Peer prediction markets to elicit unverifiable information

Aurélien Baillon [1] Cem Peker [2] Sophie van der Zee [3]

March 27, 2023

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[2] School of Management, Polytechnic University of Milan

[3] Erasmus School of Economics, Erasmus University Rotterdam

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- PhD in Economics (30.03.2023, Erasmus University Rotterdam)
  Advisors: Aurélien Baillon, Han Bleichrodt, Peter Wakker.
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- Lying and misreporting in surveys.

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Problem: **Your answer is unverifiable!**

Carefully considered and truthful answers

“Have you stood less than 6 feet apart from another person in a queue yesterday?”

Incentivize truthfulness when the truth is unverifiable?

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Peer Prediction (Miller et al., 2005):

- Your honest answer $\leftrightarrow$ Your prediction on others' answers

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Incentivize truthfulness when the truth is unverifiable?

Peer Prediction (Miller et al., 2005):

- Your honest answer $\leftrightarrow$ Your prediction on others' answers
- Prediction on others' answers is verifiable.
  $\rightarrow$ can be used for incentivization!

Peer-Prediction Market

Your prediction on others' answers is verifiable.

This paper: **Peer-Prediction Market (PPM)**

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This paper: **Peer-Prediction Market (PPM)**

- One-shot market, buy/sell a single asset.
- Trade $\equiv$ A bet on others' answers.
- Trades reveal carefully considered and truthful answers.
- Theory & evidence from 2 experimental studies.

The Formal Framework

The Framework

- *Center* asks a binary question $\{Yes, No\}$
- N risk-neutral *agents*

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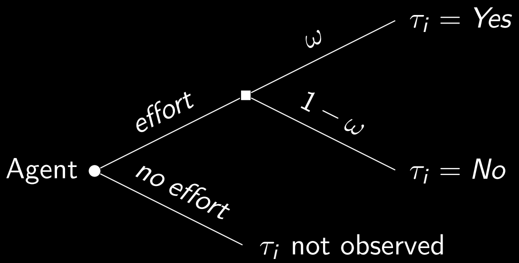

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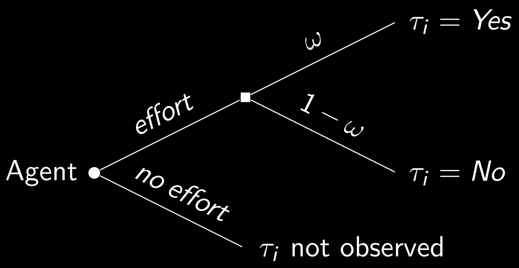
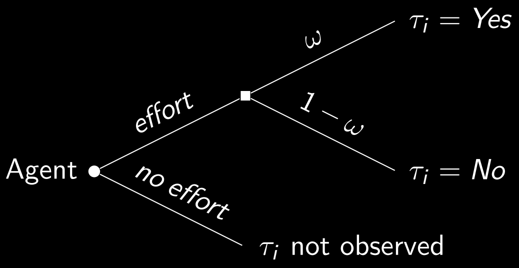


Assumptions:

- Common prior expectation $E[\omega]$ on ω.
- $E[\omega]$ is public knowledge.
- Agents follow Bayesian updating.

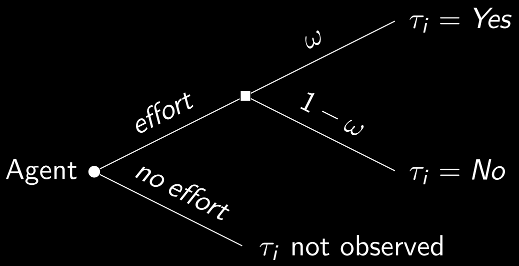
The Framework



3 groups of agents with posterior expectations:

$$E[\omega|\text{effort and } \tau_i = Yes]$$
$$E[\omega|\text{effort and } \tau_i = No]$$
$$E[\omega|\text{no effort}] = \text{Prior} = E[\omega]$$

The Framework



Posterior expectations satisfy:

$$E[\omega|\tau_i = Yes] > E[\omega] > E[\omega|\tau_i = No]$$

"Yes"-types expect $\omega > E[\omega] =$ prior.

"No"-types expect $\omega < E[\omega] =$ prior.

Peer prediction market

The Mechanism

One-shot market

- Single asset
- Asset price $= p = E[\omega]$
- Asset value $= v =$ proportion of agents who buy

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$t = 0$	$t = 1$	$t = 2$	$t = 3$
Center (market maker) sets $p = E[\omega]$.	Agents buy or sell 1 unit from the center.	Center calculates v, cancels the market if $v \in \{0, 1\}$	If $v \in (0, 1)$, buyers get $\pi(v - p)$ and sellers get $\pi(p - v)$

The Mechanism

Numerical example:

- Currency is dollar, $\pi = 10$
- Price: $p = E[\omega] = 0.5$
- 40% of the participants buy, $v = 0.4$
- Buyer's payoff: $10\,(0.4 - 0.5) = -\$1$
- Seller's payoff: $10\,(0.5 - 0.4) = \$1$

The Mechanism

Strategy = Effort or not + probability of buy in various situations

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Agent i's full strategy profile = $(e_i, R_i, R_i^{no}, R_i^{yes})$

- $e_i \in \{0, 1\}$ effort or no effort
- R_i probability of buy if $e_i = 0$,
- R_i^{no} probability of buy if $e_i = 1$ and $\tau_i = No$,
- R_i^{yes} probability of buy if $e_i = 1$ and $\tau_i = Yes$.

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Center would like: $e_i = 1$, $R_i^{no} = 0$, and $R_i^{yes} = 1$.

The Mechanism

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Center would like: $e_i = 1$, $R_i^{no} = 0$, and $R_i^{yes} = 1$.
$\rightarrow$ **Truthful strategy**: Trades reflect carefully considered and honest answers.

Bayesian game

Assumption. The following are **common knowledge**:

- The market mechanism
- Signal technology, beliefs, costs and the strategy space.
- Risk-neutrality and Bayesianism of agents.

Ensures that we have a *Bayesian game* (Osborne and Rubinstein, 1994, Definition 25.1).

For convenience, we let $N \to \infty$.

Equilibrium analysis

Equilibria

Truthful equilibrium: For $N \to \infty$, truthful strategy is a Nash equilibrium if the rewards are scaled sufficiently high such that

$$\frac{c_i}{\pi} < E[\omega]\left(E[\omega|\tau_i = Yes] - E[\omega]\right) + (1 - E[\omega])\left(E[\omega] - E[\omega|\tau_i = No]\right)$$

for all $i \in \{1, \ldots, N\}$

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for all $i \in \{1, \ldots, N\}$

In the truthful equilibrium...

- All agents make effort
- Yes-types buy, No-types sell
- Carefully considered and truthful answer $\equiv$ Equilibrium trade

Equilibria

Truthful equilibrium: Full effort, Yes-types buy, No-types sell

How?

Equilibria

Truthful equilibrium: Full effort, Yes-types buy, No-types sell

How?

$$\text{Types} \qquad E[\omega|\tau_i = No] \quad < \quad E[\omega] \quad < \quad E[\omega|\tau_i = Yes]$$

Equilibria

Truthful equilibrium: Full effort, Yes-types buy, No-types sell

How?

$$\text{Types} \qquad E[\omega|\tau_i = No] \quad < \quad E[\omega] \quad < \quad E[\omega|\tau_i = Yes]$$

$$\text{Market} \qquad\qquad\qquad p$$

Equilibria

Truthful equilibrium: Full effort, Yes-types buy, No-types sell

How?

Types	$E[\omega \mid \tau_i = No]$	$<$	$E[\omega]$	$<$	$E[\omega \mid \tau_i = Yes]$
Market	$E[v \mid \tau_i = No]$	$<$	p	$<$	$E[v \mid \tau_i = Yes]$

Asset value (v) $\equiv$ Proportion of buyers $\rightarrow$ Proportion of Yes-type (ω)

Equilibria

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Optimal: Buy if $\tau_i = Yes$, sell if $\tau_i = No$

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How?

$$\begin{array}{lccccc}
\text{Types} & E[\omega|\tau_i = No] & < & E[\omega] & < & E[\omega|\tau_i = Yes] \\
\text{Market} & E[v|\tau_i = No] & < & p & < & E[v|\tau_i = Yes]
\end{array}$$

Optimal: Buy if $\tau_i = Yes$, sell if $\tau_i = No$

Incentive to "learn" your type $\rightarrow$ effort

Equilibria

Multiple equilibria

No-effort equilibrium: If $c_i > \pi$ for all $i \in \{1, \ldots, N\}$, then Nash equilibria are characterized by $e_i = 0$ and $R_i \in \{0, E[\omega], 1\}$. Expected payoffs are 0.

$\rightarrow$ No effort when costs are too high.

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$\rightarrow$ No effort when costs are too high.

Partial effort equilibrium: There are NE in which $K < N$ agents exert no effort and buy with probability $E[\omega]$ while the other agents are truthful.

$\rightarrow$ People with low cost exert effort, others do not.

Equilibria

Multiple equilibria

All-buy or all-sell: There exists Nash equilibria such that $e_i = 0$ and $R_i = 0$ or $R_i = 1$ for all i. Expected payoffs are 0.

Equilibria

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All-buy or all-sell: There exists Nash equilibria such that $e_i = 0$ and $R_i = 0$ or $R_i = 1$ for all i. Expected payoffs are 0.

Truthful equilibrium: Strictly higher payoff than no-effort, all-buy and all-sell equilibria

Psychological costs

"Have you stood less than 6 feet apart from another person in a queue yesterday?"

Reporting "Yes" is shameful $\rightarrow$ higher cost?

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Truthful equilibrium if π is scaled appropriately

Experimental Evidence

Testing PPM

Two experimental studies.

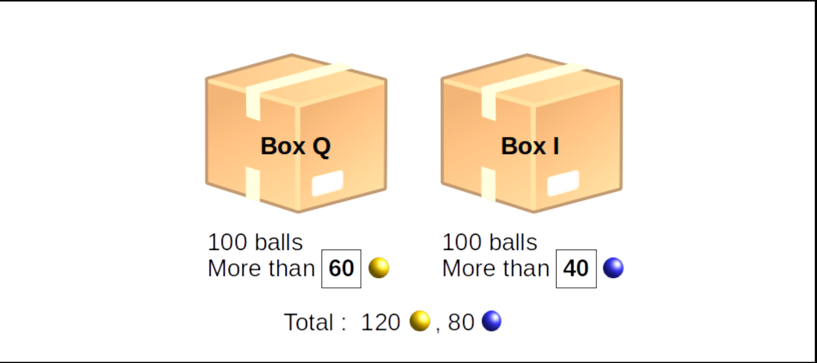
Study 1:

- Closely follows the theoretical model.
- Real effort task.

Study 2:

- Survey on behavior under Covid-19 safety guidelines.
- Psychological costs & practical feasibility.

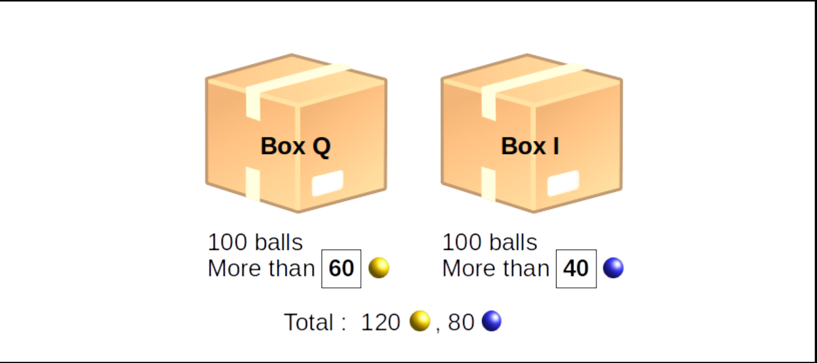
Study 1 - A pair of boxes



One of the boxes is selected at random (Q="more yellow" or I="less yellow").

Guess which one.

Study 1 - A pair of boxes



One of the boxes is selected at random (Q="more yellow" or I="less yellow").

Guess which one. Want to see a ball from the selected box?

Study 1 - Real effort task

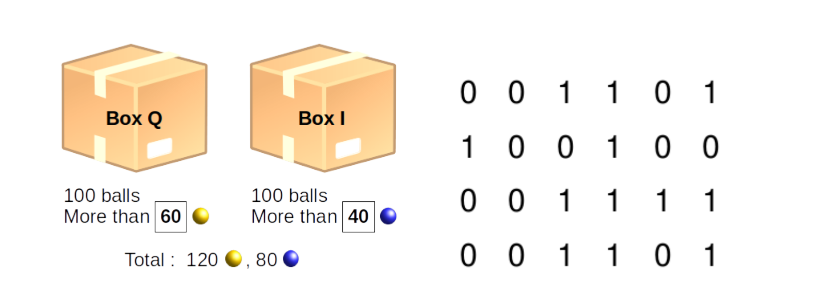
0	0	1	1	0	1
1	0	0	1	0	0
0	0	1	1	1	1
0	0	1	1	0	1

Count the number of 0s and you draw..

 OR 

Color of your draw $\equiv$ signal

Link with the theory



- Let's say a yellow draw is equivalent to ($\tau_i = Yes$).
- $E[\omega] = 0.6$ (common prior expectation on prop. yellow).

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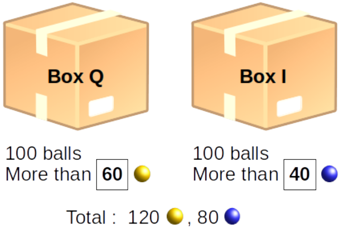

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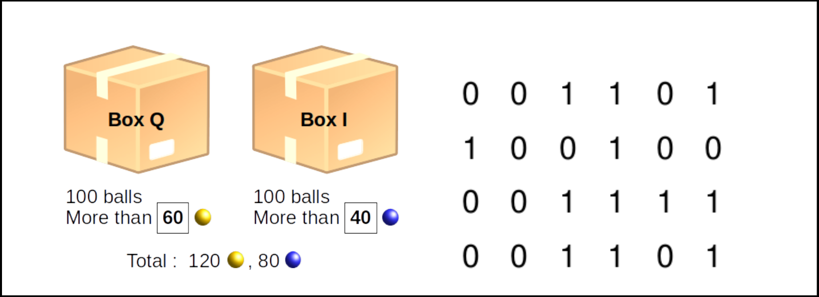

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- $E[\omega] = 0.6$ (common prior expectation on prop. yellow).
- c_i = cognitive effort of counting 0s in matrix.
- Yellow draw $\rightarrow$ Higher expectation on Yellow $\rightarrow$ Box Q is the truthful pick.

Study 1 - Three treatments

- Flat fee: £3.25 completion fee.
- Accuracy incentives: £3.25 $\pm$0.20 per prediction task if the pick is correct or not.
- PPM: £3.25 + PPM incentives.
  Bonus in each question:
  (% of people who pick the same box) − (prior).

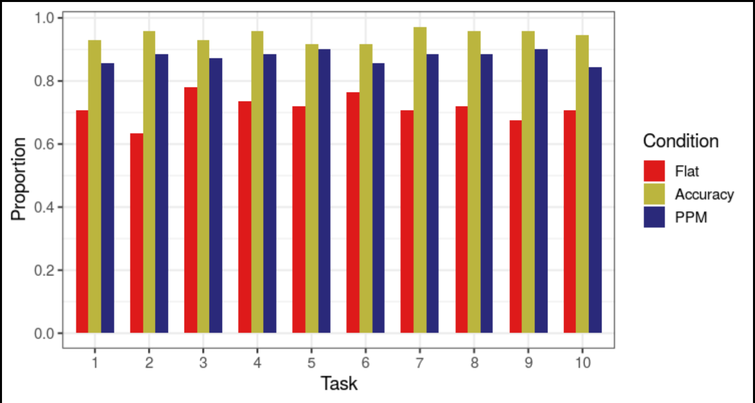
"Accuracy" is a benchmark for verifiable tasks.

Procedure

- Online experiment (Qualtrics), May 2020.
- 210 U.S. citizens, students, recruited on Prolific.
- 10 tasks (10 pairs of boxes, 10 matrices).
- Quiz about incentives (pre and post experiment).

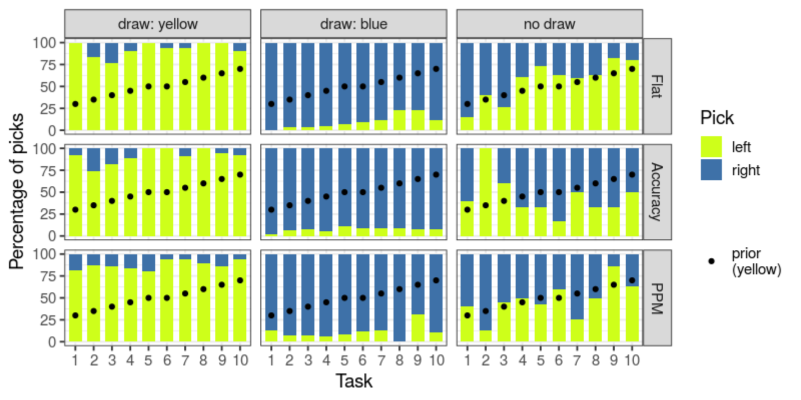
Study 1 - Effort

How often the effort task is completed?



Accuracy > *PPM* > *Flat* in effort elicitation

Study 1 - Picks



Picks are as predicted by the truthful equilibrium.

Marginal effects, logistic regression

	Dep. var.: P(effort task completed)			
	(whole sample)		(filtered sample)	
	(1)	(2)	(3)	(4)
PPM	0.16^{**}	0.14^{**}	0.16^{**}	0.14^{*}
	(0.05)	(0.06)	(0.06)	(0.06)
Accuracy	0.23^{***}	0.23^{***}	0.23^{***}	0.23^{***}
	(0.05)	(0.05)	(0.05)	(0.05)
Age		-0.00		-0.00
		(0.00)		(0.00)
Female?		0.04		0.04
		(0.04)		(0.04)
US resident?		-0.03		-0.02
		(0.07)		(0.07)
Num. obs.	2100	2070	2060	2030
LR test p-val	< 0.0001	< 0.0001	< 0.0001	< 0.0001

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$; $^{+}p < 0.1$

PPM can elicit effort when Accuracy is not feasible.

Study 2

Study 1: Simple task, carefully controlled setup.

Study 2: Online field experiment

- Health & safety guidelines during the Covid-19 pandemic.
- Did people follow them? **(Difficult to measure)**

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Study 1: Simple task, carefully controlled setup.

Study 2: Online field experiment

- Health & safety guidelines during the Covid-19 pandemic.
- Did people follow them? **(Difficult to measure)**

- Would they self-report their unsafe behavior? **(Unverifiable)**
- Covid-19 survey with the PPM incentives.
- Weekly survey in the UK, 3 weeks.

Study 2 - Covid Survey

Question 2 of 8 (show instructions)

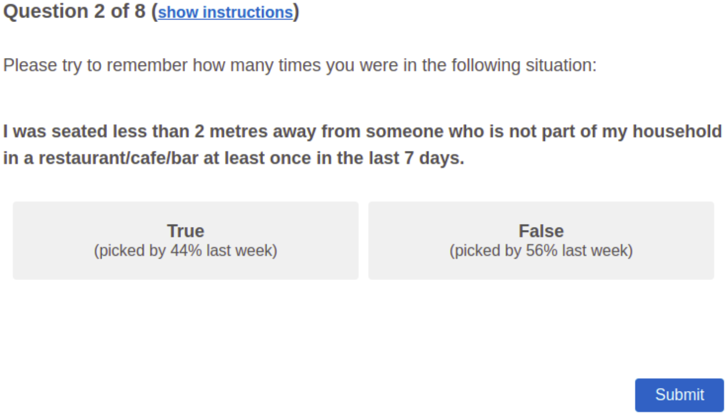
Please try to remember how many times you were in the following situation:

I was seated less than 2 metres away from someone who is not part of my household in a restaurant/cafe/bar at least once in the last 7 days.

True (picked by 44% last week)	**False** (picked by 56% last week)

Submit

Study 2 - Covid Survey



"True" could be underreported.

PPM may elicit a higher % of "True" responses

Study 2 - True/False statements

1.	I have been in an elevator with another person in it at least once in the last 7 days
2.	I may have stood less than 2 metres away from the person in front in a queue at least once in the last 7 days
3.	I was seated less than 2 metres away from someone who is not part of my household in a restaurant/cafe/bar at least once in the last 7 days
4.	I have been in a social gathering with more than 6 people who are not part of my household at least once in the last 7 days
5.	I have been in a busy shop/market with no restrictions on number of customers at least once in the last 7 days
6.	I participated in an indoor activity with more than 6 people who are not part of my household at least once in the last 7 days
7.	I have been in a shop/market where one or more of the staff did not wear a mask at least once in the last 7 days
8.	I had an interaction with someone experiencing high body temperature, persistent cough or loss of taste/smell at least once in the last 7 days

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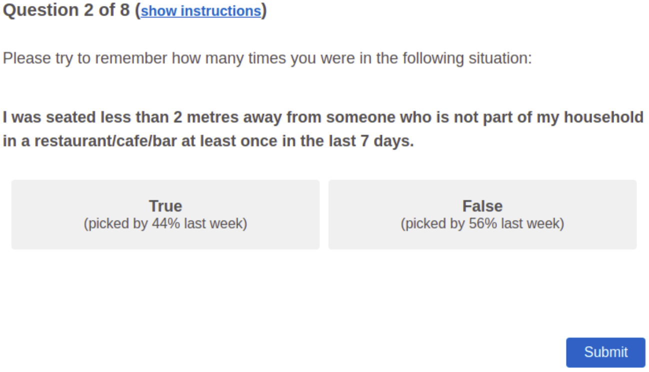
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If you report True,

PPM bonus = % True this week - % True last week (=44).

Study 2 - Link with the theory

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Analogous to PPM when,

Last week's % True $\rightarrow$ Prior for this week.

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Costly signal:

- Mental cost of remembering.
- Shame of answering “True”.

Study 2 - Treatments

Three treatments:

Flat (fixed payment)

I may have stood less than 2 metres away from the person in front in a queue at least once in the last 7 days.

True | False

Study 2 - Treatments

Three treatments:

Flat (fixed payment)

I may have stood less than 2 metres away from the person in front in a queue at least once in the last 7 days.

True	False

PPM (incentives), Flat-PastRate (fixed payment)*

True (picked by 65% last week)	False (picked by 35% last week)

* tests the effect of just showing the last week's %s.

Procedure

- Weekly survey in the UK (Qualtrics).
  Three weeks, October-November 2020.
- 50-55 subjects per week & treatment, recruited on Prolific.
  Fixed payment: £1.75.
- Week 0 initializes % True and % False.
  Weeks 1 & 2 implement all treatments.
- Response times are recorded.

Study 2 - Marginal effects, Pr(Response = "True")

	(week 1)			(week 2)		
	(filtered sample)		*(all)*	*(filtered sample)*		*(all)*
	(1)	(2)	(3)	(4)	(5)	(6)
Flat-PastRate	0.05	0.04	0.04	−0.00	−0.01	−0.00
	(0.04)	(0.04)	(0.04)	(0.03)	(0.03)	(0.03)
PPM	0.11***	0.09**	0.09**	0.08*	0.08*	0.08*
	(0.03)	(0.03)	(0.03)	(0.04)	(0.04)	(0.04)
Response time		0.00	0.00		0.00	0.00
		(0.00)	(0.00)		(0.00)	(0.00)
Age		−0.00	−0.00		−0.00	−0.00
		(0.00)	(0.00)		(0.00)	(0.00)
Female?		0.02	0.02		−0.02	−0.02
		(0.03)	(0.03)		(0.03)	(0.03)
UK citizen?		−0.00	0.00		0.04	0.04
		(0.03)	(0.03)		(0.04)	(0.04)
Num. obs.	1259	1259	1264	1279	1279	1280
LR test p-val	0.0054	0.0123	0.0144	0.0180	0.0455	0.0316

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$; $^{+}p < 0.1$

Higher rate of self-reported unsafe behavior in the PPM treatment.

Contribution

Literature

Mechanism design literature: Explored ways to reveal private signals (Crémer and McLean, 1988).

Sender-Receiver games, Bayesian Elicitation (Whitmeyer, 2019)

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Mechanism design literature: Explored ways to reveal private signals (Crémer and McLean, 1988).

Sender-Receiver games, Bayesian Elicitation (Whitmeyer, 2019)

Peer prediction method (Miller et al., 2005): Similar framework, but

- the complete prior must be known.
- scoring is not transparent.

Bayesian truth-serum (Prelec, 2004) and follow-ups:

- Detail-free (implementer needs less), but more demanding from respondents (answer + prediction).

Usually, costly effort to acquire signal not modelled.

Conclusion

Peer prediction markets: Transparent, easy to implement.

Conclusion

Peer prediction markets: Transparent, easy to implement.

Strong assumptions, but same as or weaker than in the literature.

Limitations: Binary questions only, multiple equilibria.

Thank you!

https://cempeker.github.io/

References

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