + (1 - \gamma_{2j})\{M_i \succ M_j\}).$$

The strategic game: dynamic problem

Stage 2

Given information $I_{i2} = (M_i, Q)$:

$$W_2 \left(I_{i2}; \theta\right) = \max \left\{o_2, W_{2c} \left(I_{i2}; \gamma_{-i}, \theta\right)\right\}$$

Subjective EU maximiser with probability assessment $p(\omega|\gamma_{-i})$:

$$\begin{aligned} W_{2c} \left(I_{i2}; \gamma_{-i}, \theta\right) &= u^{-1} \left(\pi_i(\gamma_{-i}) u(V(\theta))\right) \\ \pi_i(\gamma_{-i}) &= \sum_{\omega \in \Omega} f_i(\omega, \gamma_{-i}) p(\omega | I_{i2}, \gamma_{-i}). \end{aligned}$$

Recursive EU maximiser with distribution $g(\gamma_{-i})$:

$$\tilde{W}_{2c} \left(I_{i2}; \theta, \alpha\right) = \phi^{-1} \left(u^{-1} \left(\sum_{\gamma_{-i} \in \Gamma(I_{i2})} g(\gamma_{-i} | I_{i2}) \phi \left(\pi_i(\gamma_{-i}) u(V(\theta))\right) \right) \right)$$

The strategic game: dynamic problem

Stage 1

Given information $I_{i1} = m_{i1}$:

$$W_1\left(I_{i1};\theta\right) = \max\left\{o_1, W_{1c}\left(I_{i1};\gamma_{-i},\theta\right)\right\}.$$

Subjective EU maximiser with probability assessment $p(\omega|\gamma_{-i})$:

$$W_{1c}\left(I_{i1};\gamma_{-i},\theta\right) = u^{-1}\left(\sum_{I'\in\mathcal{M}\times\mathcal{Q}} p(I'|I_{i1},\gamma_{-i})u(W_2\left(I';\theta\right))\right).$$

Recursive EU maximiser with distribution $g(\gamma_{-i})$:

$$\tilde{W}_{1c}\left(I_{i1};\theta,\alpha\right) = CE\left(\sum_{\gamma_{-i}\in\Gamma(I_{i1})} g(\gamma_{-i})\phi\left(\sum_{I'} p(I'|I_{i1},\gamma_{-i})u\left(W_2\left(I';\theta\right)\right)\right)\right),$$

$$CE(x) \equiv \phi^{-1}\left(u^{-1}\left(x\right)\right).$$

Outline

Sample and winnings

Sample: 267 episodes between September 2004 and September 2010

- non-strategic game: eliminated cases, bank offers, decisions
- strategic game: mini-cases and decisions

Contestant winnings, non-strategic game

Situation	Observations	Mean	Standard deviation	Median	Min	Max
Accepts a deal	181	23266	21078	19900	2	120000
Rejects all offers	86	10263	31528	375	0.05	250000
All shows	267	19078	25599	11000	0.05	250000

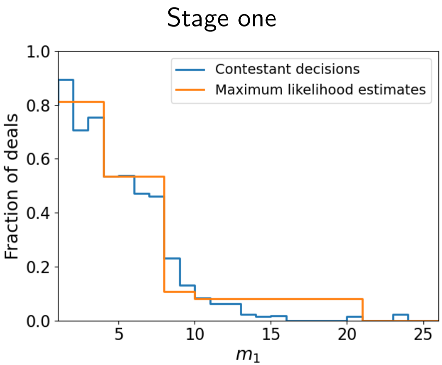
Contestant decisions

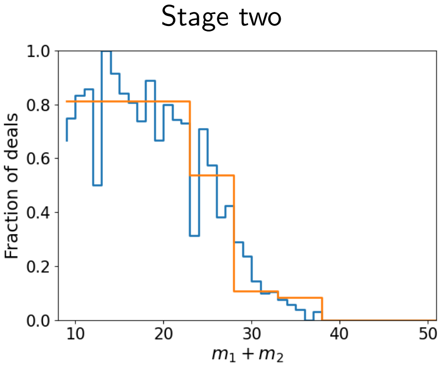
Contestants reaching and accepting by round

Phase	Strategic		Non-strategic						
Round	1	2	3	4	5	6	7	8	9
Reached	1335	1027	267	267	264	251	220	175	129
Accepted	308	357	0	3	13	31	45	46	43
Proportion	0.23	0.35	0	0.01	0.05	0.12	0.20	0.26	0.34

Notes: In Episode 104, Round 5 and Episode 109, Round 9 of our sample, instead of receiving a bank offer, contestants were given the opportunity to exchange their briefcase for another.

Cut-off policies



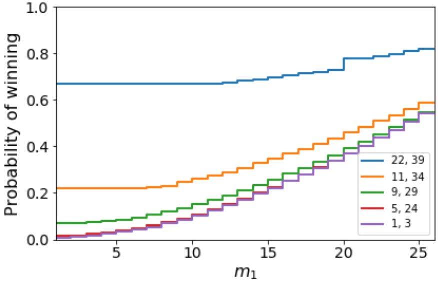


Estimated cut-off policies

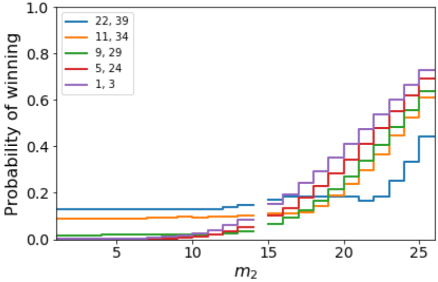
k	1	2	3	4	5
$\left(\underline{m}_1^k, \underline{m}_2^k\right)$	(1, 3)	(5, 24)	(9, 29)	(11, 34)	(22, 39)
p_k	0.186	0.277	0.429	0.025	0.082

Winning probabilities

Stage one



Stage two: four rivals, $m_1 = 15$



Outline

Equilibrium cut-off strategies

Symmetric equilibrium cut-off strategies must satisfy, for all i,

$$W_{2c}\left(I_{i2};\gamma_{-i},\theta\right) \geq o_2 \Leftrightarrow m_{i1} + m_{i2} \geq \underline{m}_2(M_i, Q),$$
$$W_{1c}\left(I_{i1};\gamma_{-i},\theta\right) \geq o_1 \Leftrightarrow m_{i1} \geq \underline{m}_1.$$

Risk-neutral equilibrium

	reject if	accept if	contingent on (M_i, Q) if
Stage 1	$m_1 \geq 8$	$m_1 \leq 7$	–
Stage 2			
$n = 5$	$m_1 + m_2 \geq 31$	$m_1 + m_2 \leq 30$	–
$n = 4$	$m_1 + m_2 \geq 30$	$m_1 + m_2 \leq 27$	$m_1 + m_2 \in \{28, 29\}$
$n = 3$	$m_1 + m_2 \geq 28$	$m_1 + m_2 \leq 23$	$m_1 + m_2 \in \{24, \ldots, 27\}$
$n = 2$	$m_1 + m_2 \geq 23$	$m_1 + m_2 \leq 16$	$m_1 + m_2 \in \{17, \ldots, 22\}$

Contestant choices

	Observations	Consistent #	Consistent (%)	Inconsistent #
Stage 1				
All games	**1335**	**1160**	**(86.9)**	**175**
$m_1 \geq 8$	966	909	(94.1)	57
$m_1 \leq 7$	369	251	(68.0)	118
Stage 2				
All games	**1027**	**820**	**(79.8)**	**207**
$n = 5$	375	292	(77.9)	83
$n = 4$	408	325	(79.7)	83
$n = 3$	204	166	(81.4)	38
$n = 2$	36	33	(91.7)	3
$n = 1$	4	4	(100.0)	0

Equilibrium: comments

Under the assumption of risk and ambiguity neutrality:

- contestants are more likely to depart from equilibrium predictions by rejecting offers when they draw low minicases;
- consistent with risk and/or ambiguity seeking.

Outline

Stochastic choice

heaps:

noun [plural], *adverb* (informal)

Definition:

- a lot

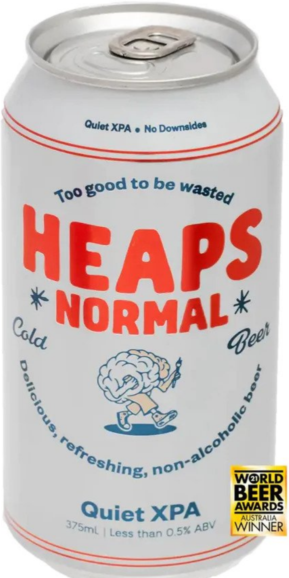
Common usage:

- Look at John's car, he must have *heaps* of money.
- This distribution has *heaps* fatter tails.

Source: Cambridge Dictionary

Stochastic choice

Stochastic choice



Stochastic choice (smooth model)

Contestant i with type $\tau_i = (\theta_i, \alpha_i, \nu_i)$ accepts in round r if

$$z_{ir}(\tau_i) + \epsilon_{ir} > 0, \qquad \epsilon_{ir} \sim F \equiv N(0, \sigma_\epsilon^2),$$

$$z_{ir}(\tau_i) = \begin{cases} \ln(o_r) - \ln(W_{rc}(I_{ir}; \theta_i, \alpha_i)) + \nu_i, & r = 1, 2 \text{ (strategic)}, \\ \ln(o_{ir}) - \ln(V_{rc}(S_{ir}; \theta_i)) + \nu_i, & r \leq 9 \text{ (non-strat)}. \end{cases}$$

Preferences: $u(x;\theta) = x^{1-\theta}/(1-\theta)$ or $(1 - e^{-\theta x})/\theta$;

$$\phi(x;\alpha) = x^{1-\alpha}/(1-\alpha).$$

Contestant heterogeneity:

Model	noise	risk	ambiguity
base	$\nu_i = 0$	$\theta_i = \theta$	$\alpha_i = \alpha$
random effects	$\nu_i \sim N(0, \sigma_\nu^2)$	$\theta_i = \theta$	$\alpha_i = \alpha$
random coeffs	$\nu_i = 0$	$\theta_i \sim N(\theta, \sigma_\theta^2)$	$\alpha_i \sim N(\alpha, \sigma_\alpha^2)$

Likelihood

Conditional likelihood of contestant i's round r choice, $c_{ir} \in \{0, 1\}$:

$$L(c_{ir}|\tau_i) = F((2c_{ir} - 1)z_{ir}(\tau_i)).$$

Likelihood of contestant i's choices, c_i:

$$L(c_i) = \int_{-\infty}^{\infty} \prod_{r \in R_{is}} \prod_{r \in R_{in}} L(c_{ir}|\tau_i) h(\tau_i) \, d\tau_i.$$

Likelihood function:

$$L(c) = \prod_{i=1}^{n} L(c_i),$$

Parameters: $(\theta, \alpha, \sigma_\epsilon, \sigma_\nu, \sigma_\theta, \sigma_\alpha)$.

Identification

Parameters:

- θ: variation in bank offers and the set of remaining cases;
- α: variation in the set of minicases revealed;
- σ_ϵ: variability of decisions conditional on a lottery;
- σ_ν: heterogeneity across contestants;
- σ_θ: heterogeneity across contestants in non-strategic game;
- σ_α: heterogeneity across contestants in strategic game.

In practice we are unable to identify σ_α:

- the first-stage cut-off is 8 or lower for most contestants;
- many contestants receive a higher first minicase;
- $\sigma_\alpha > 0$ reduces the explanatory power for these contestants.

Risk attitudes in the non-strategic game (CRRA)

Parameter	$m_1 < 21$	$m_1 \geq 21$	All contestants		
	(1)	(2)	(3)	(4)	(5)
θ	-0.005	0.095	0.050	0.096	0.185
	(0.050)	(0.024)	(0.025)	(0.043)	(0.064)
σ_ϵ	0.320	0.284	0.304	0.228	0.171
	(0.048)	(0.033)	(0.029)	(0.064)	(0.039)
σ_ν				0.165	
				(0.052)	
σ_θ					0.308
					(0.080)
$C\{0,x\}$	1.003	0.930	0.964	0.929	0.854
Log-likelihood	-197.3	-252.7	-453.8	-445.3	-435.6
Observations	597	707	1304	1304	1304
Contestants	119	148	267	267	267

Notes: C$\{0,x\}$ refers to the certainty equivalent of an even bet between 0 and $x > 0$ for the estimate of mean risk aversion, as a fraction of the expected value of the bet.

Risk attitudes in the non-strategic game (CARA)

Parameter	$m_1 < 21$	$m_1 \geq 21$	All contestants		
	(1)	(2)	(3)	(4)	(5)
θ	3.75e-6	1.50e-5	7.81e-6	1.03e-5	1.48e-5
	(1.23e-6)	(2.42e-6)	(9.35e-7)	(2.29e-6)	(4.07e-6)
σ_ϵ	0.238	0.192	0.225	0.182	0.179
	(0.023)	(0.018)	(0.013)	(0.036)	(0.028)
σ_ν				0.128	
				(0.045)	
σ_θ					1.10e-5
					(4.65e-6)
$C\{0, 10^2\}$	1.000	1.000	1.000	1.000	1.000
$C\{0, 10^4\}$	0.991	0.963	0.980	0.974	0.963
$C\{0, 10^6\}$	0.358	0.092	0.177	0.135	0.094
Log-likelihood	-187.8	-223.0	-421.3	-413.5	-415.4
Observations	597	707	1304	1304	1304
Contestants	119	148	267	267	267

Notes: a e-b refers to $a \times 10^{-b}$. C$\{0, 10^x\}$ refers to the certainty equivalent of an even bet between 0 and 10^x for the estimate of mean risk aversion, as a fraction of the expected value of the bet.

Risk attitudes in the non-strategic game

Observations:

- moderate risk aversion;
- heterogeneity in risk attitudes;
- selection into the strategic game is consistent with correlation between risk and ambiguity attitudes.

Risk and ambiguity attitudes in the full game (CRRA)

Parameter	Subjective EU		Smooth		α-Maxmin	
θ	0.012	0.035	-0.051	-0.021	-0.187	-0.149
	(0.007)	(0.012)	(0.015)	(0.024)	(0.021)	(0.032)
α			0.610	0.547	0.978	0.973
			(0.106)	(0.173)	(0.006)	(0.009)
σ_ϵ	0.776	0.663	0.845	0.734	0.971	0.860
	(0.021)	(0.053)	(0.031)	(0.065)	(0.036)	(0.074)
σ_ν		0.516		0.518		0.551
		(0.084)		(0.095)		(0.111)
$C\{0, x\}$	0.992	0.975	1.034	1.014	1.115	1.094
$A\{10, 50, 90\}$	0.992	0.975	0.867	0.866	0.329	0.319
$A\{10, 20, ..., 90\}$	0.992	0.975	0.936	0.927	0.329	0.319
$A\{40, 50, 60\}$	0.992	0.975	1.026	1.007	0.933	0.912
$A\{10, 20, 30\}$	0.981	0.943	1.024	0.984	0.745	0.706
Log-likelihood	1571.6	1524.9	1550.1	1513.0	1535.0	1506.6
Observations	3666	3666	3666	3666	3666	3666
Contestants	1335	1335	1335	1335	1335	1335

Risk and ambiguity attitudes in the full game (CRRA)

Parameter	α-Maxmin		Maxmin		Relative Entropy	
θ	-0.187	-0.149	-1.092	-0.577	-0.118	-0.099
	(0.021)	(0.032)	(0.105)	(0.158)	(0.014)	(0.022)
α	0.978	0.973			5207.3	4286.5
	(0.006)	(0.009)			(585.3)	(768.3)
σ_ϵ	0.971	0.860	4.546	4.160	0.813	0.739
	(0.036)	(0.074)	(0.026)	(0.282)	(0.024)	(0.052)
σ_ν		0.551		4.043		0.436
		(0.111)		(0.324)		(0.095)
$C\{0, x\}$	1.115	1.094	1.436	1.289	1.076	1.064
$A\{10, 50, 90\}$	0.329	0.319	0.665	0.465	1.076	1.064
$A\{10, 20, ..., 90\}$	0.329	0.319	0.665	0.465	1.076	1.064
$A\{40, 50, 60\}$	0.933	0.912	1.291	1.119	1.076	1.064
$A\{10, 20, 30\}$	0.745	0.706	1.663	1.161	1.186	1.156
Log-likelihood	1535.0	1506.6	2145.3	1979.8	1489.3	1467.8
Observations	3666	3666	3666	3666	3666	3666
Contestants	1335	1335	1335	1335	1335	1335

Risk and ambiguity attitudes in the full game (CARA)

Parameter	Subjective EU		Smooth		α-Maxmin	
θ	1.14e-6	3.00e-6	-5.05e-7	6.86e-7	-4.78e-6	-3.62e-6
	(4.50e-7)	(1.06e-6)	(7.06e-7)	(1.34e-6)	(7.97e-7)	(1.39e-6)
α			0.409	0.360	0.955	0.950
			(0.119)	(0.195)	(0.009)	(0.013)
σ_ϵ	0.746	0.623	0.806	0.683	0.994	0.843
	(0.021)	(0.051)	(0.036)	(0.071)	(0.047)	(0.091)
σ_ν		0.491		0.512		0.634
		(0.076)		(0.084)		(0.100)
$C\{0, 10^2\}$	1.000	1.000	1.000	1.000	1.000	1.000
$C\{0, 10^4\}$	0.997	0.992	1.001	0.998	1.012	1.009
$C\{0, 10^6\}$	0.728	0.429	1.125	0.832	1.713	1.632
$A\{10, 50, 90\}$	1.000	1.000	0.891	0.905	0.272	0.280
$A\{10, 20, ..., 90\}$	1.000	1.000	0.936	0.944	0.272	0.280
$A\{40, 50, 60\}$	1.000	1.000	0.995	0.995	0.818	0.820
$A\{10, 20, 30\}$	1.000	1.000	0.963	0.968	0.545	0.550
Log-likelihood	1567.2	1519.8	1557.8	1513.7	1573.8	1526.5
Observations	3666	3666	3666	3666	3666	3666
Contestants	1335	1335	1335	1335	1335	1335

Risk and ambiguity attitudes in the full game (CARA)

Parameter	α-Maxmin		Maxmin		Relative Entropy	
θ	-4.78e-6	-3.62e-6	-2.07e-5	-1.86e-5	-3.87e-6	-3.34e-6
	(7.97e-7)	(1.39e-6)	(1.05e-6)	(2.21e-6)	(4.89e-7)	(8.47e-7)
α	0.955	0.950			2633.4	2391.7
	(0.009)	(0.013)			(316.9)	(449.3)
σ_ϵ	0.994	0.843	4.501	4.119	0.853	0.759
	(0.047)	(0.091)	(0.026)	(0.280)	(0.027)	(0.057)
σ_ν		0.634		3.962		0.504
		(0.100)		(0.329)		(0.090)
$C\{0, 10^2\}$	1.000	1.000	1.001	1.000	1.000	1.000
$C\{0, 10^4\}$	1.012	1.009	1.052	1.047	1.010	1.008
$C\{0, 10^6\}$	1.713	1.632	1.933	1.926	1.653	1.606
$A\{10, 50, 90\}$	0.272	0.280	0.200	0.200	7.921	7.360
$A\{10, 20, ..., 90\}$	0.272	0.280	0.200	0.200	7.921	7.360
$A\{40, 50, 60\}$	0.818	0.820	0.800	0.800	1.468	1.444
$A\{10, 20, 30\}$	0.545	0.550	0.500	0.500	2.343	2.266
Log-likelihood	1573.8	1526.5	2087.2	1917.6	1516.6	1482.9
Observations	3666	3666	3666	3666	3666	3666
Contestants	1335	1335	1335	1335	1335	1335

Risk and ambiguity attitudes in the full game

Observations:

- lower risk aversion or even risk seeking in full game;
- substantial heterogeneity at decision and contestant level;
- substantial ambiguity aversion;
- ambiguity attitudes depend on the model of ambiguity;
- more sophisticated models do not substantially outperform SEU
- model fit is marginally better in the relative entropy model

Outline

Summary

Equilibrium analysis:

- consistent with risk and ambiguity neutrality or seeking.

Empirical model of risk and ambiguity:

- evidence for moderate risk aversion and risk seeking;
- substantial heterogeneity;
- substantial ambiguity aversion;
- similar model fit across models;
- qualified evidence of positive correlation between risk and ambiguity.