Modeling Decision Making Under Risk using Neurochemistry

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Spencer Conference
Beyond Correlation in the Study of Personality
Beyond Correlation in the Study of Personality including attitude towards economic risk
Classical Decision Theory

- Primitives based on revealed choice
- Utility specification on well defined domain
- Clean/efficient axiomatization, preferably

For examples, EU
“Behavioral” Decision Theory

• Classical decision theory + psychological considerations
“Behavioral” Decision Theory

- Classical decision theory + psychological considerations
- Prime example – prospect theory (1979):
  - Loss-gain differentiation: reference dependence, loss aversion, gain-loss differentiation of risk attitude
  - Nonlinear response to probabilistic outcomes
Valuation Function in Prospect Theory (K&T 1979)

- Weber-Fechner
- Reference point
  - Status quo
  - Endowment effect
- Loss-gain differentiation
  - Risk averse in gain
  - Risk taking in loss
- Loss looms larger than gain
  - Loss aversion

Figure 3.—A hypothetical value function.
Probability Weighting

- Weber-Fechner again?
- Pessimism and optimism
- Overweight small probabilities

Figure 4.—A hypothetical weighting function.
Beyond revealed choice

- Biomarkers (e.g., gender) and physiological variables
- Brain activation
- Genetic makeup
How might biology be incorporated?
Gene ↔ Decision

- Decision
- Brain activation
- Neurotransmitters/hormones
- Genes
Heritability of Risk Attitude

- Zhong et al., 2009
  - Genetic effect (57%)
  - Environmental effects (43%)
- Cesarini et al., 2009
  - Genetic effect (14%)
  - Environmental effects (86%)
<table>
<thead>
<tr>
<th>Study</th>
<th>N</th>
<th>Risk Attitude</th>
<th>Gene</th>
</tr>
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<tbody>
<tr>
<td>Crisan et al</td>
<td>36</td>
<td>Loss-gain framing</td>
<td>5-HTTLPR</td>
</tr>
<tr>
<td>Dreber et al</td>
<td>94</td>
<td>Portfolio choice</td>
<td>DRD4</td>
</tr>
<tr>
<td>Kuhnen &amp; Chiao</td>
<td>65</td>
<td>Portfolio choice</td>
<td>5-HTTLPR, DRD4</td>
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<td>Roe et al</td>
<td>67</td>
<td>Multiple-price list design</td>
<td>CHRNA4</td>
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<tr>
<td>Roiser et al</td>
<td>30</td>
<td>Loss-gain framing with fMRI</td>
<td>5-HTTLPR</td>
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<tr>
<td>Zhong et al (2009b)</td>
<td>325</td>
<td>Even-chance risks over gains and losses</td>
<td>Stin2, DAT1</td>
</tr>
<tr>
<td>Zhong et al (2009c)</td>
<td>325</td>
<td>Longshot risks over gains and losses</td>
<td>MAOA</td>
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Goal

• Immediate
  – Build a model of decision making under risk linking genetic makeup with revealed choice.

• Long Term
  – Develop biologically sound approach to economic modeling

• Eventually
  – behavioral x biological economics ($B^2E$)
Two Immediate Deliverables

• Predict association between gene and decision
  – Go beyond association
Immediate Deliverables

• Predict association between gene and decision
  – Go beyond association

• Predict correlation in fourfold risk attitude
  – Share common biological factors
Attitudes towards Fourfold Risks

- Moderate Hazards: Limited Risk Preference
- Skewed Hazards: Globally Risk Averse
- Moderate Prospects: Globally Risk Averse
- Skewed Prospects: Limited Risk Preference
Moderate Prospect

• Subjects valuation ($v$) of risky option (50% of getting 60 Yuan; 50% of getting nothing)
  – $V > 35$
  – $30 < V < 35$
  – $25 < V < 30$
  – $V < 25$
Moderate Hazard

• Subjects valuation (v) of risky option (50% of losing 10 Yuan; 50% of losing nothing)
  – $V > -4$
  – $-4 < V < -5$
  – $-5 < V < -6$
  – $V < -6$
Longshot Prospect

- Longshot preference (1% chance of getting 200 Yuan > 10% chance of getting 20 Yuan > 2 Yuan for sure).
  - Yes
  - No
Longshot Hazard

• Insurance (Losing 2 Yuan for sure > 0.1% chance of losing 2000 Yuan).
  – Yes
  – No
Correlations among Fourfold Risks?

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<tr>
<td>Longshot Prospect</td>
<td>?</td>
<td>?</td>
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</tr>
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<td>Moderate Hazard</td>
<td>?</td>
<td>?</td>
<td>?</td>
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<tr>
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Prediction of most models limited to:

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<tr>
<td>Longshot Prospect</td>
<td>+</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Moderate Hazard</td>
<td>NA</td>
<td>NA</td>
<td>+</td>
</tr>
<tr>
<td>Longshot Hazard</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
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Concave (convex) valuation function in gain (loss) would predict positive correlation between MP and LP (MH and LH).
### New Behavioral Evidence: Correlations among Four-fold Risks

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<th>Longshot Prospect</th>
<th>Moderate Hazard</th>
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<tbody>
<tr>
<td>Longshot Prospect</td>
<td>0.160**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderate Hazard</td>
<td>0.297***</td>
<td>0.137*</td>
<td></td>
</tr>
<tr>
<td>Longshot Hazard</td>
<td>−0.070</td>
<td>0.034</td>
<td>0.031</td>
</tr>
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Table 1. Spearman correlation between different pairs of attitude towards fourfold risks (N=325). Estimated correlation with two-tails significance indicated by * for 5%, ** for 1%, and *** for 0.1%.
Neurochemistry without Tears
Polymorphic genes coding for DA neurotransmission modulate available neurotransmitter receptor numbers that contribute to background DA firing.
Dopamine (DA)
• Gain
  – reward as well as reward prediction errors (Schultz, Dayan, and Montague, 1997)
  – novelty seeking (Cloninger, 1986; Ebstein et al., 1996)
  – expected reward (Preuschoff, Bossarts and Quartz, 2005)
• Not loss
  – does not produce negative prediction error (Fiorillo, Tobler, and Schultz, 2003).
  – administration of DA drugs affects risky decision making under gains but not under losses (Pessiglione et al 2006)
Neurochemistry without Tears

Serotonin (5HT)

• Harm avoidance (Cloninger, 1986)
• Anxiety-related personality traits (Lesch et al 1996)
• Amygdala activation and loss-gain framing (Roiser et al 2009)

DA and 5HT Opponent Partnership Hypothesis

• Opponency between reward and punishment is fundamentally asymmetric (Daw, et al, 2002; Dayan and Huys, 2009)
• Losses loom larger than gains
Saliency – salient stimuli (e.g., tones and light) that are not inherently reward related (see Ungless, 2004 for review).

• novelty of an unexpected physical stimulus (Ljungberg, Apicella, and Schultz, 1992).
• unexpected novel sound interferes, even in the absence of reward (Zink et al, 2006).
Tone
- low-level background firings in slow, irregular single-spike mode.
- Polymorphic genes modulate available neurotransmitter/receptor numbers that contribute to their background firing.
Fourfold pattern of risk attitude

Task 1: Moderate Prospect (G, ½)
(61% exhibits risk tolerance for longshot prospects)

Task 2: Longshot Prospect (G, p)
(80% exhibits risk aversion for moderate prospects):

Task 3: Moderate Hazard (L, ½)
(69% exhibits risk tolerance for moderate hazards)

Task 4: Longshot Hazard (L, q)
(69% exhibits risk aversion for longshot hazards)
Biology of Fechner-Weber Law

– Beyond psychophysics

Figure 3.—A hypothetical value function.
Berns’ Biological Bound Hypothesis

• Noting that DA are in limited supply in the brain, they lead naturally to bounds to the value function in both gains and loss domains

• This value function would be convex over losses besides being concave over gain

• Implication re “kink” at status quo

• Biological basis for the psychophysics of valuation sensitivity
Biological Bound Hypothesis + Tone
Bound + Tone Hypothesis for DA

- **Bound**: limited availability
- **Tone**: low-level background firings
- Higher DA tone, lower capacity, more concave in gain
Bound + Tone Hypothesis for 5HT

- **Tone**: low-level background firings
- **Bound**: limited availability
- Higher 5HT tone, lower capacity, more convex in loss
Hypothesis V (Dual System)

• Higher DA (5HT) tone associates with a more concave (convex) valuation function over gains (losses).
Candidate Genes ↓↑ = TONE

• **Dopamine** transporter
  – (9 ↓, 10 ↑)

• **Serotonin** transporter – 2 polymorphisms
  – **5HTTLPR** (short ↑, long ↓)
  – **STiN2** (10 ↑, 12 ↓)
Corroborating Dual System Hypothesis (Zhong et al., 2009 b)

- 325 subjects
- Risk attitude for gain and loss
- Candidate Gene – *Dopamine* transporter DAT
  - midbrain activation (Schott et al., 2006)
  - in vivo transporter availability (van Dyck et al., 2005)
    - (9 ↓, 10 ↑)
- Candidate Gene – *Serotonin* transporter
  - 5HTTLPR (short ↑, long ↓)
  - STiN2 (10 ↑, 12 ↓)

↓↑ = TONE
<table>
<thead>
<tr>
<th>Gene</th>
<th>Gain</th>
<th>OR</th>
<th>CI</th>
<th>z-value</th>
<th>p-value</th>
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<tr>
<td>DAT1</td>
<td>1.77</td>
<td>1.04</td>
<td>3.04</td>
<td>2.07</td>
<td>0.035*</td>
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<tr>
<td>STin2</td>
<td>1.22</td>
<td>0.96</td>
<td>1.54</td>
<td>1.63</td>
<td>0.104</td>
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<tr>
<td>5-HTTLPR</td>
<td>1.21</td>
<td>0.86</td>
<td>1.68</td>
<td>1.12</td>
<td>0.264</td>
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<tr>
<td>Loss</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>DAT1</td>
<td>1.63</td>
<td>0.88</td>
<td>2.99</td>
<td>1.56</td>
<td>0.118</td>
</tr>
<tr>
<td>STin2</td>
<td>1.36</td>
<td>1.03</td>
<td>1.79</td>
<td>2.18</td>
<td>0.029*</td>
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<tr>
<td>5-HTTLPR</td>
<td>1.36</td>
<td>0.97</td>
<td>1.9</td>
<td>1.78</td>
<td>0.075</td>
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Nonlinear Probability Weighting

- \( \frac{p^c}{[p^c + (1-p)^c]^{1/c}} \) (Tversky and Kahneman, 1992)
- \( \frac{sp^c}{[sp^c + (1-p)^c]} \) (Lattimore, Baker, and Witte, 1992)
- \( \exp\{-[-\ln p]^a\} \) (Prelec, 1998)
- \( \frac{1}{1 + (1-p)/ps} \) (Rachlin et al 1991)
Outcome Dependence

- Overweighting of small probabilities depends on the size of outcomes such that large outcomes engender greater curvature than smaller outcomes. (Camerer, 1992; Tversky and Kahneman, 1992)

- People tend to be more pessimistic when facing large losses (Etchart-Vincent, 2004)

- Reflecting affect salience and echo the suggestion that they can depend on the underlying outcome $x$ (Rottenstreich and Hsee, 2002)
Nonlinear Probability Weighting

- $p^c/[p^c + (1 - p)^c]^{1/c}$ (Tversky and Kahneman, 1992)
- $sp^c/[sp^c + (1 - p)^c]$ (Lattimore, Baker, and Witte, 1992)
- $\exp\{-[-\ln p]^a\}$ (Prelec, 1998)
- $1/[1 + (1 - p)/ps]$ (Rachlin et al 1991)

Incorporating outcome dependence

\[
ps(x)/[ps(x) + 1 - p]
\]
Salience function $s(x)$
Proposition A

- Under a loss-averse utility function $v$ with $v(0) = 0$ and a U-shaped salience function $s$ which is minimized at 0, the decision maker exhibits
  - aversion towards $(G, \frac{1}{2})$ if $v(G/2)/v(G) > [1 + s(0)/s(G)]^{-1}$,
  - tolerance towards $(L, \frac{1}{2})$ if $v(L/2)/v(L) < [1 + s(0)/s(L)]^{-1}$,
  - tolerance towards $(G, p)$ with $p$ sufficiently small if $s(G)/G > v'(0)s(0)/m$
  - aversion towards $(L, q)$ with $q$ sufficiently small if $s(L)/|L| > v'(0)s(0)$
Hypothesis S – DA

• **Lower DA tone** engenders a salience function $s$ that increases faster over gains and decreases faster over losses relative to the case for higher DA tone.

(A) Saliency of outcomes and DA tone
Hypothesis S – 5HT

• **Lower 5HT tone** engenders a salience function that decreases faster over losses as well as gains relative to the case for higher 5HT tone.

• **Attention focus and emotional salience**
Proposition B

Relative to the case of low DA tone, a decision maker with high DA tone will tend to be

- D(i) more averse towards moderate prospects.
- D(ii) more averse towards longshot prospects.
- D(iii) less averse towards longshot hazards.

Relative to case of low 5HT tone, a decision maker with high 5HT tone will tend to be

- S(i) less averse towards moderate hazards.
- S(ii) less averse towards longshot hazards.
- S(iii) less averse towards longshot prospects.
## Correlation among Fourfold Risks

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<tr>
<td><strong>Longshot Prospect</strong></td>
<td>Positive: $D(i)$ &amp; $D(ii)$ 0.160**</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Moderate Hazard</strong></td>
<td>Positive# 0.297***</td>
<td>Positive: $S(i)$ &amp; $S(iii)$ 0.137*</td>
<td></td>
</tr>
<tr>
<td><strong>Longshot Hazard</strong></td>
<td>Negative: $D(i)$ &amp; $D(iii)$ – 0.070</td>
<td>No implication 0.034</td>
<td>Positive: $S(i)$ &amp; $S(ii)$ 0.031</td>
</tr>
</tbody>
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Table 1. Spearman correlation between different pairs of attitude towards fourfold risks (N=325). Estimated correlation with two-tail significance indicated by * for 5%, ** for 1%, and *** for 0.1%. #Interaction between dopamine and serotonin transmitters
Association Results for Longshot Risks

(A) Percentage choosing lottery

(B) Percentage choosing insurance
Final Slide

• One small step in incorporating biology to model decision making under uncertainty
  – Neurochemical tones as reference points
  – Dual-system model: Is an individual a group?

• Consilience of biology (beyond psychology) and economics, especially decision theory
Center for Biological Economics and Decision Making, NUS
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   Shlomo ISRAEL
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   Pak C SHAM (Director)
   Stacey S CHERNY
Applied Genomic Center, HKUST
   XUE Hong (Director)
   TSANG Sue
Source Dependence via Saliency

- “Known” uncertainty is more salient than “less known” uncertainty
  - Two decks of cards
- “Familiar” uncertainty is more salient than “less familiar” uncertainty
  - Two cities in China

$s$ is more salient than $s^*$ if $s/s^*$ is nondecreasing
Ambiguity Aversion and Familiarity Bias

(A) **5-HTTLPR and familiarity bias.** Subjects with short allele tend to bet on Beijing.

(B) **DRD5 and ambiguity aversion in female.** Female subjects without 148bp allele tend to bet on known deck.

(C) **ESR2 and ambiguity aversion in female.** Subjects with short allele tend to bet on known deck.