Models of human decision-making

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OVERVIEW

1. MAGNITUDE PERCEPTION WITHOUT INTERNAL SCALES?
2. DECISION WITHOUT INTERNAL SCALES?
3. VALUATION WITHOUT INTERNAL SCALES?
4. REINFORCEMENT LEARNING MEETS PRISONER’S DILEMMA
1. MAGNITUDE PERCEPTION WITHOUT INTERNAL SCALES?

ABSOLUTE MAGNITUDE IDENTIFICATION: THE PUZZLE

- E.g., assign tones to numbers (1-5; 1-7 etc) by loudness
- Its hard!
- As if about five bins...
SIMILAR RESULTS ACROSS TYPES OF MAGNITUDE

The Limit in Information Transmitted for a Variety of Stimulus Attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Source</th>
<th>Limit/bits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency of a tone</td>
<td>Hartman (1954)</td>
<td>2.3</td>
</tr>
<tr>
<td></td>
<td>Pollack (1952)</td>
<td>2.3</td>
</tr>
<tr>
<td></td>
<td>W. Siegel (1972)</td>
<td>1.6</td>
</tr>
<tr>
<td>Intensity of a tone</td>
<td>Garner (1953)</td>
<td>2.2</td>
</tr>
<tr>
<td></td>
<td>Norwich, Wong, and Sagi (1998)</td>
<td>2.2</td>
</tr>
<tr>
<td></td>
<td>Braida and Durlach (1972; from calculations by</td>
<td>1.9</td>
</tr>
<tr>
<td></td>
<td>Marley and Cook, 1984)</td>
<td></td>
</tr>
<tr>
<td>Saltiness of a solution</td>
<td>Beebe-Center, Rogers, and O’Connell (1955)</td>
<td>1.7</td>
</tr>
<tr>
<td>Sweetness of a solution</td>
<td>Beebe-Center, Rogers, and O’Connell (1955)</td>
<td>1.7</td>
</tr>
<tr>
<td>Intensity of odor</td>
<td>Engen and Pfaffmann (1959)</td>
<td>1.5</td>
</tr>
<tr>
<td>Bissection of a scale</td>
<td>Hake and Garner (1951)</td>
<td>3.2</td>
</tr>
<tr>
<td></td>
<td>Coonan and Klemmer (as reported in Miller, 1956)</td>
<td>3.2/3.9</td>
</tr>
<tr>
<td>Line length</td>
<td>Baird, Romer, and Stein (1970)</td>
<td>2.4</td>
</tr>
<tr>
<td></td>
<td>Pollack (as cited in Miller, 1956)</td>
<td>2.6/3.0</td>
</tr>
<tr>
<td>Angle of inclination</td>
<td>Muller, Sidorsky, Shlinske, Alluisi, and Fitts</td>
<td>4.5</td>
</tr>
<tr>
<td></td>
<td>Pollack (as cited in Miller, 1956)</td>
<td>2.8/3.3</td>
</tr>
<tr>
<td>Area</td>
<td>Pollack (as cited in Miller, 1956)</td>
<td>2.6/2.7</td>
</tr>
<tr>
<td>Area of a circle</td>
<td>Alluisi and Sidorsky (1958)</td>
<td>2.7</td>
</tr>
<tr>
<td>Area of a square</td>
<td>Eriksen and Hake (1955a)</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>Eriksen and Hake (1955b)</td>
<td>2.8</td>
</tr>
<tr>
<td>Area of complex figure</td>
<td>Baird, Romer, and Stein (1970)</td>
<td>2.1</td>
</tr>
<tr>
<td>Hue</td>
<td>Chapannis and Halsey (1956)</td>
<td>3.1</td>
</tr>
<tr>
<td></td>
<td>Eriksen and Hake (1955b)</td>
<td>3.3</td>
</tr>
<tr>
<td></td>
<td>Conover (1959; as cited in Garner, 1962)</td>
<td>3.5</td>
</tr>
<tr>
<td>Brightness</td>
<td>Eriksen and Hake (1955b)</td>
<td>2.3</td>
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<tr>
<td>Cutaneous electrical intensity</td>
<td>Hawkes and Warm (1960)</td>
<td>1.7</td>
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</tbody>
</table>

Note. Limits separated by a slash denote limits for short and long duration stimulus exposure.
AND SPACING HARDLY MATTERS
A RELATIVE JUDGMENT MODEL

- Relative judgment model (Stewart et al, 2005, cf. Laming)
- Consider relative sizes of “jumps” between stimuli
- Mostly, current and last jump (but not entirely)

An even simpler model (may) work purely by binary comparisons of current stimulus vs. prior stimuli, gaps, etc.
2. DECISION WITHOUT INTERNAL SCALES?

WHAT THE COGNITIVE SYSTEM DOESN’T HAVE

No underlying “psychoeconomic” scales for
  - utility
  - subjective probability
  - time

∴ there are no relationships (e.g., trade-offs) between scales
WHAT THE COGNITIVE SYSTEM DOES HAVE

• Only binary judgments
  • $>$, $<$, $=$

• Values are compared with a small sample of “anchors”
  • from memory
  • from context

• All dimensions (gains, losses, delay, probability, quality, etc) are equal, despite different roles in “rational” model

• Preferences are constructed, depending on sampled anchor values (e.g., Slovic, 1995)
What is the utility of $300? Here its 3rd of 5 items
KEY ISSUE: HOW DO PEOPLE SAMPLE COMPARISON ANCHORS?

From memory

- Assume that samples from memory mirror distribution in the “world” (Anderson)
- Estimate using external “proxies” (e.g., via google™)

From task context

- e.g., choice can be affected by “irrelevant” options
- Manipulate experimentally
DIMINISHING “UTILITY” OF MONEY

• Utility theory

• DbS considers distribution of amounts of money
  – Only rank matters
  – So changes in money value will be valued by change in rank position in samples of amounts

• Implies risk aversion:
• £50 for certain preferred to 50% chance of £100?
ESTIMATED GAINS/LOSSES FROM A UK HIGH STREET BANK*

*Bank data analysed by Rich Lewis
RANK VS. MONEY GAIN
(COMPLETE SAMPLE)

Analogy of diminishing marginal utility of money in economics
+$300$ IS COMPARED WITH 5 RANDOM CREDITS

Probability distribution of relative ranks
relative rank of 0 = worst; relative rank of 1 = best.
COMBINE DISTRIBUTIONS FROM DIFFERENT CREDITS

The ‘bend’ in relative rank, for small samples (left) is analogous to the curvature in the full credit-rank sample (right)
LOSSES LOOM LARGER THAN GAINS
(credits and debits, bank data)

More small losses than small gains:
∴ £10 loss looms larger (in ranks)
PROSPECT THEORY’S VALUE FUNCTION, RECONSTRUCTED  
(cf. Kahneman & Tversky, 1979)

- -ively accelerating for gains
- +ively accelerating for losses
- losses worse than gains
- Discontinuity at zero
SIMILARLY, FOR RISK AND TIME...

- Judged probability (Gonzalez & Wu, 1999)
- Time discounting (google)
3. VALUATION WITHOUT INTERNAL SCALES?

ECONOMICS TYPICALLY ASSUMES ENDOGENOUS PREFERENCES AND STABLE TRADE-OFFS BETWEEN GOODS AND MONEY

• E.g, can willingness-to-pay prices provide a measuring scale for experience?

• With traded goods, confound of known prices; so use novel, non-traded, stimuli.
  
  – Ariely, Loewenstein, and Prelec (2003) found that willingness-to-pay prices to avoid annoying sounds were biased towards price anchors, but were locally coherent (“coherent arbitrariness”)

  – Current aim: to test preference formation at its root: direct test of (in)stability of valuation…
WE DESIGNED AN EXPERIMENTAL “MARKET” WHERE PEOPLE PAY MONEY TO AVOID PAINFUL ELECTRICAL SHOCKS

• Why use shocks?
  – Tangible experience but different from everyday stimuli
  – Can be evaluated and ‘consumed’ immediately
  – Consistently judged as aversive across people
  – Resistant to habituation through an experiment
  – Underlying neurophysiology is fairly well-understood
  – Affective properties dissociable from sensory properties

• Pain (and pain relief) is an important literature with great practical significance

• Observing relativistic effects would imply that the price consumers pay (e.g., for health) may be substantially determined by
  – Current context
  – Recent experiences
EACH TRIAL INVOLVED BUYING RELIEF IN A COMPUTERISED SECOND PRICE AUCTION

- You receive 40p
- You will receive a shock
- Select price to avoid 15 further shocks
- Market price is determined randomly
- You offered 14p
- Market price was 4p
  Sale authorised
  Sale price = 4p
WE USED THREE PAIN LEVELS WITHIN-SUBJECTS AND TWO MONETARY ENDOWMENTS BETWEEN-SUBJECTS

- Pain magnitudes were presented in pairs in three blocks of ten trials.

- Two endowment conditions
  - £0.40 per trial
  - £0.80 per trial
AVERAGE PRICE OFFERS DEPENDING ON ENDOWMENT AND CONTEXT PAIRING
DISCREPANCY PROVIDED BY THE CONTEXT INCREASES THROUGH EACH BLOCK

Difference between the price offers for medium pain in Low-Medium and Medium-High

- Red line: 80p, $R^2 = 0.79$
- Blue line: 40p, $R^2 = 0.51$

Payoff Difference vs. Round
ANALYSIS IN TERMS OF DEMAND CURVES

Demand curve captures quantity of pain relief expected to sell at different prices.

Economic theory assumes that demand curves are fixed by stable consumer preferences (and prior to information about price).

Prices then determined by interaction with supply curve.

All curves flipped from standard orientation.
DEMAND CURVE FOR RELIEF FROM LOW PAIN

Demand for relief of Low pain

- Low-Medium (80p)
- Low-High (80p)
- Low-Medium (40p)
- Low-High (40p)
DEMAND CURVE FOR RELIEF FROM MEDIUM PAIN

Demand for relief of Medium pain
- Low-Medium (80p)
- Medium-High (80p)
- Low-Medium (40p)
- Medium-High (40p)

Quantity

Price (pence)
DEMAND CURVE FOR RELIEF FROM HIGH PAIN

Demand for relief of high pain:
- Low-High (80p)
- Medium-High (80p)
- Low-High (40p)
- Medium-High (40p)

Price (pence) vs. Quantity

0 10 20 30 40 50 60 70 80
0 20 40 60 80 100 120 140 160 180 200
SECOND EXPERIMENT USED A WITHIN-SUBJECT DESIGN WHERE THE TWO ENDOWMENTS VARIED RANDOMLY BETWEEN TRIALS

• ... replicated all our original results

• Confirmed that the value of, say £0.30, is not the same, whether chosen from £0.40 or £0.80 endowment
  – Failure of rationality as the value of £0.30 outside the experiment is the same (the foregone good is the same)

  – cf. existence of risk aversion with small stakes gambles (Rabin 2001)
SUMMARY AND CONCLUSIONS 1
THE UNANCHORED DECISION MAKER?

1. People may not have access to absolute perceptual magnitudes; but use a relative/rank-based coding

2. Decision making variables (monetary value, probability, time) computed on-line computation by ranks
   Hence, instability of risk-aversion, loss-aversion, etc…

3. Value of “pain” (and other subjective experience) is unstable
SUMMARY AND CONCLUSIONS 2
FEEDBACK LOOPS AND PRICE/VALUE INSTABILITY?

• So prices are likely to be unanchored
  – Booms and crashes?

• People will tend to view the status quo as natural
  – Current house prices soon seem ‘normal’
  – Wage increases rapidly ‘fade out’ as contributors to happiness
    • And even lottery wins

• Tax and other cost changes have much less long-term impact on behaviour than is typically expected

PEOPLE KNOW THE PRICE OF EVERYTHING, BUT THE VALUE OF NOTHING
4. REINFORCEMENT LEARNING MEETS PRISONER’S DILEMMA

If playing C, it would receive more reinforcement if it were to play D.

Reinforcement learning gradually eliminates C in favour of D.
SIMPSON’S PARADOX MEETS PRISONER’S DILEMMA: AN EXPERIMENT

• How a positive correlation between agents’ behaviour can arise?

<table>
<thead>
<tr>
<th></th>
<th>Other 1</th>
<th>Other 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>You 1</td>
<td>-5</td>
<td>-11</td>
</tr>
<tr>
<td></td>
<td>-5</td>
<td>0</td>
</tr>
<tr>
<td>You 2</td>
<td>0</td>
<td>-6</td>
</tr>
<tr>
<td></td>
<td>-11</td>
<td>-6</td>
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very non-cooperative
Nasty game

<table>
<thead>
<tr>
<th></th>
<th>Other 1</th>
<th>Other 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>You 1</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>You 2</td>
<td>11</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>1</td>
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</table>

very cooperative
Nice game
SIMPSON’S PARADOX MEETS PRISONER’S DILEMMA: AN EXPERIMENT

Results: Cooperation rate

![Graph showing cooperation rate over rounds for Nice, Nasty, and Mixed strategies. ]
SIMPSON’S PARADOX MEETS PRISONER’S DILEMMA: AN EXPERIMENT

Our explanation for this effect requires that players’ choices are correlated in the Mixed condition.

<table>
<thead>
<tr>
<th>Decision</th>
<th>Nice games</th>
<th>Nasty games</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperate</td>
<td>30%</td>
<td>8%</td>
</tr>
<tr>
<td>Defect</td>
<td>20%</td>
<td>42%</td>
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</table>
**SIMPSON’S PARADOX MEETS PRISONER’S DILEMMA: AN EXPERIMENT**

Average payoff for playing C and D in each of the three conditions

<table>
<thead>
<tr>
<th>Decision</th>
<th>Nasty</th>
<th>Nice</th>
<th>Mixed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperate</td>
<td>-40.4</td>
<td>17.6</td>
<td>19.5</td>
</tr>
<tr>
<td>Defect</td>
<td>-30.9</td>
<td>19.1</td>
<td>-13.8</td>
</tr>
</tbody>
</table>
How the Simpson’s paradox has biased player’s judgment of the utility of each strategy in the Mixed condition?
MODEL AND MULTI-AGENT SIMULATION

\[ P(C) = \frac{U(C)}{U(C) + U(D)} \]

\( \text{Herrnstein’s Matching Law} \quad (1) \)

\[ P(C \mid nasty) = kP(C \mid nice) \quad 0 < k < 1 \quad (2) \]

\[ P(C) = \left\{ P(C \mid nice) + P(C \mid nasty) \right\}/2 \quad (3) \]
MULTI-AGENT SIMULATION: COORDINATION

![Graph showing cooperation rate over rounds for Mixed, Nice, and Nasty strategies.](image-url)
Percentage of C and D responses in the Mixed condition show coordination of responses

<table>
<thead>
<tr>
<th>Decision</th>
<th>Nice games</th>
<th>Nasty games</th>
</tr>
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<tbody>
<tr>
<td>Cooperate</td>
<td>36%</td>
<td>8%</td>
</tr>
<tr>
<td>Defect</td>
<td>11%</td>
<td>44%</td>
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MULTI-AGENT SIMULATION: REINFORCEMENT

Mixed

Nice

Nasty
MULTI-AGENT SIMULATION: REINFORCEMENT

Average payoff for playing C and D in each of the three conditions:

<table>
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<tr>
<th>Decision</th>
<th>Nasty</th>
<th>Nice</th>
<th>Mixed</th>
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<tbody>
<tr>
<td>Cooperate</td>
<td>9.1</td>
<td>9.4</td>
<td>22.4</td>
</tr>
<tr>
<td>Defect</td>
<td>20.2</td>
<td>16.1</td>
<td>17.3</td>
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</table>
COOPERATION VIA REINFORCEMENT LEARNING

• Any force that makes people liable to correlate their responses (e.g., kin, reciprocation, environmental variations) can lead to C being preferred by a reinforcement learner

• With potentially associated “Good Karma illusion”

• A cognitive error may help maintain human cooperation