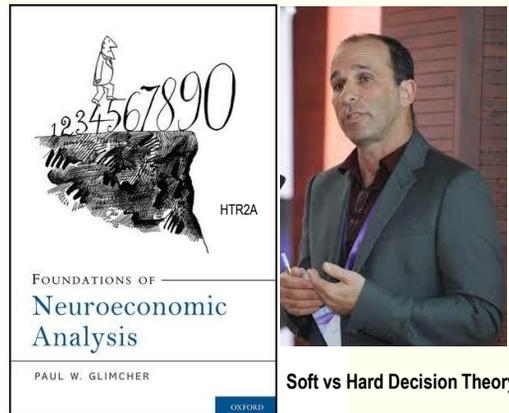


Lecture 3

Bioeconomics of Individual Decision Making

SHUFE

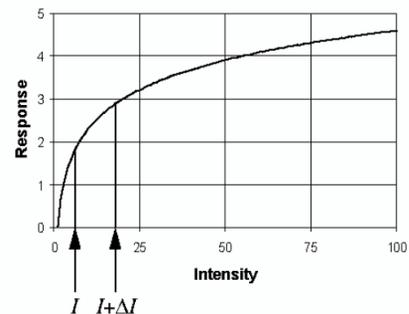


Utilitarianism – Early Days ...

- Utilitarianism since Bentham
- Principle of diminishing marginal utility
- **Cardinality?**

Psychophysics of diminishing sensitivity

Weber's Law
applied to utility theory



Utilitarianism

- Utilitarianism since Bentham
- Principle of diminishing marginal utility
- **Modelling risk attitude ...**

Modelling Risk Taking

- Bernoulli (1728) described a St Petersburg lottery which **pays 2^n dollars** if in a sequence of coin tosses, **Head first appears on the n th trial**.
 - Notice that this lottery has infinite expected payoff since it pays 2^n dollars with $1/2^n$ probability.
 - At the same time, $1/2^n$ is the chance of winning more than 2^n !
- This **St Petersburg Paradox** demonstrates that expected payoff does not provide a “good” criterion for assessing the worth of a lottery.

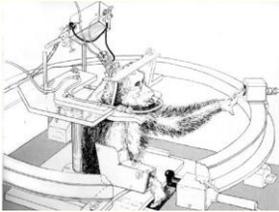
Modelling Risk Taking

- Bernoulli (1728) then suggested that the incremental “moral worth” of money x should be inversely proportional to x leading him to offer a logarithmic function for his moral worth function.
- We can check that this solves the St Petersburg paradox
- Interestingly, Bernoulli is a contemporary of Ernst Heinrich Weber (1795–1878) Weber. Sometimes, **great minds do think alike ...** 😊

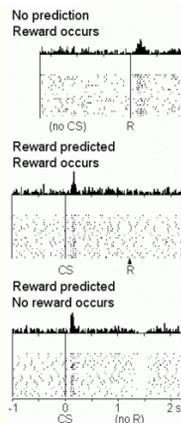
Utilitarianism

- Utilitarianism since Bentham
- Principle of diminishing marginal utility
- Modelling risk attitude a bit later ...
- **Desperately seeking cardinality ...**

Dopamine and Reward



Schultz, Dayan & Montague (1997) A Neural Substrate of Prediction and Reward. **Science**



Dopamine (DA) and gain

- Reward as well as reward prediction errors (Schultz, Dayan, and Montague, 1997)
- Novelty seeking (Cloninger, 1986)
- Expected reward (Preuschoff, Bossarts and Quartz, 2005)

Less about 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)

10

Biological Bound

- Biological constraint in the occupancy of DA receptors (Berns, Capra, & Noussair 2007)
- This delivers a neurochemical model of diminishing marginal utility coinciding with the psychophysics of diminishing sensitivity towards changes in utility

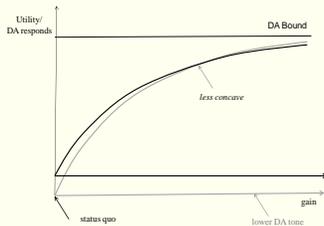
11

Cardinal Utility at last ...?

- Utilitarianism since Bentham
- Principle of diminishing marginal utility
- Modelling risk attitude a bit later ...
- **We now have a biology-based utility** which delivers *inter alia* cardinality

Neurochemical Model of Diminishing Marginal Utility

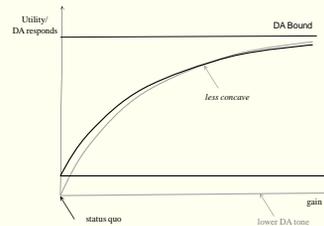
- Biological constraint in the occupancy of DA receptors (Berns, Capra, & Noussair 2007)



13

Our Biological Tone Hypothesis

- **Tone:** low-level background firings
- Higher DA tone, lower capacity, more concave in gain
 - Testable implication – greater risk aversion



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Serotonin (5HT) and Loss

- Contributes to the regulation of aversive behavior
- Harm avoidance (Cloninger, 1986)
- Anxiety-related personality traits (Lesch *et al*, 1996)
- Loss-gain framing (Roiser *et al*, 2009)
- DA and 5HT Opponent Partnership Hypothesis
 - Opponency between reward and punishment in learning is fundamentally asymmetric (Daw, et al, 2002; Dayan and Huys, 2009)

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Neurochemical Approach to Reference Dependence

- Kahneman and Tversky (1979) observed that economic outcomes tend to be perceived as changes, i.e., **gains** and **losses**, with respect to the **status quo**.
- Apply Weber's law, they conclude that the utility function would remain concave over gains but **convex over losses**, with the immediate implication of a tendency towards being **risk seeking over loss oriented risks!**

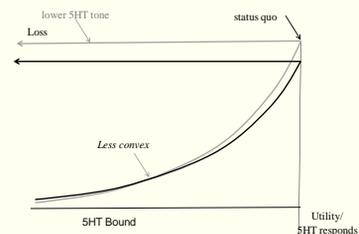
Neurochemical Model of Reference Dependence

- Biological constraint in the occupancy of DA receptors (Berns, Capra, & Noussair 2007)
- DA and 5HT are in limited supply in the brain, they lead naturally to bounds to the value function in both gains and loss domains. (Zhong et al. 2009b)
- This delivers a neurochemical model of reference-dependent utility with **tone** serving as embodiment of **status quo**.

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Biological Tone Hypothesis for Utility over Losses

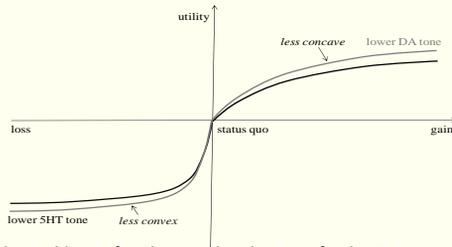
- **Tone:** low-level background firings
- **Bound:** limited availability
- Higher 5HT tone, lower capacity, more convex in loss



18

Dual System Hypothesis

- Higher DA (5HT) tone associates with a more concave (convex) valuation function over gains (losses).



- Biological basis for the psychophysics of valuation sensitivity
- implication re “kink” at status quo

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Test of the Implications of Dual-System Hypothesis

Corroborating Dual System Hypothesis (Zhong et al., 2009 b)

- Assess risk attitude over gains and losses
- Candidate Gene – **Dopamine** transporter DAT
 - Midbrain activation (Schott et al., 2006)
 - In vivo transporter availability (van Dyck et al., 2005)
 - Tone: 9 ↓, 10 ↑
- Candidate Gene – **Serotonin** transporter
 - Tone: 5HTTLPR – short ↑, long ↓; STIN2: 10 ↑, 12 ↓

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Findings Support Tone Model of Reference Dependence

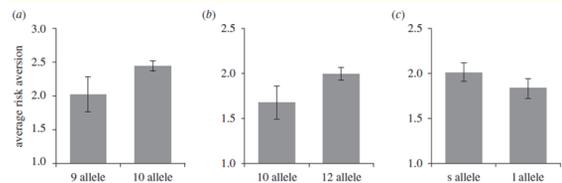


Figure 2. (a) Risk attitude over gains and DAT1. Subjects with the 9-repeat allele (**low DA tone**) are more risk-tolerant than subjects with the 10-repeat allele (**high DA tone**). (b) Risk attitude over losses and STIN2. Subjects with the 10-repeat allele (**high 5HT tone**) are more risk-tolerant than subjects with the 12-repeat allele (**low 5HT tone**). (c) Risk attitude over losses and 5-HTTLPR. Subjects with the long allele (**high 5HT tone**) are nominally more risk-tolerant than subjects with the short allele (**low 5HT tone**), though this relation is not statistically significant.

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Findings Support Tone Model of Reference Dependence

		Gene	OR	CI	p-value	
Risk attitude over gain	DA	DAT1	1.77	1.04	3.04	0.035
	5HT	STin2	1.22	0.96	1.54	0.104
	5HT	5HTTLPR	1.21	0.86	1.68	0.264
Risk attitude over loss	DA	DAT1	1.63	0.88	2.99	0.118
	5HT	STin2	1.36	1.03	1.79	0.029
	5HT	5HTTLPR	1.36	0.97	1.9	0.075

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Large Scale Study with Biologically Enriched Choice Data

- 3433 subjects: 1640 are males, mean age 21.9 years (SD = 2.3) for males and 20.8 (SD=2.4) for females
- 2191 from Singapore: 46.1% males
- 1242 from Beijing: 51.7% males
- All undergraduate Han Chinese
- Each contributed blood/saliva sample
- Average compensation of RMB400

Dopamine D4 Receptor Gene Exon III Polymorphism Predicts Curvature of the Utility Function in Han Chinese

Yushi Jiang, Mikhail Monakhov, Songfa Zhong, Richard P. Ebstein and Soo Hong Chew

Introduction

• Dopamine D4 Receptor (DRD4) gene

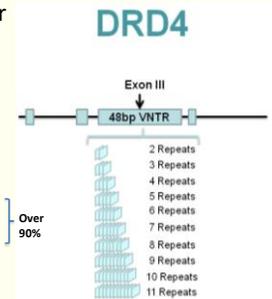
- located in chromosome 11

- a particular variant: the exon III VNTR polymorphism

- 2-11 repeats among human

- most common: **4R**

- second most common: **7R** (in Caucasians) & **2R** (in Asians)



Source: Jiang, Chew, & Ebstein, (2013)

Introduction

• Motivation

- Recently several studies with small samples of Caucasian subjects offer preliminary evidence that certain alleles of dopamine D4 receptor (*DRD4*) exon III polymorphism may be associated with a greater propensity to take financial risk (Dreber et al., 2009; Kuhnen and Chiao, 2009).

Financial Investment Task

	Investment		Total Earnings		
	√	Cash	Invest	Correct Guess	Incorrect Guess
1		\$27.00	\$0.00	\$27.00	\$27.00
2		\$24.00	\$3.00	\$31.50	\$24.00
3		\$21.00	\$6.00	\$36.00	\$21.00
4		\$18.00	\$9.00	\$40.50	\$18.00
5		\$15.00	\$12.00	\$45.00	\$15.00
6		\$12.00	\$15.00	\$49.50	\$12.00
7		\$9.00	\$18.00	\$54.00	\$9.00
8		\$6.00	\$21.00	\$58.50	\$6.00
9		\$3.00	\$24.00	\$63.00	\$3.00
10		\$0.00	\$27.00	\$67.50	\$0.00

• Endowment: \$527
• Investment amount: X
(choose among 10 options)

• Total earnings:
50%: \$527+1.5X
50%: \$527-X

Tone-based Hypothesis

- Studies of drug addiction indicate that low DA tone corresponds to higher sensitivity to reward (Volkow 2012)
- **4/4R**: most efficient genotype (Asghari et al. 1995), higher tone; **non-4/4R**: reduced striatal DRD4 availability, and thus lower tone

Literature

- Dopamine transporter (*DAT*) gene predicts economic risk attitude (Zhong et al., 2009)
- Association was reported between *DRD4* 7R and risk preference among Caucasian samples
 - 7R carriers are less risk averse
 - gender effect: association is seen only in males
 - Not always replicated
 - **Hypothesize that 2R carriers in East Asian populations**

Experiments

- Subjects were recruited via email advertisement from NUS and various universities in Beijing
- Procedure:
 - incentivized laboratory-based economic experiments;
 - biological material samples (blood or saliva);
 - online surveys including personality questionnaires.

Experiments

- 3433 subjects: 1640 are males, mean age 21.9 years (SD = 2.3) for males and 20.8 (SD=2.4) for females
 - 2191 from Singapore: 46.1% males
 - 1242 from Beijing: 51.7% males
 - all undergraduates
 - Han Chinese
- *DRD4* VNTR genotype:
 - Grouping scheme: 4/4R vs all others (non-4/4R)
 - Around 59% of the subjects are 4/4R carriers

Experiments

- Incentivized behavioral tasks:
 - Financial investment
 - Even-chance lottery
 - Sure-bet task
- Personality questionnaires:
 - NEO Personality Inventory (NEO-PI)
 - Temperament and Character Inventory Revised (TCI-R)

Even-Chance Lottery

	Option A	Option B	Decision
1	50% of receiving \$60, 50% of receiving \$0	Receiving \$15 for sure	A <input type="checkbox"/> B <input type="checkbox"/>
2	50% of receiving \$60, 50% of receiving \$0	Receiving \$19 for sure	A <input type="checkbox"/> B <input type="checkbox"/>
3	50% of receiving \$60, 50% of receiving \$0	Receiving \$23 for sure	A <input type="checkbox"/> B <input type="checkbox"/>
4	50% of receiving \$60, 50% of receiving \$0	Receiving \$25 for sure	A <input type="checkbox"/> B <input type="checkbox"/>
5	50% of receiving \$60, 50% of receiving \$0	Receiving \$27 for sure	A <input type="checkbox"/> B <input type="checkbox"/>
6	50% of receiving \$60, 50% of receiving \$0	Receiving \$29 for sure	A <input type="checkbox"/> B <input type="checkbox"/>
7	50% of receiving \$60, 50% of receiving \$0	Receiving \$30 for sure	A <input type="checkbox"/> B <input type="checkbox"/>
8	50% of receiving \$60, 50% of receiving \$0	Receiving \$31 for sure	A <input type="checkbox"/> B <input type="checkbox"/>
9	50% of receiving \$60, 50% of receiving \$0	Receiving \$33 for sure	A <input type="checkbox"/> B <input type="checkbox"/>
10	50% of receiving \$60, 50% of receiving \$0	Receiving \$35 for sure	A <input type="checkbox"/> B <input type="checkbox"/>

Switching point = indicator of risk attitude

Sure-bet Task

	Option A	Option B	Decision
1	Receiving \$30 for sure	48% of receiving \$60, 52% of receiving \$0	A <input type="checkbox"/> B <input type="checkbox"/>
2	Receiving \$30 for sure	50% of receiving \$60, 50% of receiving \$0	A <input type="checkbox"/> B <input type="checkbox"/>
3	Receiving \$30 for sure	52% of receiving \$60, 48% of receiving \$0	A <input type="checkbox"/> B <input type="checkbox"/>
4	Receiving \$30 for sure	54% of receiving \$60, 46% of receiving \$0	A <input type="checkbox"/> B <input type="checkbox"/>
5	Receiving \$30 for sure	56% of receiving \$60, 44% of receiving \$0	A <input type="checkbox"/> B <input type="checkbox"/>
6	Receiving \$30 for sure	58% of receiving \$60, 42% of receiving \$0	A <input type="checkbox"/> B <input type="checkbox"/>
7	Receiving \$30 for sure	60% of receiving \$60, 40% of receiving \$0	A <input type="checkbox"/> B <input type="checkbox"/>
8	Receiving \$30 for sure	62% of receiving \$60, 38% of receiving \$0	A <input type="checkbox"/> B <input type="checkbox"/>
9	Receiving \$30 for sure	64% of receiving \$60, 36% of receiving \$0	A <input type="checkbox"/> B <input type="checkbox"/>
10	Receiving \$30 for sure	66% of receiving \$60, 34% of receiving \$0	A <input type="checkbox"/> B <input type="checkbox"/>

10 - Switching point = indicator of risk attitude

Comparison of Tasks

- **Lottery tasks (Even-chance lottery & Sure-bet):** more **primitive** (1 bird in hand vs 2 in the tree) distinguish risk neutral and risk seeking
- **Investment task:** more **complex** ("investor" optimizing on mix between safe and risky assets)

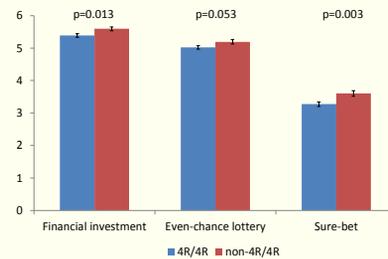
Correlation across Behavioral Tasks

	Even-chance	Sure-bet	Investment
Even-chance	1		
Sure-bet	0.311*	1	
Investment	0.282*	0.309*	1

Spearman's rho values. *p<0.001

Subjects tend to demonstrate consistent risk attitudes across the tasks.

Risk Attitude Comparison across Genotypes



Model-free OLR analysis

- Ordered Logit Regression (OLR)
 - Financial investment:** the choice number (ranging from 1-10) of investment composition is used as dependent variable (DV);
 - Even-chance lottery:** the Switching Point (SP: ranging from 0-10) from lottery to the sure amount is DV;
 - Sure-bet task:** 10 - SP (ranging from 0-10) from the sure amount to lottery is DV
- => **larger number indicates higher risk tolerance.**
- Three estimation models for each task:
 - only *DRD4*
 - DRD4* & individual characteristics (sex, city, and age)
 - DRD4* & individual characteristics & environmental factors (parents' education, number of siblings, family income level)

Association between DRD4 Exon III VNTR and Risk Attitude in Separate Tasks (OLR)

	Financial investment			Even-chance lottery			Sure-bet		
	1 (a)	1 (b)	1 (c)	2 (a)	2 (b)	2 (c)	3 (a)	3 (b)	3 (c)
DRD4	1.144**	1.144**	1.128*	1.129*	1.152**	1.164**	1.210***	1.212***	1.201***
	(0.070)	(0.070)	(0.074)	(0.072)	(0.074)	(0.079)	(0.076)	(0.077)	(0.081)
Female	0.656**	0.656**	0.656**	0.689**	0.678**	0.689**	0.876**	0.888**	0.888**
	(0.041)	(0.041)	(0.044)	(0.045)	(0.047)	(0.047)	(0.057)	(0.051)	(0.051)
City	1.133**	1.154**	1.154**	0.706**	0.689**	0.689**	1.148**	1.148**	1.127**
	(0.071)	(0.078)	(0.078)	(0.045)	(0.048)	(0.048)	(0.074)	(0.074)	(0.078)
Age	1.007	1.011	1.011	1.006	0.999	0.999	0.993	0.993	0.993
	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.014)	(0.014)	(0.014)
Father's edu.		1.006	1.006		0.985	0.985		1.045	1.045
		(0.028)	(0.028)		(0.027)	(0.027)		(0.029)	(0.029)
Mother's edu.		1.012	1.012		1.020	1.020		0.975	0.975
		(0.030)	(0.030)		(0.030)	(0.030)		(0.029)	(0.029)
Siblings		1.030	1.030		0.970	0.970		0.959	0.959
		(0.031)	(0.031)		(0.028)	(0.028)		(0.028)	(0.028)
Family inc.		0.997	0.997		0.978	0.978		0.981	0.981
		(0.017)	(0.017)		(0.016)	(0.016)		(0.017)	(0.017)
Log likelihood	-6934.141	-6746.406	-6972.710	-6587.755	-6396.202	-5757.415	-6731.134	-6578.787	-5535.892
Observations	3419	3341	3009	3147	3071	2765	3266	3189	2872

The proportional Odds Ratios from OLR are presented. Robust Standard Errors are in parentheses. *p< 0.10, **p< 0.05, ***p< 0.01; DRD4=0 if participant carries the 4R/4R genotype, 1 otherwise.

Computational model

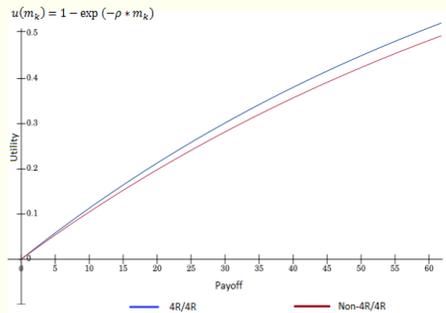
- Exponential utility function: $u(m_k) = -\exp(-\rho * m_k)$
 - where $\rho > 0$ is the Arrow-Pratt measure of risk aversion: higher $\rho \rightarrow$ more risk averse
- Parameter for risk preference: $\hat{\rho} = \hat{\rho}_0 + \hat{\beta} * X$
 - where X is the vector of observed individual characteristics & environmental factors
- MLE:
 - combining all 3 tasks
 - estimate coefficient ρ

Association between Risk Attitude and DRD4 exon III VNTR: Computational Method

	(a)	(b)	(c)
DRD4 Non-4R/4R	-0.001***	-0.001***	-0.001***
	(0.0002)	(0.0003)	(0.0003)
Female	0.002**	0.002**	0.002**
	(0.0003)	(0.0003)	(0.0003)
City	0.001**	0.001**	0.001**
	(0.0003)	(0.0003)	(0.0003)
Age	0.000	0.000	0.000
	(0.0001)	(0.0001)	(0.0001)
Father edu		0.000	0.000
		(0.0001)	(0.0001)
Mother edu		0.000	0.000
		(0.0001)	(0.0001)
Siblings		0.000	0.000
		(0.0001)	(0.0001)
Income level		0.000	0.000
		(0.0001)	(0.0001)
Constant	0.012**	0.011**	0.010**
	(0.0002)	(0.0014)	(0.0015)
Avg. ρ	0.012	0.012	0.012
(Std. dev.)	0.0004	0.0011	0.0011
Nest	0.029**	0.029**	0.029**
Log likelihood	-41203.410	-40984.986	-36014.337
Observations	67549	65941	59379
Clusters	3432	3353	3020

Clustered standard errors are in parentheses. * p < 0.10, ** p < 0.05, *** p < 0.01; The DRD4 exon III VNTR is coded as 4/4 genotype=0, otherwise=1.

Computational Model: An Illustration



Correlation between Risk Attitude and Personality Traits

	Risk Attitude					
	Financial investment		Even-chance lottery		Sure-bet	
	Odds Ratio	Std. Err.	Odds Ratio	Std. Err.	Odds Ratio	Std. Err.
NEO-PI-R						
Neuroticism	0.9940***	0.0018	0.9958**	0.0017	0.9987	0.0018
Extraversion	1.0053***	0.0019	1.0084***	0.0020	1.0035*	0.0019
Openness to experience	1.0068**	0.0024	1.0078***	0.0078	1.0034	0.0023
Agreeableness	0.9952**	0.0024	1.0005	0.0026	0.9997	0.0023
Conscientiousness	1.0012	0.0019	1.0017	0.0019	1.0018	0.0018
TCI-R						
Novelty seeking	1.0114***	0.0031	1.0170***	0.0034	1.0065**	0.0033
Harm avoidance	0.9916**	0.0026	0.9910***	0.0027	0.9945**	0.0025
Reward dependence	0.9962	0.0034	1.0078**	0.0032	1.0011	0.0033
Persistence	1.0043	0.0027	1.0060**	0.0025	1.0045	0.0025
Self-directedness	1.0003	0.0027	1.0007	0.0028	0.9995	0.0026
Cooperativeness	0.9975	0.0029	0.9998	0.0029	0.9999	0.0029
Self-transcendence	0.9975	0.0029	0.9998	0.0029	0.9999	0.0029

Association between DRD4 Exon III VNTR and Personality Traits

	DRD4 exon III VNTR		
	Coeff.	Std. Err.	P-value
NEO-PI-R			
Neuroticism	-1.2851	0.8611	0.136
Extraversion	-0.1357	0.7722	0.861
Openness to experience	-0.0077	0.6384	0.990
Agreeableness	-0.0363	0.6117	0.953
Conscientiousness	0.2701	0.7633	0.723
TCI-R			
Novelty seeking	0.2286	0.5532	0.679
Harm avoidance	-0.2762	0.7253	0.703
Reward dependence	-0.4549	0.5667	0.422
Persistence	-0.0083	0.6983	0.990
Self-directedness	-0.5798	0.6782	0.393
Cooperativeness	-0.1843	0.6065	0.761
Self-transcendence	0.4438	0.5477	0.418

Scores of each personality scales were used as dependent variable in separated linear regressions; DRD4 = 0 if participant carries the 4R/4R genotype, 1 otherwise. All regressions and estimations controlled for sex, city, and age.

Summary

- 4R allele of *DRD4* exon III VNTR is linked with higher risk aversion than the minor alleles in Han Chinese.
- Association between *DRD4* and risk attitude is not only observed with financial investment tasks, but can also be extended to more natural contexts.
- No significant association between *DRD4* and relevant personality traits.

Peripheral Serotonin Receptor 2A (*HTR2A*) Gene Expression and Loss Aversion

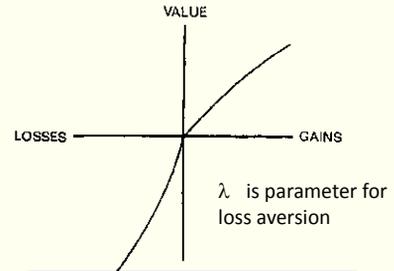
Yunfeng LU, Mikhail Monakhov,
Poh San LAI, Soo Hong CHEW,
Richard P. Ebstein

- For certain genes, e.g., serotonin receptor 2A (*HTR2A*), the level of mRNA measured in blood can serve as proxy for gene expression (Kohane & Valtchinov, 2012; Rollins, Martin, Morgan, & Vawter, 2010)
 - reflects genomic and epigenetic factors
- This approach does not work for *DRD4* which is not expressed in blood.



Genes & Environment

Structural Estimation of Value Function



$$u(x) = \begin{cases} x^\alpha, & \text{if } x \geq 0 \\ -\lambda(-x)^\alpha, & \text{if } x < 0. \end{cases} \quad (1)$$

Hypothesis

Serotonin Receptor (HTR2A) mRNA level in the blood relates positively to loss aversion.

5 Choice Tasks

- A1 = even-chance prospect
- A2 = even-chance hazard
- A3 = longshot prospect
- A4 = longshot hazard
- A5 = mixed hazard

	Probability 1	Probability 2	Prize 1	Prize 2
A1	50%	50%	\$60	\$0
A2	50%	50%	-\$15	\$0
A3	1%	99%	\$200	\$0
A4	2%	98%	-\$30	\$0
A5	50%	50%	\$30	-\$16

Design

- Subsample of 205 Singapore based subjects
- We adopt the price-list design

	Option A	Option B	Decision
1	50% of losing \$15, 50% of losing \$0	Losing \$8.00 for sure	A B
2	50% of losing \$15, 50% of losing \$0	Losing \$7.80 for sure	A B
3	50% of losing \$15, 50% of losing \$0	Losing \$7.60 for sure	A B
4	50% of losing \$15, 50% of losing \$0	Losing \$7.50 for sure	A B
5	50% of losing \$15, 50% of losing \$0	Losing \$7.40 for sure	A B
6	50% of losing \$15, 50% of losing \$0	Losing \$7.20 for sure	A B
7	50% of losing \$15, 50% of losing \$0	Losing \$7.00 for sure	A B
8	50% of losing \$15, 50% of losing \$0	Losing \$6.80 for sure	A B
9	50% of losing \$15, 50% of losing \$0	Losing \$6.60 for sure	A B
10	50% of losing \$15, 50% of losing \$0	Losing \$6.40 for sure	A B

Descriptive Statistics

Table 1. Summary Statistics

Variable	Observation	Mean	Std. Dev.	Min	Max
A1	205	5.14	2.75	0	10
A2	200	6.56	2.98	0	10
A3	201	5.82	3.17	0	10
A4	204	6.48	3.75	0	10
A5	165	4.72	3.23	0	10
HTR2A	205	2.96	0.95	-0.891	4.92
Female	205	0.47	0.50	0	1

Patterns in Switching Point

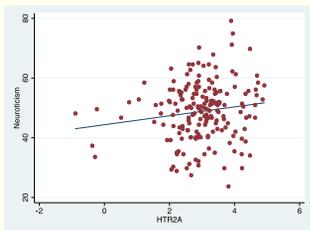
- Fourfold pattern of risk attitudes

Task	A1	A2	A3	A4	A5
Name	Moderate gain	Moderate loss	Longshot gain	Longshot loss	Mixture gamble
Risk aversion	153 74.6%	28 14%	52 25.9%	81 39.7%	131 79.4%
Risk neutral and risk loving	52 25.4%	172 86%	149 74.1%	123 60.3%	34 20.6%
Total observations	205	200	201	204	165

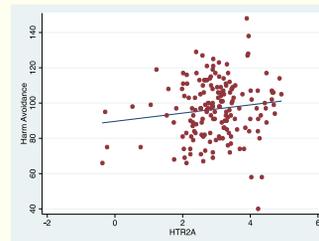
Main Results

Variable	(1)	(2)	(3)
β_1			
Constant	1.50 *** (.07)	1.47 * (0.80)	1.63 * (0.94)
<i>HTR2A</i>		-.15 ** (.06)	-.12 ** (.06)
Female		-.33 ** (.14)	-.23 ** (.14)
Age		-.02 (.04)	-.03 (.04)
β_2			
Constant	.95 *** (.02)	.79 *** (.15)	.95 *** (.02)
<i>HTR2A</i>		.02 (.01)	
Female		-.08 ** (.03)	
Age		.01 (.01)	
β_3			
Constant	.82 *** (.03)	.82 *** (.03)	.82 *** (.03)
<i>Log(u)</i>	1.38 *** (.08)	1.36 *** (.08)	1.37 *** (.07)
Observation	10250	10250	10250
Log likelihood	-6519.68	-6452.15	-6479.96

HTR2A and Neuroticism (NEO)



HTR2A and Harm Avoidance (TCI)

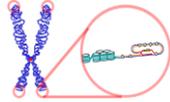
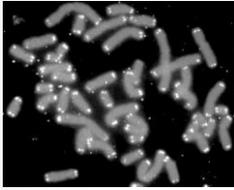


Conclusion

- Hypothesis is supported – Higher peripheral *HTR2A* gene expression level is associated with greater degree of loss aversion.
- Direction of association is consistent with previous findings on anxiety-related personality traits.
- First finding linking gene expression in blood with financial risk attitude.

**Relating Telomere (“end-part”) Length
with Temporal Discounting
and Risk Diversification**

Telomere in Nutshell



Human chromosomes (grey) capped by telomeres (white)

Telomere in Nutshell

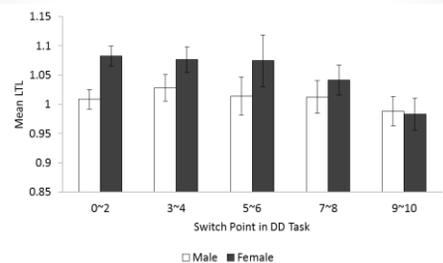
- **Cellular ageing** – Each time a cell divides, some of the telomere is lost. When the telomere becomes too short, the chromosome reaches a "critical length" and can no longer replicate. This means that a cell becomes "old" and dies.
- External factors may cause shortening of telomere length, such as cumulative life time stress, unhealthy lifestyle (smoking, alcohol abuse, insufficient sleep durations, etc)

Temporal Discounting

	Tomorrow	31 days later	Decision
1	\$100	\$101	A <input type="checkbox"/> B <input type="checkbox"/>
2	\$100	\$104	A <input type="checkbox"/> B <input type="checkbox"/>
3	\$100	\$107	A <input type="checkbox"/> B <input type="checkbox"/>
4	\$100	\$110	A <input type="checkbox"/> B <input type="checkbox"/>
5	\$100	\$113	A <input type="checkbox"/> B <input type="checkbox"/>
6	\$100	\$116	A <input type="checkbox"/> B <input type="checkbox"/>
7	\$100	\$119	A <input type="checkbox"/> B <input type="checkbox"/>
8	\$100	\$122	A <input type="checkbox"/> B <input type="checkbox"/>
9	\$100	\$125	A <input type="checkbox"/> B <input type="checkbox"/>
10	\$100	\$128	A <input type="checkbox"/> B <input type="checkbox"/>

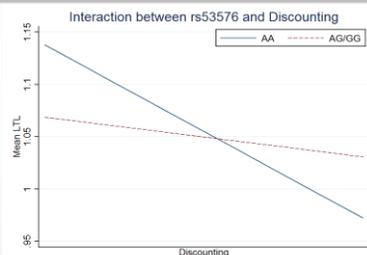
Discounting and Leukocyte telomere length

- Discount rate is negatively correlated with telomere length (Coefficient = -0.005; $P < 0.05$)
- The correlation is mainly driven by female sample (Coefficient = -0.009, $P < 0.01$)



Interaction between OXTR gene and Discounting on Telomere Length (Female Sample)

- Individuals with the G allele are optimistic and empathetic;
- The G allele would reduce the negative impact of impatience on ageing (Coefficient = 0.013, $P < 0.05$)
- Involvement of OXTR accounts for gender difference

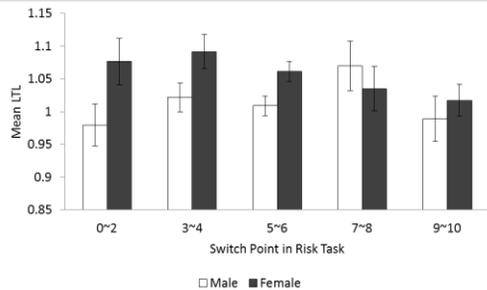


Risk Diversification in Portfolio Choice Task

	Investment		Total Earnings		
	√	Cash	Invest	Correct Guess	Incorrect Guess
1		\$27.00	\$0.00	\$27.00	\$27.00
2		\$24.00	\$3.00	\$31.50	\$24.00
3		\$21.00	\$6.00	\$36.00	\$21.00
4		\$18.00	\$9.00	\$40.50	\$18.00
5		\$15.00	\$12.00	\$45.00	\$15.00
6		\$12.00	\$15.00	\$49.50	\$12.00
7		\$9.00	\$18.00	\$54.00	\$9.00
8		\$6.00	\$21.00	\$58.50	\$6.00
9		\$3.00	\$24.00	\$63.00	\$3.00
10		\$0.00	\$27.00	\$67.50	\$0.00

Risk attitude and telomere length

- Risk aversion is negatively correlated with telomere length in female sample (Coefficient = -0.0095, $P < 0.05$)

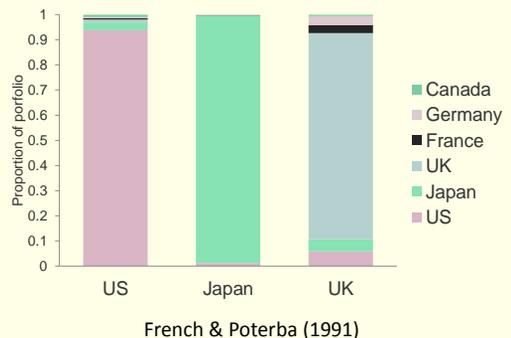


Imaging Genetics of Familiarity Bias

6 Major Puzzles in International Macroeconomics: Is There a Common Cause? Obstfeld & Rogoff (2000, NBER)

- *Home-bias portfolio puzzle*: Home investors prefer to hold home equity assets
- *Home-bias-in-trade puzzle*: People have strong preference for consumption of home goods
- *Consumption correlations puzzle*: Why isn't consumption more highly correlated across OECD countries?
- *Feldstein-Horioka puzzle*: Current-account imbalances tend to be small relative to saving and investment when measured over any sustained period
- *Purchasing-power-parity puzzle*: Half-life of real exchange-rate innovations tend to be three to four years
- *Exchange-rate disconnect puzzle*: Exchange rates are volatile and disconnected from fundamentals

International Home Market Bias



Familiarity breeds Investment

Huberman (2001, RFS)

Shareholders of a Regional Bell Operating Company (RBOC) tend to live in the area which it serves, and an RBOC's customers tend to hold its shares rather than other RBOCs' equity. The geographic bias of the RBOC investors is closely related to the general tendency of households' portfolios to be concentrated, of employees' tendency to own their employers' stocks in their retirement accounts, and to the home country bias in the international arena. Together, these phenomena provide compelling evidence that people invest in the familiar while often ignoring the principles of portfolio theory.

- Also, "Home Market Bias at Home" Coval and Moskowitz (2002, JF)

Small Worlds:

Modeling Preference among Sources of Uncertainty

Chew and Sagi (2008, JET)

- Introduce *small worlds* as homogeneous collections of events on which the decision maker behaves probabilistically
- Provides foundation for modelling source-dependent risk attitude.
 - Accounts for ambiguity aversion in terms of comparative risk attitude across small worlds.

Immediate Deliverable

Enables modelling of source preference without worrying about whether you'd violate transitivity!

different vNM utility functions to model
distinct attitudes towards risks from
different sources of uncertainty

User Friendly Example

Consider a CRRA EU form:

$$E(x^r, F^s)$$

where F refers to a probability distribution based on RV defined on a source of uncertainty s .

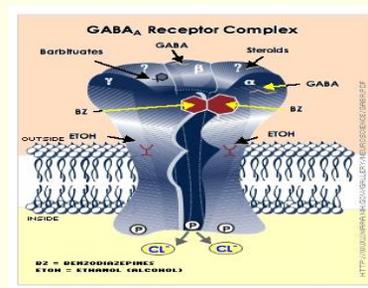
User Friendly Example ... Cont'd

Consider a source-dependent CRRA EU form:

$$E(x^{r(s)}, F^s)$$

- Can bound behavior of $r(\cdot)$, e.g.:
 - risk versus ambiguity,
 - strategic uncertainty,
 - familiarity

Imaging Genetics Study of Familiarity Bias focusing on GABA



GABA and Anxiety

- Major inhibitory neurotransmitter in nervous system acting as brake to prevent excitatory transmission, e.g., dopaminergic or serotonergic, from reaching GABAergic-neuron rich regions
- Evidence supports notion that dysfunction of GABAergic system contributes to anxiety (see review by Kalueff and Nutt, 1996)
- Diazepam, e.g., Valium, as agonists for Type A GABA receptor ($GABA_A$), used for anxiety disorders (Haefely, 1992; Sieghart, 1992)

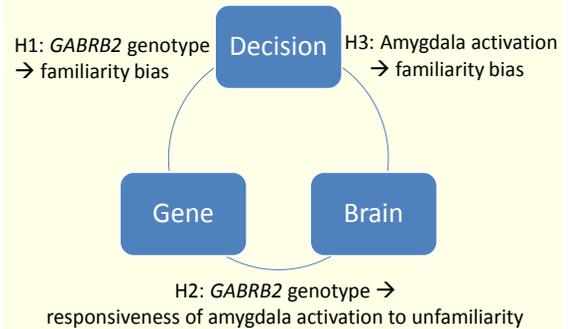
GABA and Anxiety



GABRB2 as Candidate Gene

- We hypothesize that individual differences in the effectiveness of the GABAergic systems in coping with anxiety may explain differences in familiarity bias
- *GABRB2* is the β_2 subunit gene forming the GABA_A receptor sitting on chromosome 5

Gene-Brain-Decision Hypothesis



Study 1 establishes gene-behavior link

- 325 Beijing based subjects
- Betting on whether temperature is odd or even

Beijing: RMB 11



Tokyo: RMB 13

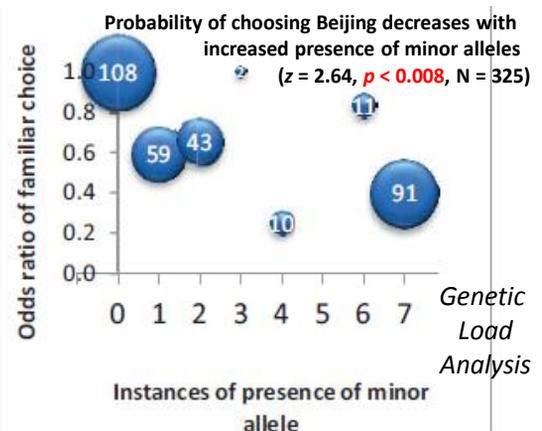


10 GABA SNPs

dbSNP ID	Variation (M/m)	Minor allele frequency (%)	Genotype Call rate	z-scores	p-values
	T/C	19.25	322	2.80	0.005
	T/C ^B	40.40	323	2.47	0.014
	C/A	19.00	321	2.44	0.015
	T/C	16.40	317	2.40	0.016
	A/G	27.19	320	2.31	0.021
	G/C	16.41	323	2.30	0.022
	G/T	15.69	325	2.27	0.023
	G/C	8.33	324	0.43	0.668
	G/A	13.08	325	-0.23	0.815
	C/T	13.35	322	-0.05	0.958

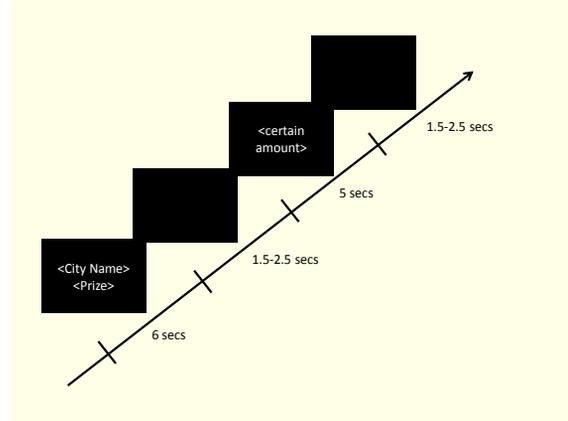
Allele - Genotype

- Allele
 - Minor allele (m)
 - Major allele (M)
- Genotype
 - Homozygous minor (mm)
 - Heterozygous (mM)
 - Homozygous major (MM)



Study 2 establishes G-B-D link with imaging

- 37 subjects selected from the 325 subjects using most balanced SNP
- Matched genotype
 - CC or CT: 22 (minor)
 - TT: 15 (major)
- 80 trials (20 cities varying degree of familiarity)
 - Varying prizes and certainty amounts
- Self-reported familiarity ratings of the 20 cities were collected after the scanning



City	In Chinese	Average Familiarity (s.d.)
Shanghai	上海	1.93 (2.45)
Hangzhou	杭州	1.78 (2.41)
Tianjin	天津	1.73 (2.66)
Wuhan	武汉	1.49 (2.90)
Chengdu	成都	1.34 (2.81)
Guangzhou	广州	1.17 (2.68)
Shenzhen	深圳	1.07 (2.80)
Harbin	哈尔滨	0.93 (2.63)
Sanya	三亚	0.85 (2.38)
Kunming	昆明	0.20 (2.72)
Baotou	包头	-0.63 (3.23)
Liuzhou	柳州	-0.98 (3.09)
Yibin	宜宾	-1.27 (3.20)
Wuhu	芜湖	-1.54 (3.25)
Jining	济宁	-1.71 (3.00)
Changde	常德	-1.76 (3.26)
Golmud	格尔木	-2.12 (3.28)
Jinzhou	锦州	-2.22 (3.07)
Yingtian	鹰潭	-3.17 (2.96)
Tongchuan	铜川	-3.44 (2.72)

Post Scanning Familiarity Rating

Familiarity-Dependent Expected utility

• Source dependent EU specification

- having possibly distinct SEU preferences, with different von Neumann-Morgenstern (vNM) utility functions for risks arising from different sources of uncertainty

$$- SEU_{\text{San Francisco}} SEU_{\text{Istanbul}} SEU_{\text{Singapore}} \dots$$

$$U(p, x) = p x^{r_0 + r_1 f}$$

where f is the familiarity rating

Unconditional Familiarity Bias Not Observed

- Estimation (Harrison 2007) using STATA to estimate a **Smithian model of familiarity bias**

$$U(p, x) = p x^{r_0 + r_1 f}$$

$$r_0 = .7426$$

$$r_1 = -.001808 \quad (p > .4)$$

Genotype-Dependent Familiarity Bias Observed

$$u(x, p) = p \cdot x^{r_0 + r_{0,G} \text{Genotype} + (r_1 + r_{1,G} \text{Genotype}) \times \text{fam}}$$

where

$\text{Genotype} = 0$, if minor allele (CC or CT)

$\text{Genotype} = 1$, if major allele (TT)

$$r_0 = .7560$$

$$r_{0,G} = -.03597 \quad (p > 0.3)$$

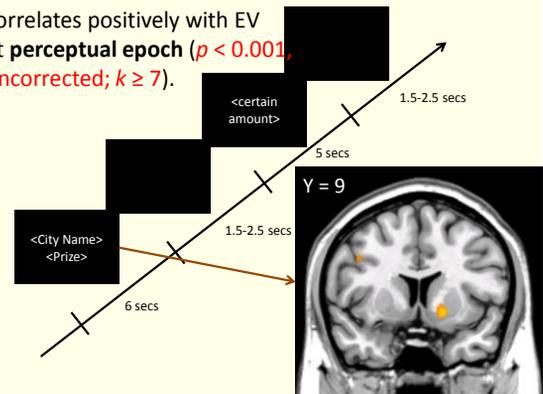
$$r_1 = -.006471 \quad (p > 0.1)$$

$$r_{1,G} = .01072 \quad (p < 0.05)$$

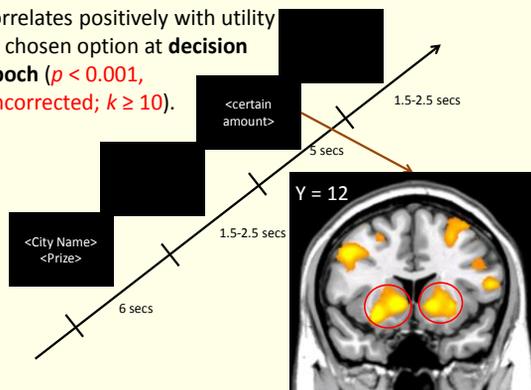
Reassuring Finding – Reward

- **EV correlates positively with activity in the ventral striatum**
 - Reward prediction (e.g., Breiter et al. 2001; Hsu et al. 2005; Knutson et al. 2003; Tom et al. 2007)
- **Decision utility (utility of chosen option) correlates positively with activity in the striatum**

Activation in ventral striatum correlates positively with EV at **perceptual epoch** ($p < 0.001$, uncorrected; $k \geq 7$).



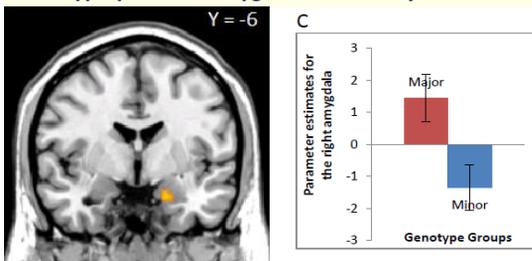
Activation in bilateral striatum correlates positively with utility of chosen option at **decision epoch** ($p < 0.001$, uncorrected; $k \geq 10$).



Novel Finding – Amygdala

- Amygdala activation
 - Predicts degree of familiarity bias
 - Predicted by genotypes

Genotype predicts Amygdala Sensitivity to Familiarity



Left: Correlate with degree of familiarity bias.

Right. TT group exhibits higher amygdala response to unfamiliarity than non-TT group ($p < 0.02$).

Revisiting Keynes' Quote

“Most, probably, of our decisions to do something positive, the full consequences of which will be drawn out over many days to come, can only be taken as the result of **animal spirits** – a spontaneous urge to action rather than inaction, and **not** as the outcome of a weighted average of quantitative benefits multiplied by quantitative probabilities”

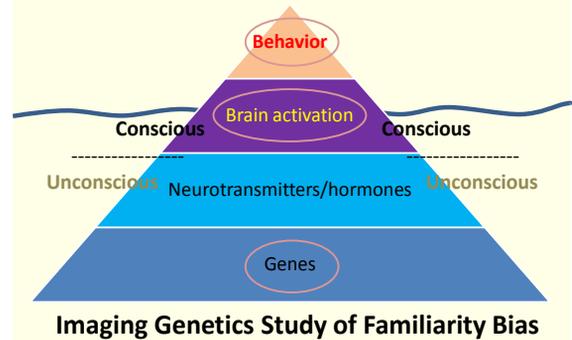
General Theory, 1936

Somatic Marker Hypothesis

Damasio's Rejoinder to Keynes

- Somatic states triggered by primary inducers via amygdala are fast, automatic, obligatory, without much thought/effort before one can figure out what happened.
- Somatic states influence decision making **nonconsciously** via brainstem and ventral striatum and **consciously** via higher cortical cognitive processing.
- **Hypothesis:** Somatic markers direct **attention** towards advantageous options, simplifying decision making.
- **Bottom line:** **Gut feeling** involving somatic markers inducing associated affective states – physiological and neural – can impact decision making!
– *Is this surprising?*

Beyond Revealed Choice



Homo/Bio-Economicus

Unbounded

Bounded

	Unbounded	Bounded
Consciousness	Full	Limited
• Attention • Encoding • Storage • Recall		• Admits possibility of fantasy & delusion
Computational Ability	Unbounded	Bounded
Preference-Choice Coherence	Complete	Limited
	• Only conscious choice	• Admits influence of the unconscious

Concluding Remarks

- Gene-Brain-Decision hypothesis supported.
– Specific minor allele is under positive selection and acts as agonist for GABA_A
- **Market implication:** Between 'home' and 'foreign', the amygdala 'GABAergic circuits' may **nudge** one to choose the familiar over the less familiar to ameliorate anxiety
- Might familiarity bias be the **Common Cause** of the 6 Puzzles in International Macroeconomics?