Lionel Robbins Memorial Lectures:
The Psychology of Saving and Investment

David Laibson
Harvard University and NBER
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The Psychology of Saving and Investment

Lecture 1: Intertemporal Choice

Lecture 2: Investment for Dummies (Household Finance)

Lecture 3: Sticky biases and the Curse of Education (Behavioral IO)
Conceptual Outline

• People are not internally consistent decision-makers
• Internal conflicts can be modeled and measured
• Conflicts and confusion lead people to behave passively
• Defaults are more influential than (all?) other interventions that have been studied
• In some cases competitive markets protect people from making mistakes, but in many cases competitive markets provide little or no protection to imperfectly rational agents
Lecture 1: Intertemporal Choice

1. Motivating experimental evidence
2. Theoretical framework
3. Field evidence
4. Neuroscience foundations
5. Neuroimaging evidence
   – Study 1: Amazon gift certificates
   – Study 2: chips and juice
1. Motivating Experiments

A Thought Experiment

Would you like to have
A) 15 minute massage now
   or
B) 20 minute massage in an hour

Would you like to have
C) 15 minute massage in a week
   or
D) 20 minute massage in a week and an hour
Read and van Leeuwen (1998)

If you were deciding today, would you choose fruit or chocolate for next week?
Patient choices for the future:

Choosing Today | Eating Next Week

Today, subjects typically choose fruit for next week. | 74% choose fruit

Time
Impatient choices for today:

Choosing and Eating Simultaneously

If you were deciding today, would you choose fruit or chocolate for today?

Lindt
SWISS PREMIUM CHOCOLATE
Milk Chocolate
Time Inconsistent Preferences:

Choosing and Eating Simultaneously

70% choose chocolate
Read, Loewenstein & Kalyanaraman (1999)

Choose among 24 movie videos
- Some are “low brow”: *Four Weddings and a Funeral*
- Some are “high brow”: *Schindler’s List*

- Picking for tonight: 66% of subjects choose low brow.
- Picking for next Monday: 37% choose low brow.
- Picking for second Monday: 29% choose low brow.

Tonight I want to have fun…
next week I want things that are good for me.
Extremely thirsty subjects

• Choosing between, less juice now or more juice in 5 minutes, 60% of subjects choose the former.
• Choosing between less juice in 20 minutes or more juice in 25 minutes, 30% of subjects choose the former.

• We estimate that the 5-minute discount rate is 50% and the “long-run” discount rate is 0%.
• Ramsey (1930s), Strotz (1950s), & Herrnstein (1960s) were the first to understand that discount rates are higher in the short run than in the long run.
2. Theoretical Framework

- Classical functional form: exponential functions.
  
  \[ D(t) = \delta^t \]
  
  \[ D(t) = 1, \delta, \delta^2, \delta^3, ... \]
  
  \[ U_t = u_t + \delta u_{t+1} + \delta^2 u_{t+2} + \delta^3 u_{t+3} + ... \]

- But exponential function does not show instant gratification effect.

- Discount function declines at a constant rate.

- Discount function does not decline more quickly in the short-run than in the long-run.
Exponential Discount Function

Discounted value of delayed reward

Week (time = t)

-\frac{D'(t)}{D(t)} = rate of decline of a discount function

Constant rate of decline
Discount Functions

- **Exponential:** Rapid rate of decline in short run.
- **Hyperbolic:** Slow rate of decline in long run.
An exponential discounting paradox.

Suppose people discount at least 1% between today and tomorrow.

Suppose their discount functions were exponential.
Then 100 utils in t years are worth $100 \times e^{-0.01 \times 365 \times t}$ utils today.

- What is 100 today worth today? 100.00
- What is 100 in a year worth today? 2.55
- What is 100 in two years worth today? 0.07
- What is 100 in three years worth today? 0.00
An Alternative Functional Form

Quasi-hyperbolic discounting
(Phelps and Pollak 1968, Laibson 1997)

\[ D(t) = 1, \beta \delta, \beta \delta^2, \beta \delta^3, \ldots \]

\[ U_t = u_t + \beta \delta u_{t+1} + \beta \delta^2 u_{t+2} + \beta \delta^3 u_{t+3} + \ldots \]

\[ U_t = u_t + \beta [\delta u_{t+1} + \delta^2 u_{t+2} + \delta^3 u_{t+3} + \ldots] \]

\(\beta\) uniformly discounts all future periods.
\(\delta\) exponentially discounts all future periods.
Building intuition

- To build intuition, assume that $\beta = \frac{1}{2}$ and $\delta = 1$.
- Discounted utility function becomes
  \[ U_t = u_t + \frac{1}{2} [u_{t+1} + u_{t+2} + u_{t+3} + ...] \]
- Discounted utility from the perspective of time $t+1$.
  \[ U_{t+1} = u_{t+1} + \frac{1}{2} [u_{t+2} + u_{t+3} + ...] \]
- Discount function reflects dynamic inconsistency: preferences held at date $t$ do not agree with preferences held at date $t+1$. 
Procrastination  

- Assume that $\beta = \frac{1}{2}$ and $\delta = 1$.
- Suppose exercise (cost 6) generates delayed benefits (value 8).
- When will you exercise?
  
- Exercise Today: $-6 + \frac{1}{2} [8] = -2$
- Exercise Tomorrow: $0 + \frac{1}{2} [-6 + 8] = 1$

- Agent would like to make plans today to exercise tomorrow.
- Agent won’t follow through without commitment.
3. Field Evidence
Della Vigna and Malmendier (2004)

- Average cost of gym membership: $75 per month
- Average number of visits: 4
- Average cost per visit: $19
- Cost of “pay per visit”: $10

- **Survey**
  - Mailed to 590 employees (random sample)
  - 195 usable responses
  - Matched to administrative data on actual savings behavior
- **Consider a population of 100 respondents**
  - 68 report saving too little
  - 24 of 68 plan to raise 401(k) contribution in next 2 months
  - Only 3 of 24 actually do so in the next 4 months
Laibson, Repetto, and Tobacman (2007)

Use MSM to estimate discounting parameters:
   – Substantial illiquid retirement wealth: $W/Y = 3.9$.
   – Extensive credit card borrowing:
     • 68% didn’t pay their credit card in full last month
     • Average credit card interest rate is 14%
     • Credit card debt averages 13% of annual income
   – Consumption-income comovement:
     • Marginal Propensity to Consume $= 0.23$
       (i.e. consumption tracks income)
LRT Simulation Model

- Stochastic Income
- Lifecycle variation in labor supply (e.g. retirement)
- Social Security system
- Life-cycle variation in household dependents
- Bequests
- Illiquid asset
- Liquid asset
- Credit card debt

- Numerical solution (backwards induction) of 90 period lifecycle problem.
LRT Results:

\[ U_t = u_t + \beta [\delta u_{t+1} + \delta^2 u_{t+2} + \delta^3 u_{t+3} + ...] \]

- \( \beta = 0.70 \) (s.e. 0.11)
- \( \delta = 0.96 \) (s.e. 0.01)
- Null hypothesis of \( \beta = 1 \) rejected (t-stat of 3).
- Specification test accepted.

Moments: Empirical Simulated (Hyperbolic)

<table>
<thead>
<tr>
<th>%Visa:</th>
<th>68%</th>
<th>63%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visa/Y:</td>
<td>13%</td>
<td>17%</td>
</tr>
<tr>
<td>MPC:</td>
<td>23%</td>
<td>31%</td>
</tr>
<tr>
<td>f(W/Y):</td>
<td>2.6</td>
<td>2.7</td>
</tr>
</tbody>
</table>
4. Neuroscience Foundations

- What is the underlying mechanism?
- Why are our preferences inconsistent?
- Is it adaptive?
- How should it be modeled?
- Does it arise from a single time preference mechanism (e.g., Herrnstein’s reward per unit time)?
- Or is it the resulting of multiple systems interacting (Shefrin and Thaler 1981, Bernheim and Rangel 2004, O’Donoghue and Loewenstein 2004, Fudenberg and Levine 2004)?
Shiv and Fedorikhin (1999)

- Cognitive burden/load is manipulated by having subjects keep a 2-digit or 7-digit number in mind as they walk from one room to another.
- On the way, subjects are given a choice between a piece of cake or a fruit-salad.

<table>
<thead>
<tr>
<th>Processing burden</th>
<th>% choosing cake</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low (remember only 2 digits)</td>
<td>41%</td>
</tr>
<tr>
<td>High (remember 7 digits)</td>
<td>63%</td>
</tr>
</tbody>
</table>
Meso-limbic dopamine system vs. Fronto-Parietal System

Frontal cortex

Parietal cortex

Caudate nucleus and putamen (striatum)

Nucleus accumbens (ventral striatum)

Ventral tegmental area

Substantia nigra

Mesolimbic dopamine system
Relationship to quasi-hyperbolic model

- Hypothesize that mesolimbic dopamine system is impatient.
- Hypothesize that the fronto-parietal systems is patient.
- Here’s one implementation of this idea:

\[
U_t = u_t + \beta \left[ \delta u_{t+1} + \delta^2 u_{t+2} + \delta^3 u_{t+3} + \ldots \right]
\]

\[
\frac{1}{\beta}U_t = \frac{1}{\beta}u_t + \delta u_{t+1} + \delta^2 u_{t+2} + \delta^3 u_{t+3} + \ldots
\]

\[
\frac{1}{\beta-1}U_t = \frac{1}{\beta-1}u_t + [\delta^0 u_t + \delta^1 u_{t+1} + \delta^2 u_{t+2} + \delta^3 u_{t+3} + \ldots]
\]

limbic

fronto-parietal cortex
Overview of candidate discount functions, $D(t)$, and value functions, $V(t)$.

\[ D(t) = \frac{1}{1 + kt} \quad \text{hyperbolic} \]

\[ V(t) = u(c_t) + \beta \sum_{\tau=1}^{\infty} \delta^\tau u(c_{t+\tau}) \quad \text{quasi-hyperbolic} \]

\[ V(t) = \left( \frac{1}{\beta} - 1 \right) u(c_t) + \sum_{\tau=0}^{\infty} \delta^\tau u(c_{t+\tau}) \quad \text{affine transformation of quasi-hyperbolic} \]

\[ V(t) = \sum_{\tau=0}^{\infty} D_\beta(\tau) u(c_{t+\tau}) + \sum_{\tau=0}^{\infty} D_\delta(\tau) u(c_{t+\tau}) \quad \text{two system generalization} \]

\[ V(t) = \omega \sum_{\tau=0}^{\infty} \beta^\tau u(c_{t+\tau}) + (1 - \omega) \sum_{\tau=0}^{\infty} \delta^\tau u(c_{t+\tau}) \quad \text{two system: double exponential} \]

Limbic  Cortical
Hypothesis:

Limbic system discounts reward at a higher rate than does the prefrontal cortex.

\[ D(t) = \omega \beta^t + (1 - \omega)\delta^t \]
5. Neuroimaging Evidence

- Do agents think differently about immediate rewards and delayed rewards?
- Does immediacy have a special emotional drive/reward component?
- Does emotional (mesolimbic) brain discount delayed rewards more rapidly than the analytic (fronto-parietal cortex) brain?
Choices involving Amazon gift certificates:

Hypothesis: fronto-parietal cortex.

Hypothesis: fronto-parietal cortex and limbic.
Methods

Subjects given a series of choices between \((R \text{ at } d)\) and \((R' \text{ at } d')\) where \(R < R'\) and \(d < d'\).

\[
d \in \{ \text{Today, 2 weeks, 1 month} \}
\]

\[
d' - d \in \{ 2 \text{ weeks, 1 month} \}
\]

\[
\frac{(R' - R)}{R} \in \{1\%, 3\%, 5\%, 10\%, 15\%, 25\%, 35\%, 50\%\}
\]
Emotional system responds only to immediate rewards

McClure, Laibson, Loewenstein, and Cohen

Neural activity

VStr  MOFC  MPFC  PCC

Seconds

- $d =$ Earliest reward available today
- $d =$ Earliest reward available in 2 weeks
- $d =$ Earliest reward available in 1 month
Analytic brain responds equally to all rewards

- **d** = Earliest reward available today
- **d** = Earliest reward available in 2 weeks
- **d** = Earliest reward available in 1 month
Brain Activity in the **Frontal System** and **Emotional System** Predict Behavior
(Data for choices with an immediate option.)
Conclusions of Amazon study

• Time discounting results from the combined influence of two neural systems:
  • Mesolimbic dopamine system is impatient.
  • Fronto-parietal system is patient.
• These two systems are separately implicated in ‘emotional’ and ‘analytic’ brain processes.
• When subjects select delayed rewards over immediately available alternatives, analytic cortical areas show enhanced changes in activity.
Open questions

1. What is now and what is later?
   • Our “immediate” option (Amazon gift certificate) did not generate immediate “consumption.”
   • Also, we did not control the time of consumption.

2. How does the limbic signal decay as rewards are delayed?

3. Would our results replicate with a different reward domain?

4. Would our results replicate over a different time horizon?

→ New experiment on primary rewards: Juice McClure, Ericson, Laibson, Loewenstein, Cohen (Journal of Neuroscience, 2007)
Subjects water deprived for 3hr prior to experiment

From: "Phillip C Hughes (phughes@Princeton.EDU)" <phughes@Princeton.EDU>
Subject: I hate you
Date: December 14, 2004 3:57:34 PM EST
To: dardenne@Princeton.EDU
Cc: smcclure@Princeton.EDU

I'm already thirsty! It's 4:00!

(subject scheduled for 6:00)
Figure 1
Experiment Design

\[ d \in \{ \text{This minute, 10 minutes, 20 minutes} \} \]
\[ d' - d \in \{ \text{1 minute, 5 minutes} \} \]
\[ (R, R') \in \{(1,2), (1,3), (2,3)\} \]

\[
\begin{align*}
d &= \text{This minute} \\
d' - d &= 5 \text{ minutes} \\
(R, R') &= (2,3)
\end{align*}
\]
Behavioral evidence for non-exponential discounting

![Graph showing the probability of choosing early against delay to early reward (d). The x-axis represents the delay in minutes (This minute, 10 minutes, 20 minutes), and the y-axis represents the probability of choosing early.]
Behavioral evidence for non-exponential discounting

![Graph showing the probability of choosing early (P(choose early)) over different delays (d) and d' - d values. The graph demonstrates a decrease in probability as the delay increases.]
Discount functions fit to behavioral data

\[ V(t) = u(c_t) + \beta \sum_{\tau=1}^{\infty} \delta^\tau u(c_{t+\tau}) \]

\[ V(t) = \left( \frac{1}{\beta} - 1 \right) u(c_t) + \sum_{\tau=0}^{\infty} \delta^\tau u(c_{t+\tau}) \]

- Limbic
- Cortical

\[ V(t) = \omega \sum_{\tau=0}^{\infty} \beta^\tau u(c_{t+\tau}) + (1 - \omega) \sum_{\tau=0}^{\infty} \delta^\tau u(c_{t+\tau}) \]

- Evidence for two-system model
- Can reject restriction to a single exponential: t-stat > 5
- Double exponential generalization fits data best

\[ \beta = 0.53 \ (se = 0.041) \]

\[ \delta = 0.98 \ (se = 0.014) \]

\[ \beta = 0.47 \ (se = 0.101) \]

\[ \delta = 1.02 \ (se = 0.018) \]
Neuroimaging data

Areas that respond primarily to immediate rewards

Areas that show little discounting
Comparison with Amazon experiment:

**Impatient areas (p<0.001)**
- x = 0mm
- y = 8mm

**Impatient areas (p<0.01)**
- x = -4mm
- y = 12mm

**Patient areas (p<0.001)**
- x = 0mm
- x = -48mm

**Patient areas (p<0.01)**
- x = 0mm
- x = -48mm

- Red: Juice only
- Green: Amazon only
- Yellow: Both

Figure 5
Measuring discount functions using neuroimaging data

- Impatient voxels are in the emotional (mesolimbic) reward system
- Patient voxels are in the analytic (prefrontal and parietal) cortex
- Average (exponential) discount rate in the impatient regions is 4% per minute.
- Average (exponential) discount rate in the patient regions is 1% per minute.
Average Beta Area Activation, Actual and Predicted

- **Actual** (X)
- **Predicted** (●)

---

(D=0, D'=1)
(D=0, D'=5)
(D=10, D'=11)
(D=10, D'=15)
(D=20, D'=21)
(D=20, D'=25)
Average Delta Area Activation, Actual and Predicted

Normed Activation vs. Time to later reward

(D=0, D'=1) (D=0, D'=5) (D=10, D'=11) (D=10, D'=15) (D=20, D'=21) (D=20, D'=25)

Actual and Predicted

Crosses represent Actual data, and circles represent Predicted data.
What determines immediacy?

Is mesolimbic reward activation associated with relatively “early” (or earliest) options?

or

Do juice and money have different discount functions?

or

Does thirst invoke more intense discounting?
Summary of neuroimaging evidence

• One system associated with midbrain dopamine neurons (mesolimbic dopamine system) discounts at a high rate.

• Second system associated with lateral prefrontal and posterior parietal cortex discounts at a low rate.

• Combined function of these two systems accounts for decision making consistently across choice domains, including non-exponential discounting regularities.
Conclusion

1. Experimental evidence for dynamic inconsistency.
3. Field evidence: dynamic decisions.
4. Neuroscience:
   – Mesolimbic Dopamine System (emotional, impatient)
   – Fronto-Parietal Cortex (analytic, patient)
5. Neuroimaging evidence
   – Study 1: Amazon gift certificates
   – Study 2: juice squirts
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