# Pinocchio's Pupil:

**Using Eyetracking and Pupil Dilation To Understand Truth-telling and Deception in Sender-Receiver Games**

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## Security Analyst Stock Ratings

- 1=Buy
- 2=Accumulate
- 3=Neutral
- 4=Reduce
- 5=Sell

- 2-1 means:

  Short run: Accumulate,
  Long run: Buy

- Short run: 0-12 months
- Long run: beyond 1 year

## Henry Blodget covers LFMN

$22.69 — Blodget: 2-1

From: Blodgett, Henry (RSCH)
Sent: Monday, December 04, 2000 1:08 PM
To: Glatt, Eve (RSCH)
Subject: RE: Internet ad spend-media conference

LFMN at $4. I can't believe what a POS [piece-of-sh-t] that thing is. Shame on me/us for giving them any benefit of the doubt.

Blodget: 2-1 — $4

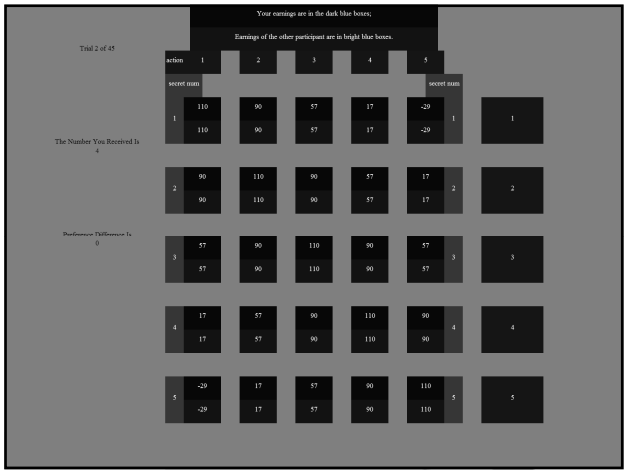
## Some Examples of Strategic Information Transmission

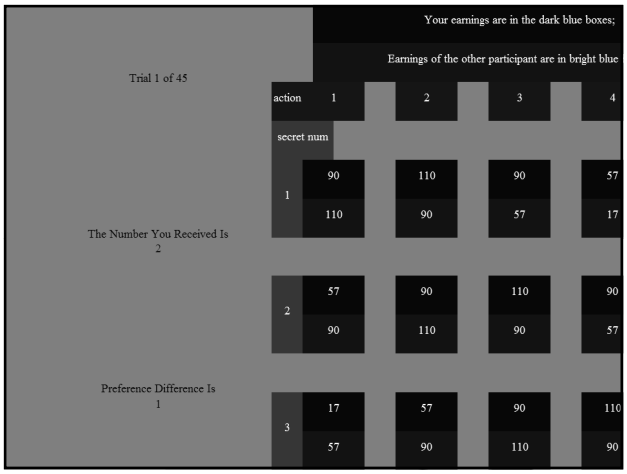
- Managers Inflating Earning Prospectives
  - "My personal belief is that Enron stock is an incredible bargain."
  - "We will hit our numbers." ~Kenneth Lay
- Grade Inflation
- Teacher Cheating Student Tests
- Government-Expert
- Doctor-Patient
- Congress Floor-Committee

## Strategic Information Transmission

(Cheap Talk, Biased Transmission Game)

- Sender sees "secret number" S=1,2,3,4,5
- Sender sends message M
- Receiver gets message M, *but not S*
- Receiver chooses action A
- Payoffs depend on S and A
  - Sender earns most if receiver picks A=S+b
  - Receiver earns most if receiver picks A=S
  - b is "bias" (b=0: truth-telling, b=2: babbling) (b=1: partition)

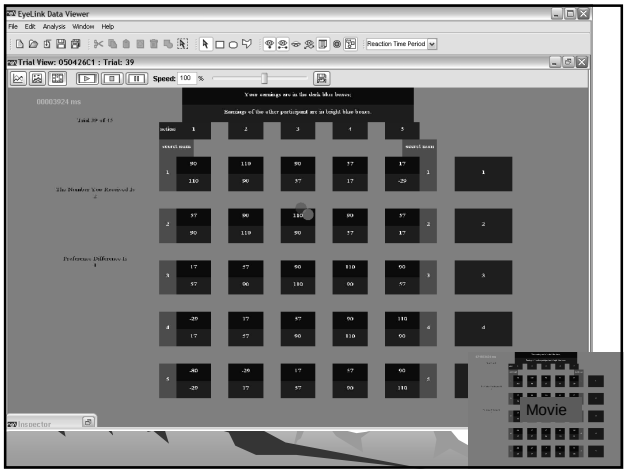





## Eyetracking and Pupil Dilation

- Mount Subjects with Eyelink II Eyetracker

- Observe Eye Movements (Info. Search)
- Observe Pupil Dilation (Arousal, Stress, Cognitive Difficulty, …)




## Why Eyetracking?

- Observe "Unobservable Variables"
  - Information acquisition ("by-products")
  - Cognitive difficulty ("energy consumption")
- Make Better Predictions
  - Lookups and pupil dilation may explain behavior (beyond financial incentives)
- Much Cheaper than fMRI
  - Costs: One eyetracker = one fMRI study
- Pupil dilation already used in lie-detection

## Past Use of Eye/mouse-tracking

- Look at critical parameters?
  - Johnson, Camerer et al., J Econ Theory 02
    - Alternating-offer bargaining ("shrinking pie")
    - Not looking ahead (future stage pie size)
- Look at other's payoff?
  - Costa-Gomes et al., Econometrica 01
    - Distinguish L1 and D1 by lookup at other's payoffs
- Direct search strategy measures expertise
  - Hunton and McEwen, Accounting Review 97

## Experimental Design

- Subjects were either senders or receivers throughout the experiments
- 3 practice rounds, 45 paid rounds
- Bias b=0, 1, 2 [1/3 each or (0.2, 0.4, 0.4)]
- Caltech students recruited via Caltech's Social Sciences Experimental Lab (SSEL)
- Two designs:
  - Display Bias vs. Hidden Bias

## Display Bias vs. Hidden Bias

Display Bias Design

1. Two subjects faced each other 45 rounds
   - Repeated game effect
2. Bias is sufficient
   - No need to look at the payoff table
3. Payoffs are the same
   - Memory effect?

Hidden Bias Design

1. Three pairs randomly matched in 45 rounds
   - Minimize repeated game effect
2. Sender can't see Bias
   - Force to look at payoffs
3. Payoffs perturbed with noise ~{-4,…,+4}
   - Vary across rounds

## Research Question

- What is the behavior (choices)?
  - How does a Level-k model of heterogeneous beliefs explain this data?
- How does subject behavior (choices) match with eyetracking lookup patterns and pupil dilation?
  - Do they support level-k model assumptions?
- Can we predict lies before they happen?

## Main Results

1. Choices reproduce theoretical comparative statics; Overcommunication (when bias = 2)
   - A Level-k model explains the choices
2. Lookup results justify level-k assumptions
   - Attention to structure
   - Self-centeredness
   - Incorrect beliefs
   - Strategizing from a truth-telling anchor
3. PDR: The more you lie, the bigger your pupil
4. Predict true state with lookups and message

## Choices: Theoretical Predictions

- Game theory:
  - b=0 truth-telling; if S, announce M=S
  - b=1 S=1 should announce M={1}
    S=2,3,4,5, should announce M={2,3,4,5}
  - b=2 "babbling", should announce M={1,2,3,4,5}
- Comparative Statics with respect to bias b:
  - Information transmission decreases with b

## Choices: Theoretical Predictions

- Level-k Model:
  - Start with anchor type L0; higher types best respond (BR) to lower types
- L0:
  - L0 sender: Tell the truth
  - L0 receiver: Follow message (BR to L0 sender)
- L1:
  - L1 sender: Inflate message (BR to L0 receiver)
  - L1 receiver: Discount message (BR to L1 sender)

## Choices: Theoretical Predictions

- L2:
  - L2 sender: BR to L1 receiver
  - L2 receiver: BR to L2 sender
- Eq: (=L3 in this game)
  - Eq sender: BR to L2 receiver
  - Eq receiver: BR to Eq sender
- SOPH:
  - BR to the empirical distribution of opponent behavior (know distribution of types…)

## Choices: Theoretical Predictions

- In this game, L3 and above are all Eq types
  - May not be true in general
- Comparative Statics with respect to bias b:
  - Information transmission decreases with b
- However, even when standard game theory predicts babbling (b=2), the Level-k model still allows positive information transmission
  - Lower types still send informative messages

## Choices: Results

- Aggregate information transmission decreases as bias b increase
  - Correlation between (S, M), (M, A), and (S, A)
  - Receiver Payoffs ("Economic value", but can be game specific)
- Individual choices are consistent with a Level-k model [Display Bias / Hidden Bias ]
  - Hidden Bias: (L0,L1,L2,Eq,SOPH) = (1,4,3,4,4)
  - Display Bias: (L0,L1,L2,Eq,SOPH) = (4,3,4,1,1)

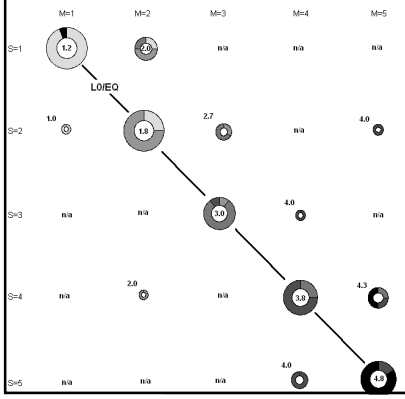
## Table 2: Information Transmission [ Display Bias / Hidden Bias ]

| BIAS | r(S, M) | r(M, A) | r(S, A) | Predicted r(S, A) |
|---|---|---|---|---|
| 0 | 0.99<br>0.93 | 1.00<br>0.92 | 0.99<br>0.86 | 1.00 |
| 1 | 0.73<br>0.64 | 0.74<br>0.71 | 0.72<br>0.49 | 0.65 |
| 2 | 0.63<br>0.34 | 0.57<br>0.58 | 0.59<br>0.32 | 0.00 |

## Table 3: Sender & Receiver's Payoffs [ Display Bias / Hidden Bias ]

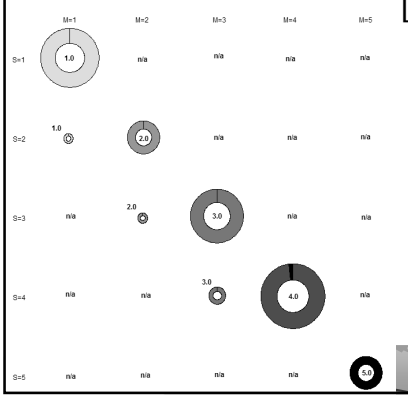
| BIAS | u_S (std) | u_R (std) | Predicted u_R (std) |
|---|---|---|---|
| 0 | 109.14 (4.07)<br>101.30 (17.28) | 109.14 (4.07)<br>101.27 (17.69) | 110.00<br>(0.00) |
| 1 | 93.35 (20.75)<br>73.28 (37.46) | 94.01 (19.86)<br>86.88 (27.59) | 91.40<br>(19.39) |
| 2 | 41.52 (49.98)<br>43.31 (52.79) | 85.52 (25.56)<br>80.55 (27.57) | 80.80<br>(20.76) |

## Figure 1: Raw Data Pie Chart (b=0) [ Hidden Bias ]




- **Each cell contains the average action taken by the receivers and a pie chart break down of the actions.**
- **Actions are in a gray scale, from white (a=1) to black (a=5).**
- **The size of the pie chart is scaled by the occurrences for each s & m.**

## Figure S2: Raw Data Pie Chart (b=0) [ Display Bias ]

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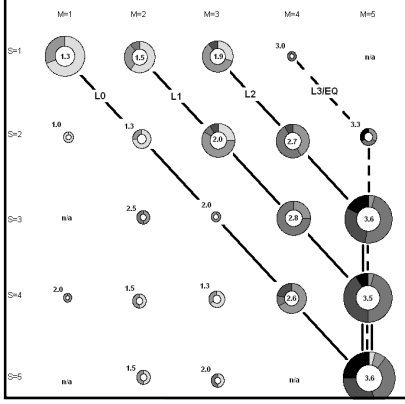
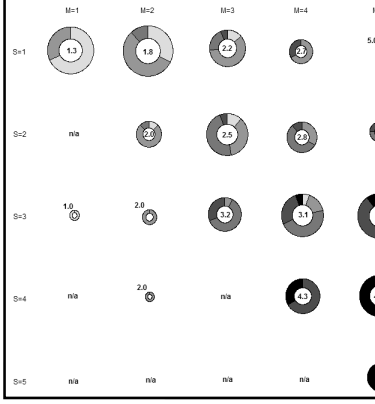
- **Actions are in a gray scale, from white (a=1) to black (a=5).**
- **The size of the pie chart is scaled by the occurrences for each s & m.**

## Figure 2: Raw Data Pie Chart (b=1)
[ Hidden Bias ]



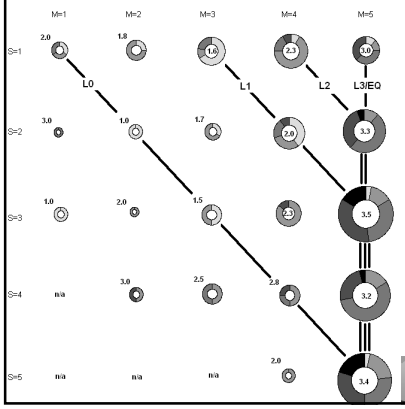

- **Each cell contains the average action taken by the receivers and a pie chart break down of the actions.**
- **Actions are in a gray scale, from white (a=1) to black (a=5).**
- **The size of the pie chart is scaled by the occurrences for each s & m.**

## Figure S3: Raw Data Pie Chart (b=1)
[ Display Bias ]



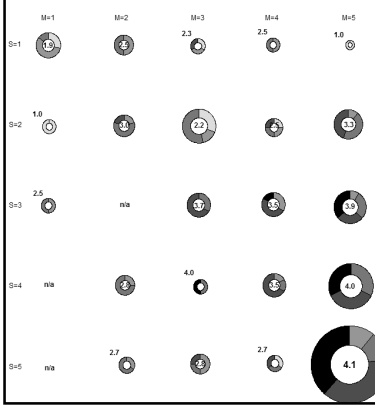

- **Each cell contains the average action taken by the receivers and a pie chart break down of the actions.**
- **Actions are in a gray scale, from white (a=1) to black (a=5).**
- **The size of the pie chart is scaled by the occurrences for each s & m.**

## Figure 3: Raw Data Pie Chart (b=2)
[ Hidden Bias ]




- **Each cell contains the average action taken by the receivers and a pie chart break down of the actions.**
- **Actions are in a gray scale, from white (a=1) to black (a=5).**
- **The size of the pie chart is scaled by the occurrences for each s & m.**

## Figure S4: Raw Data Pie Chart (b=2)
[ Display Bias ]




- **Each cell contains the average action taken by the receivers and a pie chart break down of the actions.**
- **Actions are in a gray scale, from white (a=1) to black (a=5).**
- **The size of the pie chart is scaled by the occurrences for each s & m.**

## Table 4: Level-k Classification Results
[ Display Bias / Hidden Bias ]

| Level | Display Bias | Hidden Bias |
|---|---|---|
| L0 | #1, #2, #3, #7 | #6-3 |
| L1 | #4, #9, #10 | #1-2, #2-1, #4-1, #5-1 |
| L2 | #8, #11, #12 | #1-3, #5-2, #6-1 |
| Eq | #6 | #2-2, #3-3, #4-3, #5-3 |
| SOPH | #5 | #1-1, #2-3, #3-2, #6-2 |

Note: #3-1 is unclassified; #4-2 dropped due to technical difficulty.

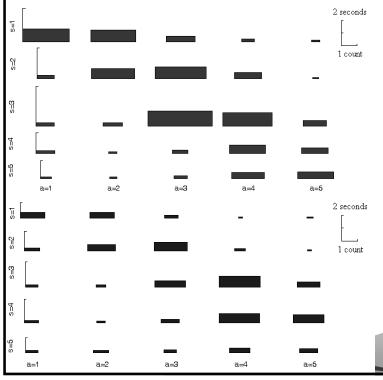
## Table 5: Sender Lookup Time (sec.)
[ Display Bias / Hidden Bias ]

| BIAS | Response Time | | State | Bias | Sender Payoffs | Receiver Payoffs | Sender-to-Receiver Ratio |
|---|---|---|---|---|---|---|---|
| | 1-15 | 31-45 | | | | | |
| 0 | 5.42 | 2.39 | 0.65 | 0.41 | 0.73 | 0.27 | 2.70 |
| | 9.78 | 7.24 | 0.83 | - | 2.93 | 1.71 | 1.71 |
| 1 | 7.92 | 5.44 | 1.47 | 0.99 | 2.29 | 1.05 | 2.18 |
| | 11.77 | 8.76 | 0.81 | - | 3.80 | 2.66 | 1.43 |
| 2 | 9.73 | 8.12 | 1.72 | 1.52 | 3.03 | 1.50 | 2.02 |
| | 16.84 | 8.99 | 0.91 | - | 4.67 | 3.26 | 1.43 |
| all | 8.07 | 5.25 | 1.34 | 1.02 | 2.14 | 1.00 | 2.14 |
| | 13.47 | 8.52 | 0.86 | - | 3.99 | 2.72 | 1.47 |

## Table 6: Lookup Time per Row (sec.)
[ Display Bias / Hidden Bias ]

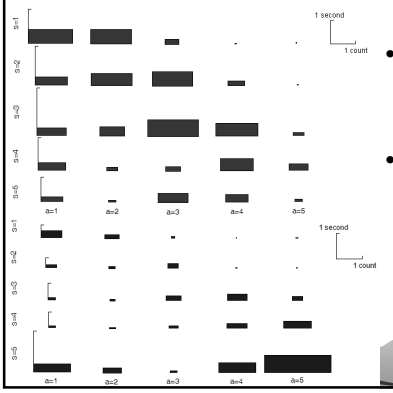
| BIAS | True State Rows | Other Rows | True-to-Other Ratio |
|---|---|---|---|
| 0 | 0.54<br>2.76 | 0.11<br>0.47 | 4.91<br>5.87 |
| 1 | 2.06<br>3.88 | 0.32<br>0.64 | 6.44<br>6.06 |
| 2 | 2.24<br>4.29 | 0.57<br>0.91 | 4.28<br>4.71 |
| all | 1.71<br>3.83 | 0.36<br>0.72 | 4.75<br>5.32 |

## Figure 4: Icon Graph (b=1), Hidden Bias



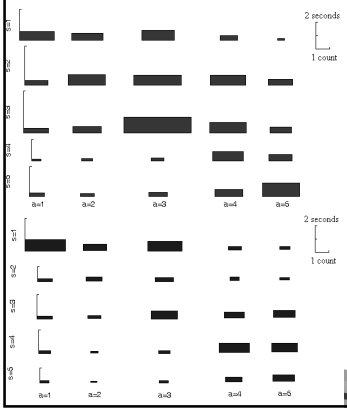
- Height: average lookup time per round
- Width: average lookup counts per round

## Figure S6: Icon Graph (b=1), Display Bias



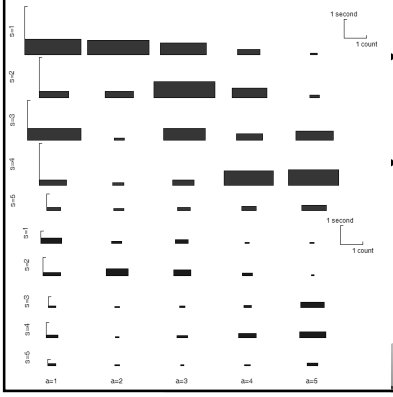
- Height: average lookup time per round
- Width: average lookup counts per round

## Figure 5: Icon Graph (b=2), Hidden Bias



- Height: average lookup time per round
- Width: average lookup counts per round

## Figure S7: Icon Graph (b=2), Display Bias



- Height: average lookup time per round
- Width: average lookup counts per round

$$PUPIL_i = \alpha + \sum_{b=0}^{2} \beta_{1b} \cdot LIE\_SIZE \cdot BIAS_b + \sum_{b\neq 2} \beta_{2b} \cdot BIAS_b + \sum_{s\neq 3} \beta_{3s} \cdot STATE_s + \sum_{k\neq 6} \alpha_k \cdot SUBJ_k + \sum_{k=1}^{K} \left( \gamma_{k,1} ROUND \cdot SUBJ_k + \gamma_{k,2} ROUND^2 \cdot SUBJ_k \right) + \varepsilon$$

- $PUPIL_k$ = Average pupil size at time frame *i*
- $LIE\_SIZE$ = | state – message |
- $BIAS_b$ = Dummy for different biases
- $STATE_s$ = Dummy for different states
- $SUBJ_k$ = Dummy variable for subject k
- $ROUND$ = Number or round

## Pupil Dilation

- Pinocchio's Nose?
  - The more you lie, the wider your pupil
- Subjects' pupil sizes before and after their decision are larger if they exaggerate more
  - Random effect with "robust" standard errors (correct serial correlation and heteroscedasticity)
- More so for Display Bias than Hidden Bias
  - Maybe "Hidden Bias" raises "baseline" dilation...

## Table 7: Pupil Size Regressions [ Display Bias ]

| $PUPIL_i$ | secs | (-1.2, -0.8) | (-0.8, -0.4) | (-0.4, 0.0) | (0.0, 0.4) | (0.4, 0.8) |
|---|---|---|---|---|---|---|
| Constant | $\alpha$ | 99.59 | 99.78 | 104.62 | 111.81 | 109.95 |
| | | (2.45) | (2.41) | (2.19) | (1.84) | (2.07) |
| LIE_SIZE | $\beta_{10}$ | 1.20 | 6.41 | 3.92 | -3.91 | 0.58 |
| * BIAS | | (3.21) | (6.38) | (3.06) | (2.76) | (7.36) |
| interactions | $\beta_{11}$ | 2.79* | 3.40** | 3.28** | 4.55*** | 4.20*** |
| | | (1.19) | (1.17) | (0.97) | (0.86) | (0.73) |
| | $\beta_{12}$ | 3.49*** | 3.71*** | 3.04*** | 2.90** | 3.28** |
| | | (0.99) | (0.98) | (0.84) | (0.87) | (0.90) |

Note: t-Test p-values lower than *5%, ** 1%, and *** 0.1%.

## Table 7: Pupil Size Regressions [ Hidden Bias ]

| $PUPIL_i$ | secs | (-1.2, -0.8) | (-0.8, -0.4) | (-0.4, 0.0) | (0.0, 0.4) | (0.4, 0.8) |
|---|---|---|---|---|---|---|
| Constant | $\alpha$ | 107.27 | 108.03 | 106.19 | 109.56 | 108.67 |
| | | (2.81) | (2.55) | (2.57) | (2.05) | (2.16) |
| LIE_SIZE | $\beta_{10}$ | 2.83 | 2.36 | 3.07 | 5.35** | 5.57* |
| * BIAS | | (1.85) | (2.22) | (2.46) | (1.16) | (2.19) |
| interactions | $\beta_{11}$ | -1.02 | -0.46 | -0.36 | 2.16^ | 2.64* |
| | | (1.26) | (1.31) | (1.28) | (1.21) | (1.15) |
| | $\beta_{12}$ | 2.06* | 1.52^ | 1.47* | 1.83* | 2.00** |
| | | (0.86) | (0.79) | (0.75) | (0.75) | (0.74) |

Note: t-Test p-values lower than ^10%, *5%, ** 1%, and *** 0.1%.

## Predicting True States

- We can "figure out" the true state using message, lookup patterns and pupil dilation
  - Message
  - Most lookup rows (self and other)
- We can increase actual receiver payoffs using these predictions
  - Paired: Improve by 6-8% (86→92, 93→100)
  - Random Match: Improve by 16~21% (80, 87→98~101)

(As high as "actual payoffs" when b=0!)

## Table 8: Predicting True State

**Much Stronger Lookup Effect**

| | | Y | Display Bias | | | |
|---|---|---|---|---|---|---|
| MESSAGE*B | | **Message sent** | 0.64* (0.22) | | 0.46** (0.12) | |
| MESSAGE*B | | | 0.91** (0.23) | | 0.42** (0.09) | |
| $ROW_{self}$ * BIAS=1 | $\beta_{31}$ | | 0.98** (0.21) | | 1.07** (0.24) | |
| $ROW_{self}$ * BIA | | **Lookups** | 1.00** (0.27) | | 1.72* (0.20) | |
| $ROW_{other}$ * BIAS=1 | $\beta_{41}$ | | 0.25 (0.16) | | 1.27** (0.22) | |
| $ROW_{other}$ * BIAS=2 | $\beta_{42}$ | | 0.39* (0.17) | | 0.44** (0.15) | |
| **6-8% Increase** | | | Actual | Hold-out | Actual | Hold-out |
| Aver. predicted $u_R$ (b=1) | | | 93.4 (22.3) | 100.7* (2.4) | 87.5 (28.8) | 101.7** (2.1) |
| Aver. predicted $u_R$ (b=2) | | | 86.2 (23.8) | 91.8* (3.4) | 80.9 (26.9) | 98.0** (2.2) |

**16-21% Increase; Near Actual Payoff at b=0 (=100.9)**

## Conclusion

- More deception as bias increases
- But "not enough" deception (as equilibrium theory)
- Level-k model predicts individual behavior
- Look at "true state rows" in the payoff table
- Pupil dilation correlated with deception
- Prediction gain: receiver payoffs increase by 16-21% (6-8% for Display Bias)
  - Hidden Bias: close to "actual payoffs" at b=0

# Conclusion

- Friedrich Nietzsche (1878)
  - "Why do almost all people tell the truth in ordinary everyday life? --Certainly not because a god has forbidden them to lie. The reason is, firstly because it is easier; for lying demands invention, dissimulation and a good memory." (Human, All Too Human, II.54)
- Mark Twain
  - "If you tell the truth, you don't have to remember anything."
- Can lie-detection be done?