

# Peer prediction markets to elicit unverifiable information

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Aurélien Baillon <sup>1</sup>   Cem Peker <sup>2</sup>   Sophie van der Zee <sup>3</sup>

December 5, 2022

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<sup>3</sup>Erasmus School of Economics, Erasmus University Rotterdam

# Background

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## Education:

- PhD in Economics (30.03.2023, Tinbergen Institute, Netherlands)
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## Publications:

- Peker, C. (2022). Extracting the collective wisdom in probabilistic judgments. *Theory and Decision*. doi: 10.1007/s11238-022-09899-4
- Peker, C. (2022). Incentives for self-extremized expert judgments to alleviate the shared-information problem. *Decision*. doi.org: 10.1037/dec0000198

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**Today's paper:** Peer prediction markets to elicit unverifiable information  
(joint with A. Baillon and S. van der Zee)

**More info:** <https://cempeker.github.io/>

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## Imagine a survey...

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Incentivize carefully considered and truthful answers?

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Incentivize carefully considered and truthful answers?

**Your answer is unverifiable!**

## Carefully considered and truthful answers

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

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**Peer Prediction** (Miller et al., 2005):

- “Yes” and “No” types have different beliefs on others’ answers

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**Peer Prediction** (Miller et al., 2005):

- “Yes” and “No” types have different beliefs on others’ answers
- **Your prediction on others’ answers is verifiable!**

# Peer-Prediction Market

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Your prediction on others' answers is verifiable!

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

- One-shot market, buy/sell a single asset
- Trade  $\equiv$  A bet on others' answers

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- 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

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

# The framework

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- *Center* asks a binary question  $\{ \text{Yes}, \text{No} \}$
- $N$  risk-neutral *agents*
- Each agent  $i$  **can receive** a costly signal  $\tau_i \in \{ \text{Yes}, \text{No} \}$ .  
Signal cost =  $c_i$

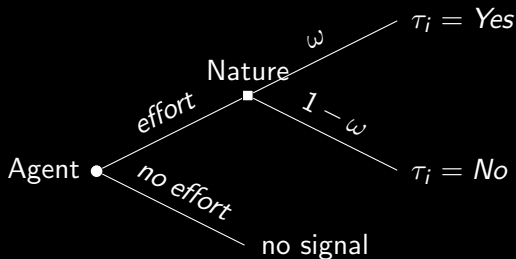
# The framework

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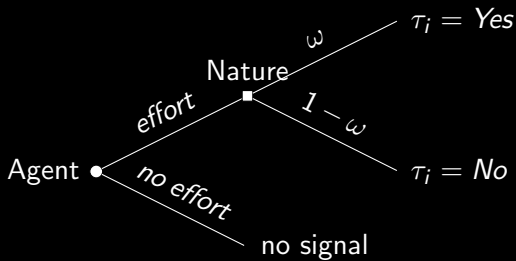
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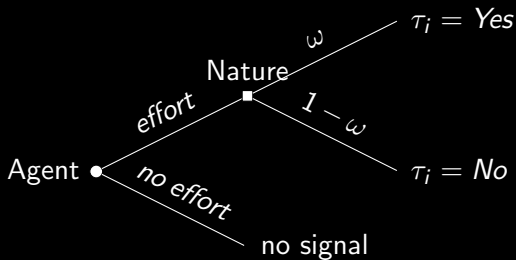
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“Have you stood less than 6 feet apart from another person in a queue yesterday?”

Signal  $\tau_i \equiv$  honest answer. Why is  $\tau_i$  costly?

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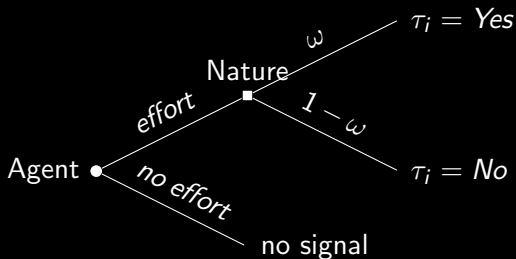


“Have you stood less than 6 feet apart from another person in a queue yesterday?”

Signal  $\tau_i \equiv$  honest answer. Why is  $\tau_i$  costly?

**Socially stigmatized behavior**  $\rightarrow$  **Unwilling to recall**

# The framework

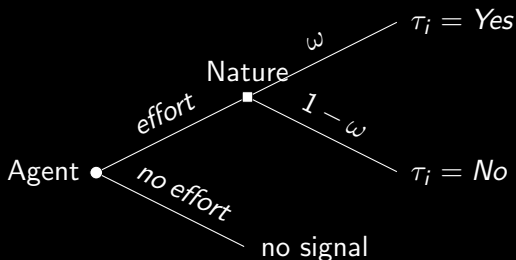


Assumptions:

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



# The framework



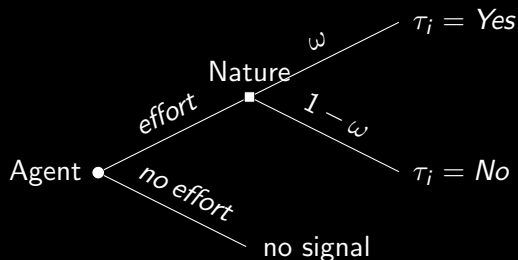
3 groups of agents with posterior expectations:

$$E[\omega | \text{effort and } \tau_i = \text{Yes}]$$

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

$$E[\omega | \text{no effort}] = \text{Prior} = E[\omega]$$

# The framework



Posterior expectations satisfy:

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

“Yes”-types expect  $\omega > E[\omega] = \text{prior}$ .

“No”-types expect  $\omega < E[\omega] = \text{prior}$ .

Peer prediction market

# The mechanism

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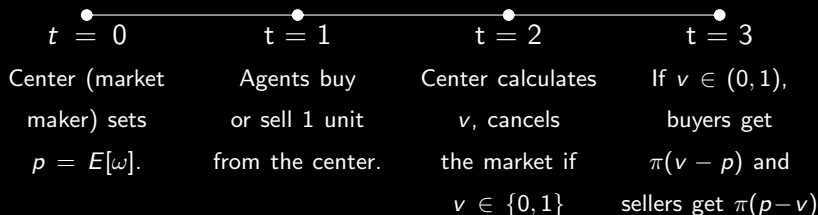
## One-shot market

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

# The mechanism

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# The mechanism

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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

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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  $R_i^{yes} = 1$ .

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⇒ **Truthful strategy**: Trades reflect honest answers.

# Bayesian game

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**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  $N \rightarrow \infty$ .

# Equilibrium analysis

# Equilibria

---

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

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

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

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**In the truthful equilibrium...**

- All agents exert effort
- Yes-types buy, No-types sell
- Truthful answer  $\equiv$  Equilibrium trade

# Equilibria

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

How?

# Equilibria

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How? Suppose,

- Agent  $i$  exerts effort ( $e_i = 1$ )
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Types  $E[\omega | \tau_i = \text{No}] < E[\omega] < E[\omega | \tau_i = \text{Yes}]$

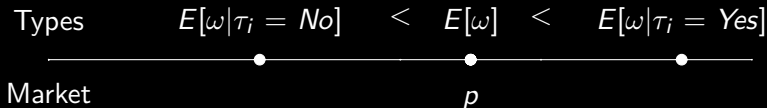


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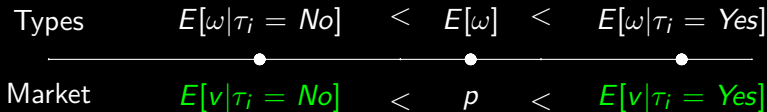


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Asset value ( $v$ )  $\equiv$  Proportion of buyers  $\rightarrow$  Proportion of Yes-type ( $\omega$ )

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Types	$E[\omega \tau_i = \text{No}]$	$<$	$E[\omega]$	$<$	$E[\omega \tau_i = \text{Yes}]$
Market	$E[v \tau_i = \text{No}]$	$<$	$p$	$<$	$E[v \tau_i = \text{Yes}]$

**Optimal:** Buy if  $\tau_i = \text{Yes}$ , sell if  $\tau_i = \text{No}$

**Incentive to “learn” your type  $\rightarrow e_i = 1$**

# Equilibria

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## Multiple equilibria

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

Expected payoffs are 0.

→ No effort when costs are too high.

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→ 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.

→ 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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## Multiple equilibria

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



## Psychological costs

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- **Asymmetric reporting cost:** Cost  $a_i \geq 0$  of reporting “Yes”, no matter (presence of) signal.
- **Deception cost:** The cost  $d_i \geq 0$  of reporting “Yes” when  $\tau_i = \text{No}$  or “No” when  $\tau_i = \text{Yes}$ .

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**Truthful equilibrium if  $\pi$  is scaled appropriately**

# Experimental Evidence

# Testing PPM

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Two experimental studies.

Study 1:


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

Study 2:


- Health survey, questions of 6-feet-apart type.
- Psychological costs & practical feasibility



## Study 1 - A pair of boxes



100 balls  
More than 60 



100 balls  
More than 40 


Total : 120  , 80 

One of the boxes has been selected (Q=“more yellow” or I=“less yellow”).


Guess which one.



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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 theory



100 balls  
More than 60 



100 balls  
More than 40 


Total : 120 , 80 

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


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



## Link with theory



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- $E[\omega] = 0.6$  (common prior expectation on prop. yellow).
- $c_i$  = cognitive effort of counting 0s in matrix.
- Picking Box Q  $\equiv$  Buying  $\equiv$  Reporting yellow ("Yes").

## Study 1 - 3 treatments

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- **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: (% of people who pick the same box) – (prior).

“Accuracy” is a benchmark for verifiable tasks.

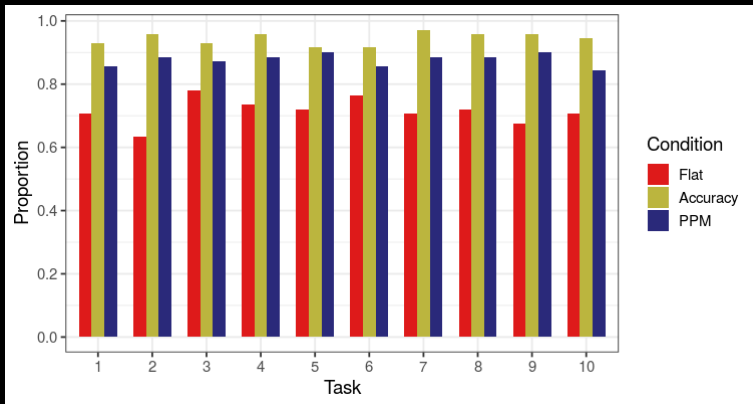
# Participants

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- Online experiment, May 2020
- 210 U.S. citizens, students, recruited on Prolific
- 10 tasks (10 pairs of boxes, 10 matrices).

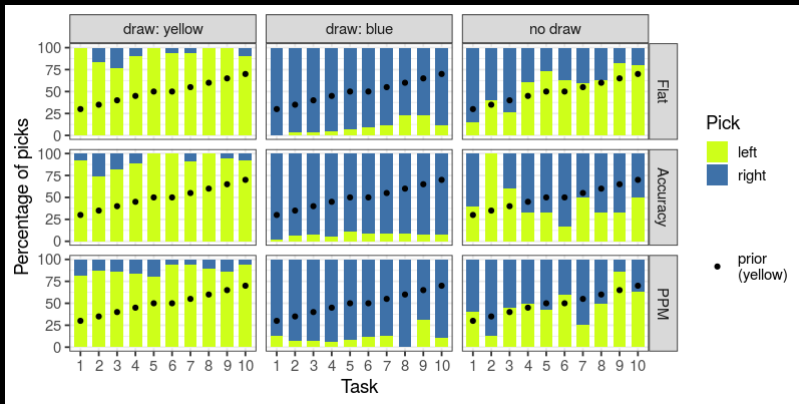
# Study 1 - Effort

Proportion of subjects who complete the effort task



*Accuracy > PPM > Flat* in effort elicitation

# Study 1 - Picks



Picks are as predicted by the truthful equilibrium.



## Marginal effects, logistic regression

	<i>Dep. var.: P(effort task completed)</i>			
	<i>(whole sample)</i>		<i>(filtered sample)</i>	
	(1)	(2)	(3)	(4)
PPM	0.10** (0.03)	0.09** (0.03)	0.10** (0.03)	0.08** (0.03)
Accuracy	0.18*** (0.03)	0.18*** (0.03)	0.18*** (0.03)	0.18*** (0.03)
Age		−0.00 (0.00)		−0.00 (0.00)
Female?		0.04 (0.03)		0.04 (0.03)
US resident?		−0.02 (0.06)		−0.02 (0.06)
Num. obs.	2100	2070	2060	2030

\*\*\*  $p < 0.001$ ; \*\*  $p < 0.01$ ; \*  $p < 0.05$ ; +  $p < 0.1$

PPM can elicit effort when incentives for accuracy are not feasible (unverifiable questions).

## Study 2

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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?

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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)**
- A health survey with PPM incentives

## 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

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“True” could be underreported.

Would a PPM 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

## Study 2 - Link with theory

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**True**

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Submit

If you report True,  $\text{bonus} > 0$  if  $\% \text{ True this week} > 0.44$



## Study 2 - Link with theory

### 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

If you report True,  $\text{bonus} > 0$  if  $\% \text{ True this week} > 0.44$

Analogous to PPM:

- $v = \% \text{ True this week}$
- $p = E[\omega] = 0.44$  (common prior on True)

## Study 2 - Link with theory

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**True**

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**False**

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Submit

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

## Study 2 - Experimental conditions

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Weekly survey in the UK, 3 weeks, November 2020

### 3 Experimental conditions

#### Control-1 (flat fee)

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 - Experimental conditions

Weekly survey in the UK, 3 weeks, November 2020

### 3 Experimental conditions

#### Control-1 (flat fee)

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

#### Treatment (PPM incentives), Control-2 (flat fee)\*

**True**

(picked by 65% last week)

**False**

(picked by 35% last week)

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

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

	(week 2)		(week 3)	
	(1)	(2)	(3)	(4)
(Intercept)				
Control-2	0.05 (0.04)	0.04 (0.04)	-0.01 (0.04)	-0.00 (0.04)
PPM	0.11*** (0.03)	0.10** (0.03)	0.08* (0.04)	0.08* (0.04)
Age		-0.00 (0.00)		-0.00 (0.00)
Female?		0.02 (0.03)		-0.02 (0.03)
UK citizen?		-0.00 (0.03)		0.03 (0.04)
Num. obs.	1259	1259	1279	1279

\*\*\*  $p < 0.001$ ; \*\*  $p < 0.01$ ; \*  $p < 0.05$ ; +  $p < 0.1$

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

Contribution

# Conclusion

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

Peer-prediction markets: Novel solution for eliciting effort & truthful revelation.

# Conclusion

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

Peer-prediction markets: Novel solution for eliciting effort & truthful revelation.

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

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Peer prediction markets: Transparent, easy to implement.

# Conclusion

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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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