Prediction Markets and the Wisdom of Crowds

David Pennock, Yahoo! Research

Joint with:
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Bet = Credible Opinion

Obama will win the 2008 US Presidential election

“I bet $100 Obama will win at 1 to 2 odds”

• Which is more believable?
  More Informative?

• Betting intermediaries
  • Las Vegas, Wall Street, Betfair, Intrade,...
  • Prices: stable consensus of a large number of quantitative, credible opinions
  • Excellent empirical track record
A Prediction Market

• Take a random variable, e.g.
  Bin Laden captured in 2008? (Y/N)

• Turn it into a financial instrument
  payoff = realized value of variable

I am entitled to:

$1 if Bin Laden caught ’08
$0 if Bin Laden caught ’08
### Current Events - Osama Bin Laden

Osama Bin Laden Conclusion (Rule 1.8 Applies)

<table>
<thead>
<tr>
<th>Contract</th>
<th>Bid</th>
<th>Ask</th>
<th>Last</th>
<th>Vol</th>
<th>Chge</th>
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</thead>
<tbody>
<tr>
<td><strong>OSAMA_CAPTURE_DEC08</strong> Osman Bin Laden to be captured/neutralised by 31 Dec 2008</td>
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Dec 04 - 8:17PM GMT
Outline

• The Wisdom of Crowds
• The Wisdom of Markets
  • Prediction Markets: Examples & Research
  • Does Money Matter?
  • Combinatorial Betting
A WOC Story

- ProbabilitySports.com
- Thousands of probability judgments for sporting events
  - Alice: Jets 67% chance to beat Patriots
  - Bob: Jets 48% chance to beat Patriots
  - Carol, Don, Ellen, Frank, ...
- Reward: Quadratic scoring rule: Best probability judgments maximize expected score
Individuals

- Most individuals are poor predictors
- 2005 NFL Season
  - Best: 3747 points
  - Average: -944  Median: -275
  - 1,298 out of 2,231 scored below zero (takes work!)
Individuals

- Poorly calibrated (too extreme)
  - Teams given < 20% chance actually won 30% of the time
  - Teams given > 80% chance actually won 60% of the time
The Crowd

• Create a *crowd predictor* by simply averaging everyone’s probabilities
  • Crowd = \( \frac{1}{n}(\text{Alice} + \text{Bob} + \text{Carol} + \ldots) \)
  • 2005: Crowd scored 3371 points (7th out of 2231)!

• Wisdom of fools: Create a predictor by averaging everyone who scored below zero
  • 2717 points (62nd place)!
  • (the best “fool” finished in 934th place)
The Crowd: How Big?

Expected score vs Number of experts aggregated (2004 data)

More:
http://www.overcomingbias.com/2007/02/how_and_when_to.html
Can We Do Better?: ML/Stats

- Maybe Not
  - CS “experts algorithms”
  - Other expert weights
  - Calibrated experts
  - Other averaging fn’s (geo mean, RMS, power means, mean of odds, ...)
  - Machine learning (NB, SVM, LR, DT, ...)

- Maybe So
  - Bayesian modeling + EM
  - Nearest neighbor (multi-year)

[Dani et al. UAI 2006]
Can we do better?: Markets

Prediction Performance of Markets Relative to Individual Experts

Week into the NFL season

Rank NewsFutures Tradesports
Prediction Markets: Examples & Research
The Wisdom of Crowds
Backed in dollars

- What you can say/learn % chance that
  - Obama wins
  - GOP wins Texas
  - YHOO stock > 30
  - Duke wins tourney
  - Oil prices fall
  - Heat index rises
  - Hurricane hits Florida
  - Rains at place/time

- Where
  - IEM, Intrade.com
  - Intrade.com
  - Stock options market
  - Las Vegas, Betfair
  - Futures market
  - Weather derivatives
  - Insurance company
  - Weatherbill.com
## Prediction Markets

**With Money**

<table>
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<tr>
<th>Contract</th>
<th>B Qty</th>
<th>Bid</th>
<th>Ask</th>
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<td>1</td>
<td>72.2</td>
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### Androids Beat Humans in Soccer (BOTS)

Will a team of androids beat the human World Cup champs at a game of soccer by 2050?

**Price:** POP$ 47.75  
**Status:** ACT

### Fuel-Cell-Powered Laptop (FCELL)

Will the first fuel-cell-powered laptop go on sale in the U.S. by the end of 2008?

**Price:** POP$ 43.75  
**Status:** ACT

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## Without

### Barack Obama will be the Democratic Presidential Nominee in 2008

**82%**

---

**intra!**  
The Prediction Market

**PPX**  
The PopSci Predictions Exchange
The Wisdom of Crowds
Backed in “Points”

• HSX.com
• Newsfutures.com
• InklingMarkets.com
• Foresight Exchange
• CasualObserver.net
• FTPredict.com
• Yahoo!/O’Reilly Tech Buzz
• ProTrade.com
• StorageMarkets.com
• TheSimExchange.com
• TheWSX.com
• Alexadex, Celebdaq, Cenimar, BetBubble, Betocracy, CrowdIQ, MediaMammon, Owise, PublicGyan, RIMDEX, Smarks, Trendio, TwoCrowds

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<td>£3961</td>
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<td>3.25</td>
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<td>Barcelona</td>
<td>£83838</td>
<td>£8541</td>
<td>£15392</td>
<td>£4432</td>
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<td>The Draw</td>
<td>£3591</td>
<td>£1457</td>
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Screen capture 2008/05/07

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<tr>
<td>Trade MLB.METS</td>
<td>5</td>
<td>13.0</td>
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<td>150</td>
<td>13.7</td>
<td>1910</td>
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<td>Trade MLB.YANKEES</td>
<td>5</td>
<td>10.3</td>
<td>11.0</td>
<td>151</td>
<td>12.4</td>
<td>2082</td>
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Screen capture 2007/05/18
Example: IEM 1992
IEM versus Polls: 1996
(Berg, Nelson and Rietz, 2001)
Predictive Accuracy

Berg, Forsythe, Nelson and Rietz (2001)

Source: Berg, DARPA Workshop, 2002
Does it work?

Yes, evidence from real markets, laboratory experiments, and theory

- Racetrack odds beat track experts [Figlewski 1979]
- Orange Juice futures improve weather forecast [Roll 1984]
- HP market beat sales forecast 6/8 [Plott 2000]
- Sports betting markets provide accurate forecasts of game outcomes [Gandar 1998][Thaler 1988][Debnath EC’03][Schmidt 2002]
- Laboratory experiments confirm information aggregation [Plott 1982;1988;1997][Forsythe 1990][Chen, EC’01]
- Market games work [Servan-Schreiber 2004][Pennock 2001]
Prediction Markets: Does Money Matter?
The Wisdom of Crowds
With Money
IEM: 237 Candidates
Without
HSX: 489 Movies

Predictive Accuracy
Berg, Forsythe, Nelson and Rietz (2001)
The Wisdom of Crowds
With Money
Without
Real markets vs. market games

**probabilistic forecasts**

<table>
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<tr>
<th>Forecast Source</th>
<th>Avg Log Score</th>
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<tr>
<td>F1P6 linear scoring</td>
<td>-1.84</td>
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<tr>
<td>F1P6 F1-style scoring</td>
<td>-1.82</td>
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<tr>
<td>Betting odds</td>
<td>-1.86</td>
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<tr>
<td>F1P6 flat scoring</td>
<td>-2.03</td>
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<tr>
<td>F1P6 winner scoring</td>
<td>-2.32</td>
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</table>
Does money matter? 
Play vs real, head to head

**Experiment**
- 2003 NFL Season
- ProbabilitySports.com
  Online football forecasting competition
  - Contestants assess probabilities for each game
  - Quadratic scoring rule
  - ~2,000 “experts”, plus:
  - NewsFutures (play $)
  - Tradesports (real $)
    - Used “last trade” prices

**Results:**
- Play money and real money performed similarly
  - 6th and 8th respectively
- Markets beat most of the ~2,000 contestants
  - Average of experts came 39th (caveat)

*Electronic Markets*, Emile Servan-Schreiber, Justin Wolfers, David Pennock and Brian Galebach
Observed Frequency of Victory
Trading ... points; n=416 teams in 208 games
Market Forecast Winning Probability and Actual Winning Probability
Prediction Accuracy
TradeSports: Correlation=0.96
NewsFutures: Correlation=0.94
Prices: TradeSports and NewsFutures
Fitted Value: Linear regression
45 degree line
Prediction Performance of Markets Relative to Individual Experts
Week into the NFL season
Rank
TradeSports
NewsFutures
n=416 over 208 NFL games
Correlation between TradeSports and NewsFutures prices = 0.97
**Does money matter?**
**Play vs real, head to head**

<table>
<thead>
<tr>
<th></th>
<th>Probability-Football Avg</th>
<th>TradeSports (real-money)</th>
<th>NewsFutures (play-money)</th>
<th>Difference TS - NF</th>
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</thead>
<tbody>
<tr>
<td>Mean Absolute Error</td>
<td>0.443</td>
<td>0.439</td>
<td><strong>0.436</strong></td>
<td>0.003</td>
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<tr>
<td>= lose_price</td>
<td>(0.012)</td>
<td>(0.011)</td>
<td>(0.012)</td>
<td>(0.016)</td>
</tr>
<tr>
<td>[lower is better]</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Root Mean Squared Error</td>
<td>0.476</td>
<td>0.468</td>
<td><strong>0.467</strong></td>
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<tr>
<td>= ?Average(lose_price²)</td>
<td>(0.025)</td>
<td>(0.023)</td>
<td>(0.024)</td>
<td>(0.033)</td>
</tr>
<tr>
<td>[lower is better]</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Average Quadratic Score</td>
<td>9.323</td>
<td>12.410</td>
<td><strong>12.427</strong></td>
<td>-0.017</td>
</tr>
<tr>
<td>= 100 - 400*(lose_price²)</td>
<td>(4.75)</td>
<td>(4.37)</td>
<td>(4.57)</td>
<td>(6.32)</td>
</tr>
<tr>
<td>[higher is better]</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Average Logarithmic Score</td>
<td>-0.649</td>
<td>-0.631</td>
<td><strong>-0.631</strong></td>
<td>0.000</td>
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<tr>
<td>= Log(win_price)</td>
<td>(0.027)</td>
<td>(0.024)</td>
<td>(0.025)</td>
<td>(0.035)</td>
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<tr>
<td>[higher (less negative) is better]</td>
<td></td>
<td></td>
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</table>

Statistically:
TS ~ NF
NF >> Avg
TS > Avg
Discussion

- Are incentives for virtual currency strong enough?
  - Yes (to a degree)
  - Conjecture: Enough to get what people already know; not enough to motivate independent research
  - Reduced incentive for information discovery possibly balanced by better interpersonal weighting
- Statistical validations show HSX, FX, NF are reliable sources for forecasts
  - HSX predictions $\geq$ expert predictions
  - Combining sources can help
A Problem w/ Virtual Currency Printing Money

Alice
1000

Betty
1000

Carol
1000
A Problem w/ Virtual Currency

Printing Money

Alice
5000

Betty
1000

Carol
1000
Yootles
A Social Currency

Alice 0
Betty 0
Carol 0
Yootles
A Social Currency

I owe you 5

Alice
-5

Betty
0

Carol
5
Yootles
A Social Currency

Alice
-5

Betty
0

Carol
5

I owe you 5

credit: 5

credit: 10
Yootles
A Social Currency

I owe you 5

credit: 5

I owe you 5

credit: 10

Alice
-5

Betty
0

Carol
5
Yootles
A Social Currency

I owe you 5

credit: 5
credit: 10

Alice 3995
Betty 0
Carol 5
Yootles
A Social Currency

- For tracking gratitude among friends
- A yootle says “thanks, I owe you one”
Combinatorial Betting
Combinatorics Example

March Madness

2005 NCAA Division I Men's Basketball Championship

First Round

Second Round

Regions National Semifinals National Championship National Semifinals Regions Second Round First Round

St. Louis April 2

NATIONAL CHAMPION

St. Louis April 4

***ALL TIMES ARE LOCAL***

On March 13, the basketball committee will select two teams to play the opening round game March 15 in Dayton. The winning team will be a 16 seed in the first round.

*First- and second-round and regional sites will be placed in the bracket by the NCAA Division I Men's Basketball Committee March 13.
March 17 and 19 first- and second-round sites: Boise, Cleveland, Indianapolis, Tucson
March 18 and 20 first- and second-round sites: Charlotte, Nashville, Oklahoma City, Worcester
March 24 and 26 regional sites: Chicago and Albuquerque

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Combinatorics Example

March Madness

- Typical today
  - Non-combinatorial
    - Team wins Rnd 1
    - Team wins Tourney
    - A few other “props”
    - Everything explicit (By def, small #)
    - Every bet indep: Ignores logical & probabilistic relationships
  
- Combinatorial
  - *Any* property
  - Team wins Rnd k
    - Duke > \{UNC,NCST\}
    - ACC wins 5 games
  - \(2^{63}\) possible props (implicitly defined)
  - 1 Bet effects related bets “correctly”; e.g., to enforce logical constraints
Expressiveness: Getting Information

• Things you can say today:
  – (63% chance that) Obama wins
  – GOP wins Texas
  – YHOO stock > 30 Dec 2007
  – Duke wins NCAA tourney

• Things you can’t say (very well) today:
  – Oil down, DOW up, & Obama wins
  – Obama wins election, *if* he wins OH & FL
  – YHOO btw 25.8 & 32.5 Dec 2007
  – #1 seeds in NCAA tourney win more than #2 seeds
Expressiveness: Processing Information

- Independent markets today:
  - Horse race win, place, & show pools
  - Stock options at different strike prices
  - Every game/proposition in NCAA tourney
  - Almost everything: Stocks, wagers, intrade, ...

- Information flow (inference) left up to traders
- Better: Let traders focus on predicting whatever they want, however they want: Mechanism takes care of logical/probabilistic inference
- Another advantage: Smarter budgeting
Market Combinatorics

Permutations

- A > B > C  .1
- A > C > B  .2
- B > A > C  .1
- B > C > A  .3
- C > A > B  .1
- C > B > A  .2
# Market Combinatorics

**Permutations**

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<th>Probability</th>
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<td>B &gt; D &gt; A &gt; C</td>
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<tr>
<td>D &gt; B &gt; A &gt; C</td>
<td>0.02</td>
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</table>
Bidding Languages

• Traders want to bet on properties of orderings, not explicitly on orderings: more natural, more feasible
  • A will win; A will “show”
  • A will finish in [4-7]; {A,C,E} will finish in top 10
  • A will beat B; {A,D} will both beat {B,C}
• Buy 6 units of “$1 if A>B” at price $0.4
• Supported to a limited extent at racetrack today, but each in different betting pools
• Want centralized auctioneer to improve liquidity & information aggregation
Example

• A three-way match
  • Buy 1 of “$1 if A>B” for 0.7
  • Buy 1 of “$1 if B>C” for 0.7
  • Buy 1 of “$1 if C>A” for 0.7
Pair Betting

- All bets are of the form “A will beat B”
- Cycle with sum of prices > k-1 ==> Match (Find best cycle: Polytime)
- Match =/=> Cycle with sum of prices > k-1

- Theorem: The Matching Problem for Pair Betting is NP-hard (reduce from min feedback arc set)
Automated Market Makers

- A market maker (a.k.a. bookmaker) is a firm or person who is almost always willing to accept both buy and sell orders at some prices

- Why an institutional market maker? **Liquidity!**
  - Without market makers, the more expressive the betting mechanism is the less liquid the market is (few exact matches)
  - Illiquidity discourages trading: Chicken and egg
  - Subsidizes information gathering and aggregation: Circumvents no-trade theorems

- Market makers, unlike auctioneers, bear risk. Thus, we desire mechanisms that can **bound the loss of market makers**
  - Dynamic pari-mutuel market [Pennock 2004]
# Overview: Complexity Results

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• March Madness bet constructor
• Bet on any team to win any game
  – Duke wins in Final 4
• Bet “exotics”:
  – Duke advances further than UNC
  – ACC teams win at least 5
  – A 1-seed will lose in 1st round
New Prediction Game: Yoopick
An Application on Facebook
Catalysts

• Markets have long history of predictive accuracy: why catching on now as tool?
• No press is bad press: Policy Analysis Market ("terror futures")
• Surowiecki's "Wisdom of Crowds"
• Companies:
  • Google, Microsoft, Yahoo!; CrowdIQ, HSX, InklingMarkets, NewsFutures
• Press: BusinessWeek, CBS News, Economist, NYTimes, Time, WSJ, ...

http://us.newsfutures.com/home/articles.html
CFTC Role

- MayDay 2008: CFTC asks for help
- Q: What to do with prediction markets?
- Yahoo!, Google entered suggestions
- Right now, the biggest prediction markets are overseas, academic (1), or just for fun
- CFTC may clarify, drive innovation
  Or not
Conclusion

- Prediction Markets: hammer = market, nail = prediction
  - Great empirical successes
  - Momentum in academia and industry
  - Fascinating (algorithmic) mechanism design questions, including combinatorial betting
- Points-paid peers produce pretty good predictions