Lecture 9:
Incentive Design: Financial Incentives

Questions: https://sli.do #26386

Instructor: Chien-Ju (CJ) Ho

Logistics: Deadlines

- Assignment 2: Due this Friday
- Assignment 3: Due Oct 27 (Tue)

- Project milestone 1: Due Oct 30 (Fri)
  - Initial literature survey (know what other works are out there)
  - A plan on what you want to do for the remaining of the semester
    - Formalize your research question and approaches, e.g.,
      - Theory/simulation project: formalize your models
      - Data-analysis project: figure out where and how to get data and what you plan to do with it
      - Experiment/application project: have a prototype design and an evaluation plan
    - Include a timeline (weekly or biweekly) on what you plan to do

Assignment 2

- Some implementation hints

Recap

Game Theory Basics

- Key elements of game theoretical models
  - Players, strategies, payoffs

- Normal-form game

B

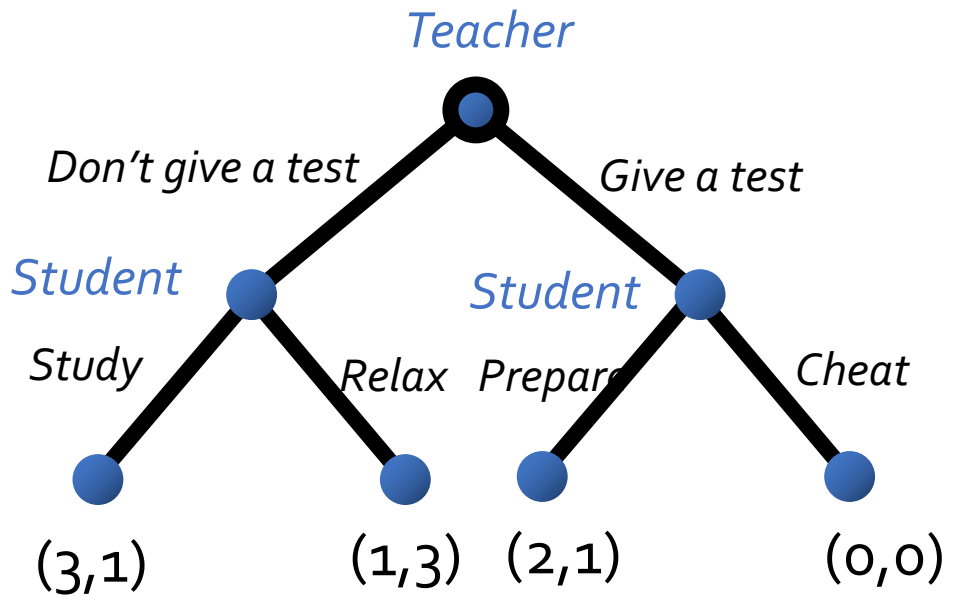
A

	Stay Silent	Confess
Stay Silent	A: 6 months B: 6 months	A: 10 years B: free
Confess	A: free B: 10 years	A: 5 years B: 5 years

Game Theory Basics

- Key elements of game theoretical models
  - Players, strategies, payoffs

- Extensive-form game



Solutions Concepts

- Informally, predictions of what rational agents will do given the game

- Nash equilibrium
  - If everyone else follows Nash equilibrium, it's your best interest to follow

B

A	Movie	Bar
Movie	(2, 1)	(0, 0)
Bar	(0, 0)	(1, 2)

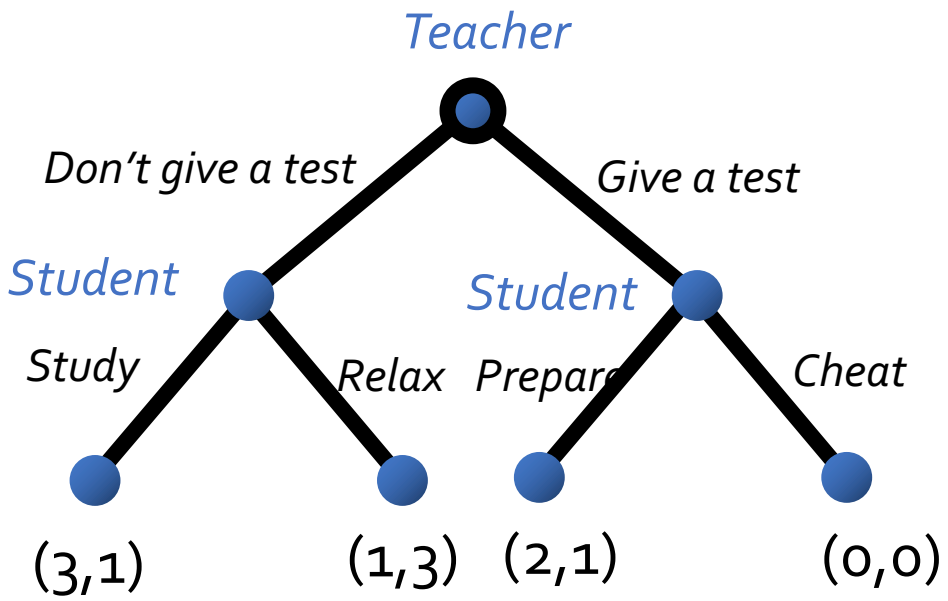
(Movie, Movie) and **(Bar, Bar)** are pure strategy Nash equilibria

Generally speaking, finding a Nash is hard, but verifying whether it's a Nash is easy

Solutions Concepts

- Informally, predictions of what rational agents will do given the game

- Subgame perfect equilibrium
  - Play in each ”subgame” is a Nash equilibrium



- Subgame perfect equilibrium
  - Teacher chooses “Give a test”
  - Student chooses (“Relax”, “Prepare”)

Mechanism Design

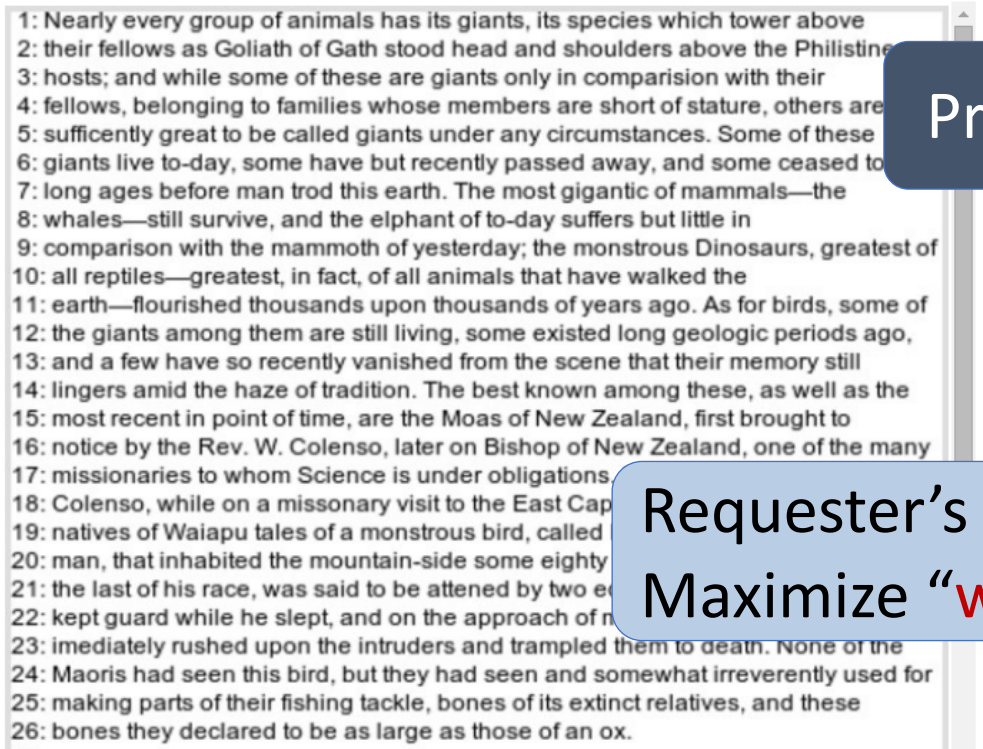
- Game theoretical analysis
  - Given the game, analyze what rational agents will do

- Mechanism design (reverse game theory)
  - Give a goal of what you want rational agents do, design the game rules (e.g., what payoffs agents can receive) such that agents choose the actions you want them to choose.

Lecture Today

Financial Incentive in Crowdsourcing

- Fixed payment
  - Post a price for the task, workers can choose to accept it or not
- Contract: Performance-based payments (PBP)



Proofread this text, earn $0.50

Earn an extra bonus $0.10 for every typo found

Requester's goal:
Maximize "work quality minus payment"

Static Contract Design

Requester

Contract

Task value	Bad Outcome worth $1	Good Outcome worth $5
Payment	$1	$3

Set payments to maximize [expected task value – expected payment]

Worker

	Bad Outcome	Good Outcome	
High effort	Prob: 0.1	Prob: 0.9	Cost: $1
Low effort	Prob: 0.8	Prob: 0.2	Cost: $0

Choose effort to maximize [expected payment – cost]

Static Contract Design

Requester

Contract

Task value	Bad Outcome worth $1	Good Outcome worth $5
Payment	$1	$3

- Expected payoff: $0.1\times\$1 + 0.9\times\$5 - 0.1\times\$1 - 0.9\times\$3 = \$1.8$

  expected value – expected payment

Worker

	Bad Outcome	Good Outcome	
High effort	Prob: 0.1	Prob: 0.9	Cost: $1
Low effort	Prob: 0.8	Prob: 0.2	Cost: $0

- Expected payoff of high effort: $0.1\times\$1 + 0.9\times\$3 - \$1 = \$0.18$
- Expected payoff of low effort: $0.8\times\$1 + 0.2\times\$3 - \$0 = \$0.14$

  Expected payment - cost

Static Contract Design

Requester

Contract

Task value	Bad Outcome worth $1	Good Outcome worth $5
Payment	$1	$3

worker

	Bad Outcome	Good Outcome	
High effort	Prob: 0.1	Prob: 0.9	Cost: $1
Low effort	Prob: 0.8	Prob: 0.2	Cost: $0

- Contract Design:
  - How to find the “optimal” payment that maximizes the requester’s payoff?
  - In the “full information” setting, i.e., we know everything about the worker
    - Well-studied principal-agent problem in economics

Contract Design in Crowdsourcing

Requester

Contract

	Bad Outcome worth $1	Good Outcome worth $5
Task value		
Payment	?	?

- **Multiple** workers
- **Unknown** parameters
- **Unknown** distributions

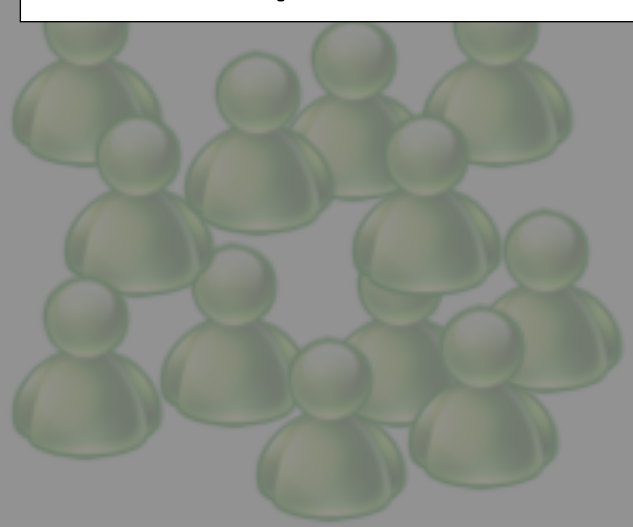
- Interact with one worker at a time
- Workers are i.i.d. drawn

Contract Design in Crowdsourcing

Contract

Task value	Bad Outcome worth $1	Good Outcome worth $5
Payment	?	?

Can we **adaptively** update contracts to maximize the requester's expected payoff over time



- **Multiple** workers
- **Unknown** parameters
- **Unknown** distributions

- Interact with one worker at a time
- Workers are i.i.d. drawn

Adaptive Contract Design in Crowdsourcing Markets

joint work with

Alex Slivkins
Microsoft Research

Jenn Wortman Vaughan
Microsoft Research

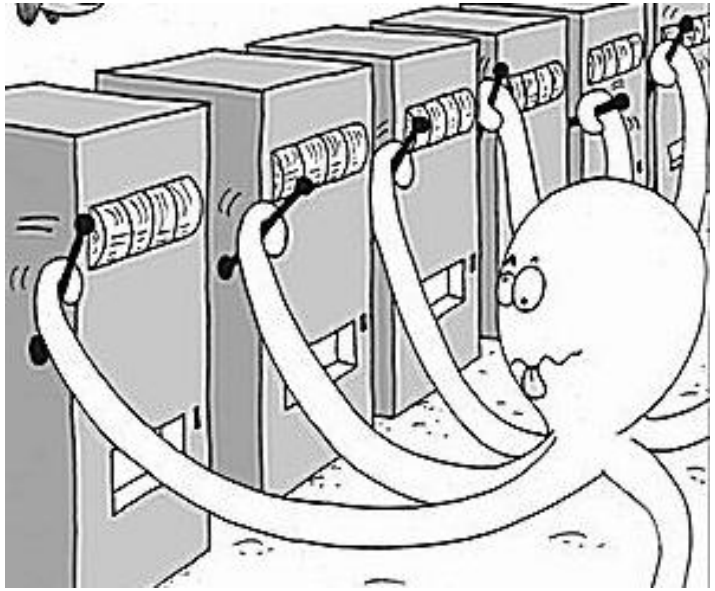
Appeared In ACM EC'14 and JAIR'16

Contract Design as A Machine Learning Problem

- At each time step
  - the requester posts a payment
  - a worker completes the task and returns the result
  - the requester observes the result and updates the payment

- An online learning problem (bandit learning)
  - exploring the payoff of each payment
  - exploiting the optimal payment
  - exploration/exploitation tradeoff

- Challenge:
  - An infinite number of possible payments (arms)!
  - Bandits with infinitely many arms

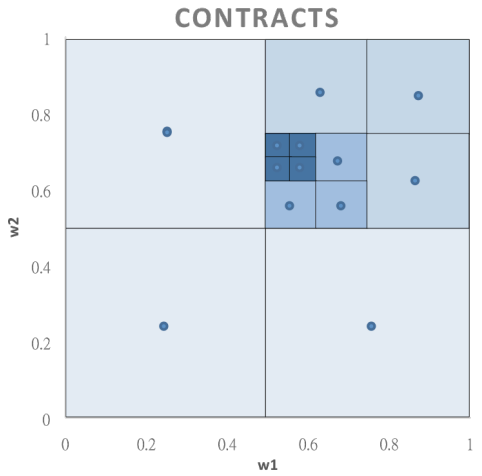


Dealing with Infinitely Many Payments

- Make assumptions on worker behavior
  - Workers are **rational**: workers exert effort that maximizes their payments minus costs
  - Workers are **myopic**: worker arrive only once and/or won't try to "game" the system

- When posting a PBP (performance-based payments), we learn the payoffs of the posted payment and similar payments

Algorithm and Result



- Agnostic Zooming Algorithm:
  - Adaptively refine the search space and "zoom in" into more promising regions of PBPs

- Main theorem
  If workers are rational and myopic,
  we can learn the optimal payment efficiently!

The average difference of running our algorithm for T rounds and running the optimal algorithm for T rounds is bounded by $O(1/T^{\alpha})$, where $\alpha > 0$ indicates the difficulty of learning.

Discussion

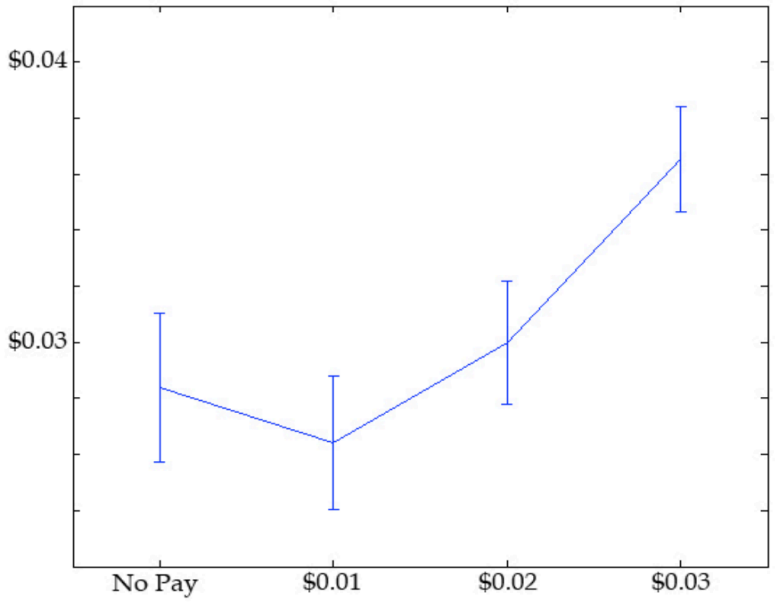
- The two main assumptions made in this paper
  - Rational: crowd workers want to maximize their payments minus cost
  - Myopic: crowd workers only care about the payoff “now” at this round

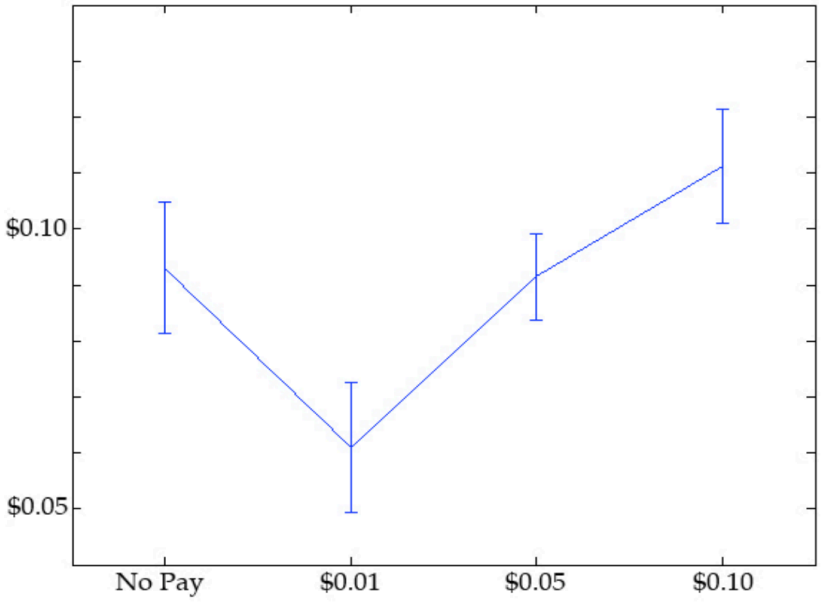
- How comfortable are you with these two assumptions? What are the example scenarios these assumptions break? How can you examine empirically that these assumptions hold or not? Are there alternatives for the modeling choices?

- Are there other implicit/explicit assumptions out these?

Anchoring effect:
Workers' Perceptions of Fair Payments

- When asked how much do they think the payment should be after tasks





X-axis: the payment they receive
Y-axis: the payment they think it should be

Financial Incentives and the "Performance of Crowds". Mason and Watts. HCOMP 2009.

Incentivizing High Quality Crowdwork

joint work with

Alex Slivkins
Microsoft Research

Sid Suri
Microsoft Research

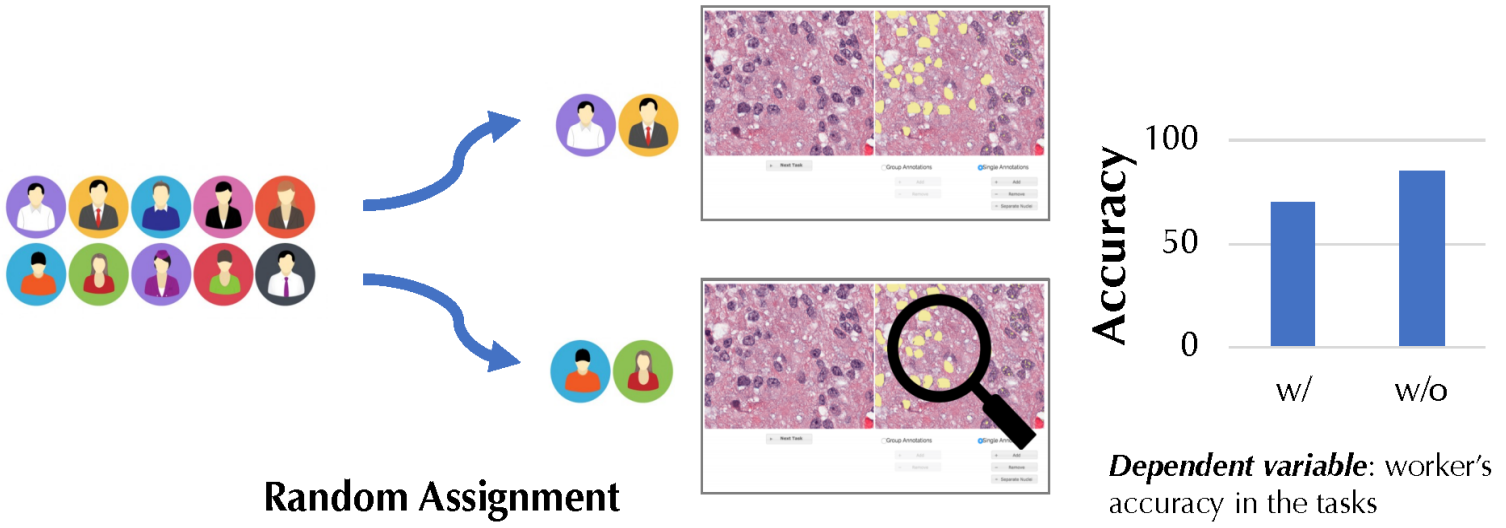
Jenn Wortman Vaughan
Microsoft Research

Are workers really *rational*?

Goal: Investigate the casual effects of financial incentives on the quality of crowdwork.

Causality ≠ Correlation

- To infer causality (whether A causes B), randomized experiment is the gold solution at the moment



Dependent variable: worker's accuracy in the tasks

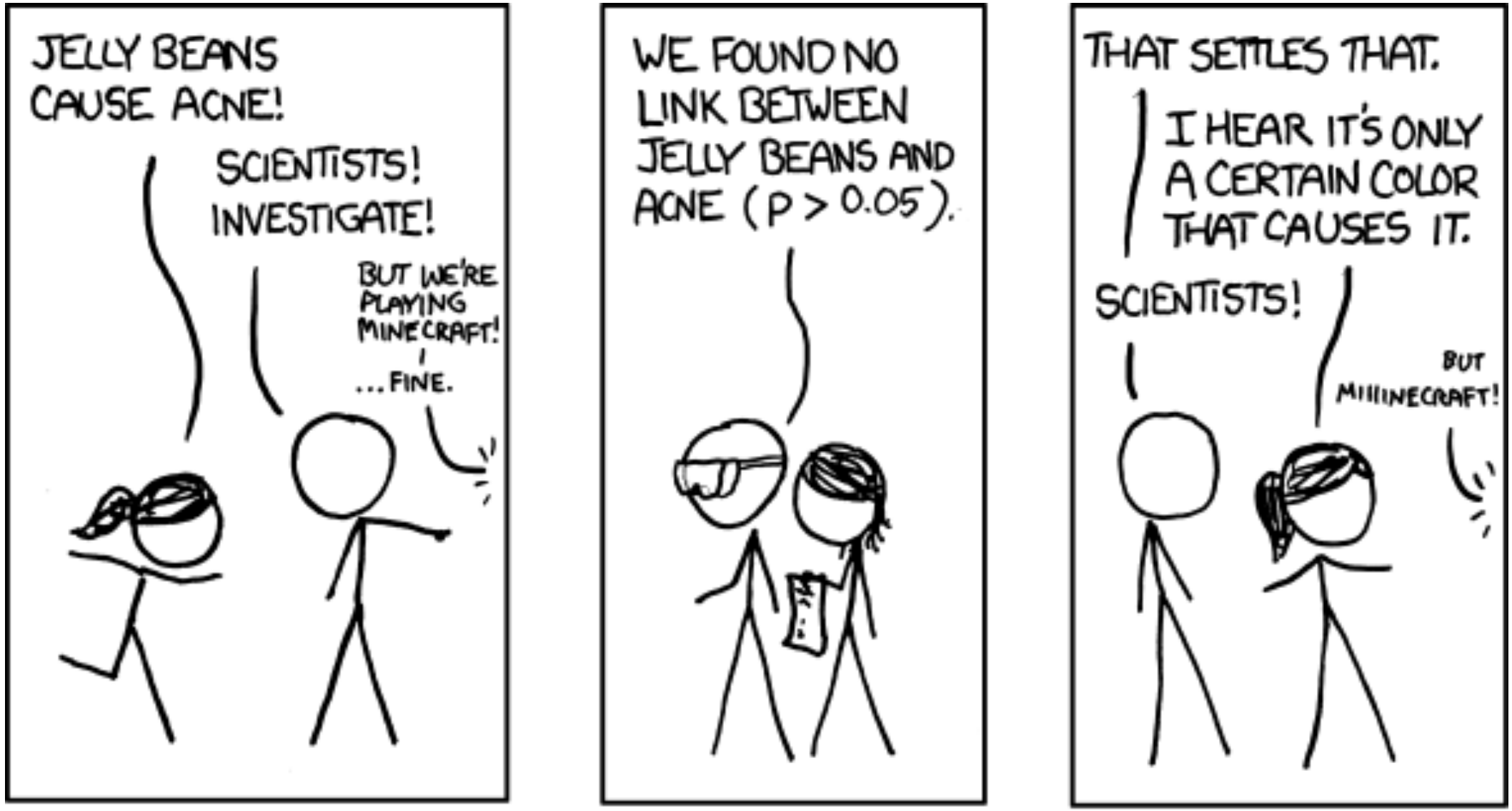
Statistical tests: t-tests, rank-sum tests, etc.

There have been studies on inferring causality using observational data, but they require some assumptions.

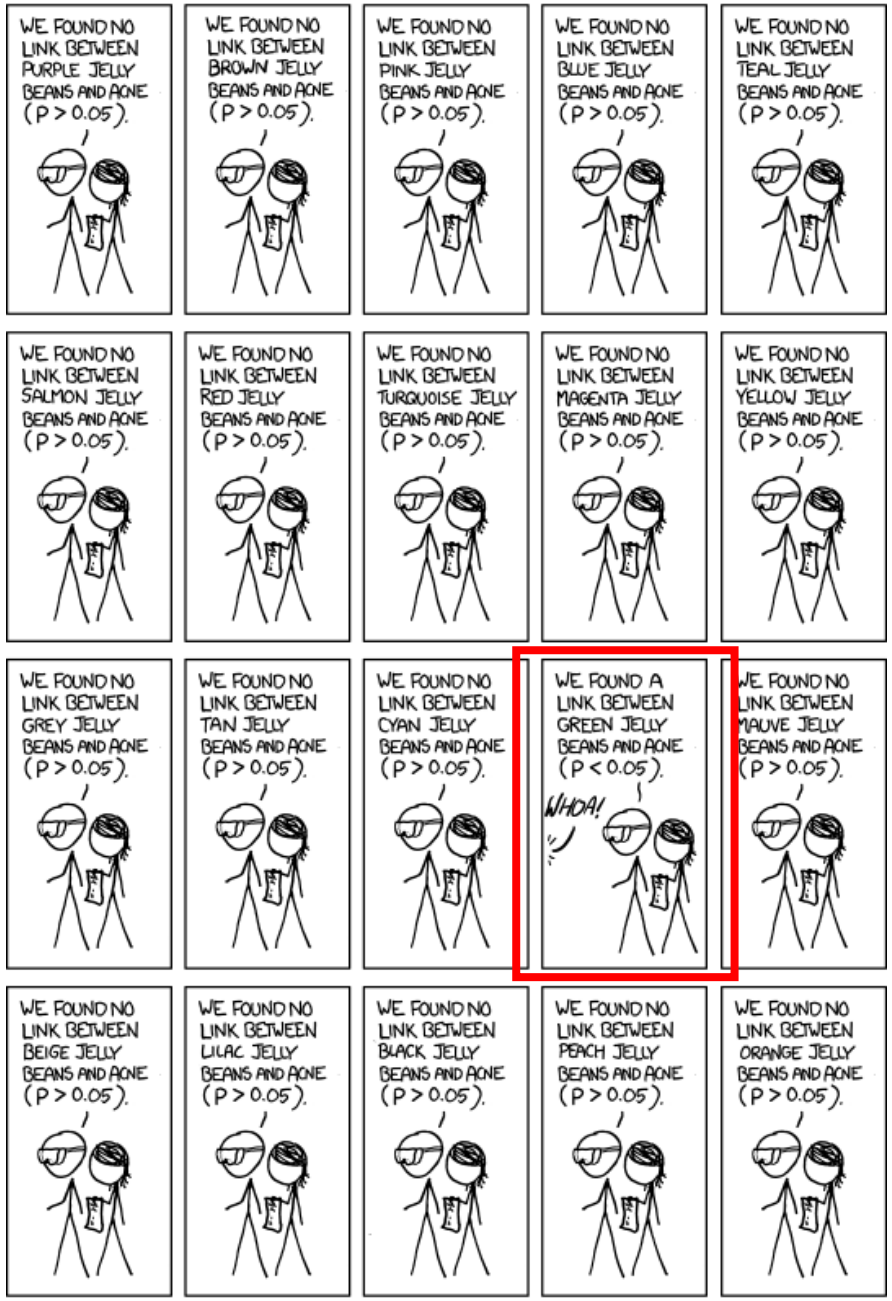
A bit more notes…

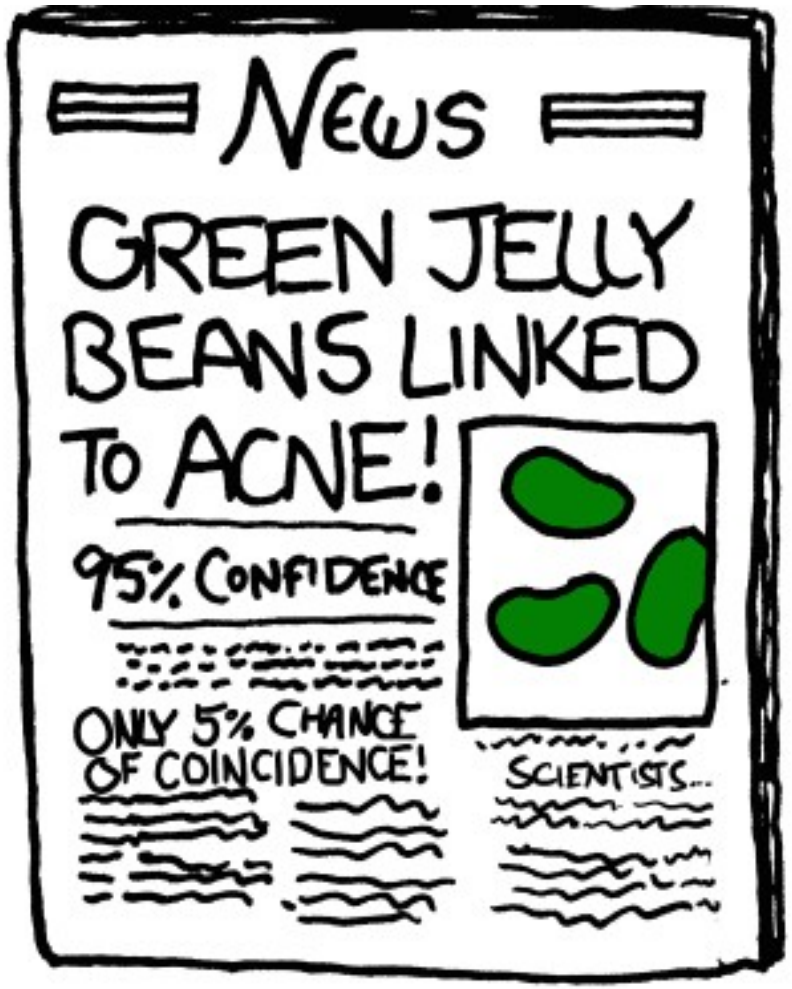
- How do we know whether a COVID-vaccine works?
  - Randomized experiments!
    - Control: people receiving placebo
    - Treatment: people receive the vaccine
  - Measure their immunity afterwards

- Need principled way of conducting the experiments
  - Pre-registered hypothesis
  - Don’t peek at the data before it finalizes (or deal with it appropriately)
    - In the COVID vaccine experiments, a common protocol allows the company to “peek” at the data a few times before the experiment ends, so there is a chance to end the experiment early
    - Need to take care of this effect in the statistical analysis



From xkcd, by Randall Munroe: http://xkcd.com/882





From xkcd, by Randall Munroe: http://xkcd.com/882

How do workers really react to performance-based payments (PBPs)?

In the economics literature...

- PBPs improve quality in lab experiments [CH99] and can help in real firms (observational study) [L00]

In crowdsourcing markets...

- Paying more increases the quantity of work, but not the quality [MW09, RK+11, BKG11, LRR14]
- Mixed results on whether PBPs help
  - PBPs improve performance [H11, YCS14]
  - PBPs do not improve performance [SHC11]
  - Bonus size does not matter [YCS13]

Which led to this work…

- We explore whether, when, why, and where performance-based payments (PBPs) improve the quality of crowdwork on Amazon Mechanical Turk.

- We propose a novel but simple worker model coherent with our empirical results.

Experiment 1: Does PBP work?

- Verify that performance-based payments (PBPs) can lead to higher quality crowdwork at least for some tasks.

- Determine if there exists an implicit PBP effect:
  workers have subjective beliefs on the quality of work they must produce to receive the base payment, and therefore already behave as if payments are (implicitly) performance-based.

Experiment 1: Does PBP work?

- Task: Proofread an article and find spelling errors.

1: Nearly every group of animals has its giants, its species which tower above
2: their fellows as Goliath of Gath stood head and shoulders above the Philistine
3: hosts; and while some of these are giants only in comparision with their
4: fellows, belonging to families whose members are short of stature, others are
5: sufficently great to be called giants under any circumstances. Some of these
6: giants live to-day, some have but recently passed away, and some ceased to be
7: long ages before man trod this earth. The most gigantic of mammals—the
8: whales—still survive, and the elphant of to-day suffers but little in
9: comparison with the mammoth of yesterday; the monstrous Dinosaurs, greatest of
10: all reptiles—greatest, in fact, of all animals that have walked the
11: earth—flourished thousands upon thousands of years ago. As for birds, some of
12: the giants among them are still living, some existed long geologic periods ago,
13: and a few have so recently vanished from the scene that their memory still
14: lingers amid the haze of tradition. The best known among these, as well as the
15: most recent in point of time, are the Moas of New Zealand, first brought to
16: notice by the Rev. W. Colenso, later on Bishop of New Zealand, one of the many
17: missionaries to whom Science is under obligations. Early in 1838, Bishop
18: Colenso, while on a missonary visit to the East Cape region, heard from the
19: natives of Waiapu tales of a monstrous bird, called Moa, having the head of a
20: man, that inhabited the mountain-side some eighty miles away. This mighty bird,
21: the last of his race, was said to be attened by two equally huge lizards that
22: kept guard while he slept, and on the approach of man wakened the Moa, who
23: imediately rushed upon the intruders and trampled them to death. None of the
24: Maoris had seen this bird, but they had seen and somewhat irreverently used for
25: making parts of their fishing tackle, bones of its extinct relatives, and these
26: bones they declared to be as large as those of an ox.
27:
28: About the same time another missionary, the Rev. Richard Taylor, found a bone
29: ascribed to the Moa, and met with a very similer traditition among the natives of
30: a near-by district, only, as the foot of the rainbow moves away as we move
31: toward it, in his case the bird was said to dwell in quite a diffrent locality
32: from that given by the natives of East Cape. While, however, the Maoris were

- We randomly insert 20 typos
  - sufficiently -> sufficently
  - existence -> existance
  - …
- Useful properties:
  - Quality is measurable
  - Exerting more effort leads to better results

Experiment 1: Does PBP work?

Base payment: $0.50; Bonus payment: $1.00

Three Bonus Treatments:

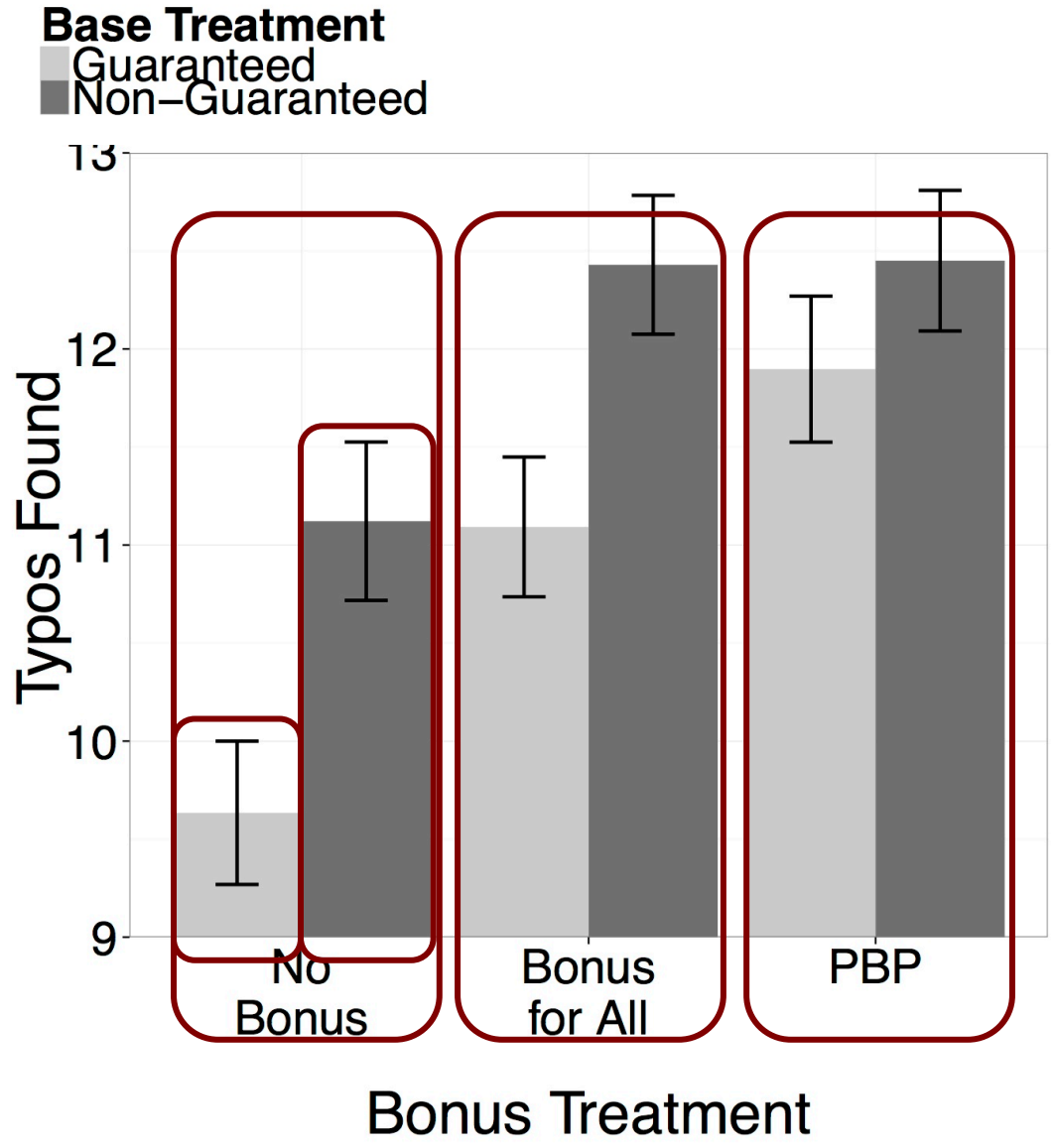
- *No Bonus:* no bonus or mention of a bonus
- *Bonus for All:* get the bonus unconditionally
- *PBP:* get the bonus if you find 75% of the typos found by others

Two Base Treatments:

- *Guaranteed:* guaranteed to get paid
- *Non-Guaranteed:* no mention of a guarantee

Workers saw exactly the same description before accepting the task.
After accepting the task, they are randomly assigned to the treatments.

Experiment 1: Does PBP work?

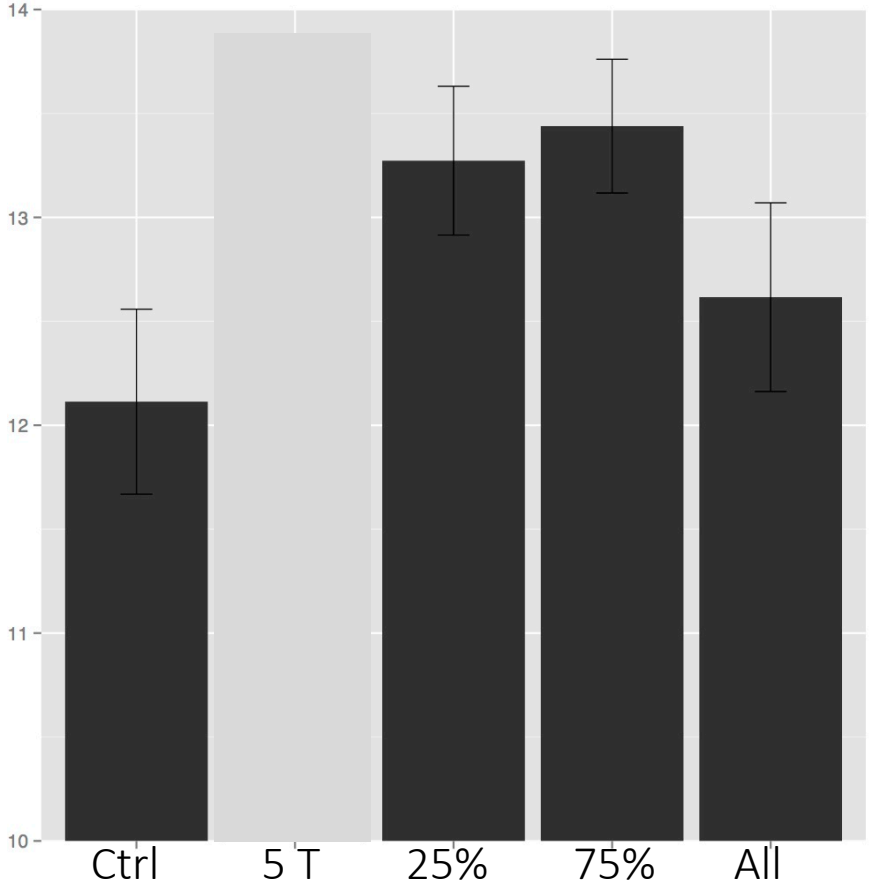


- Results from 1000 unique workers
- Guaranteed payments hurt (implicit PBP)
- PBP improves quality
- Paying more also improves quality

Experiment 2: When does PBP work?

Bonus threshold (585 unique workers)

- $0.50 base + $1.00 bonus for finding *X* typos

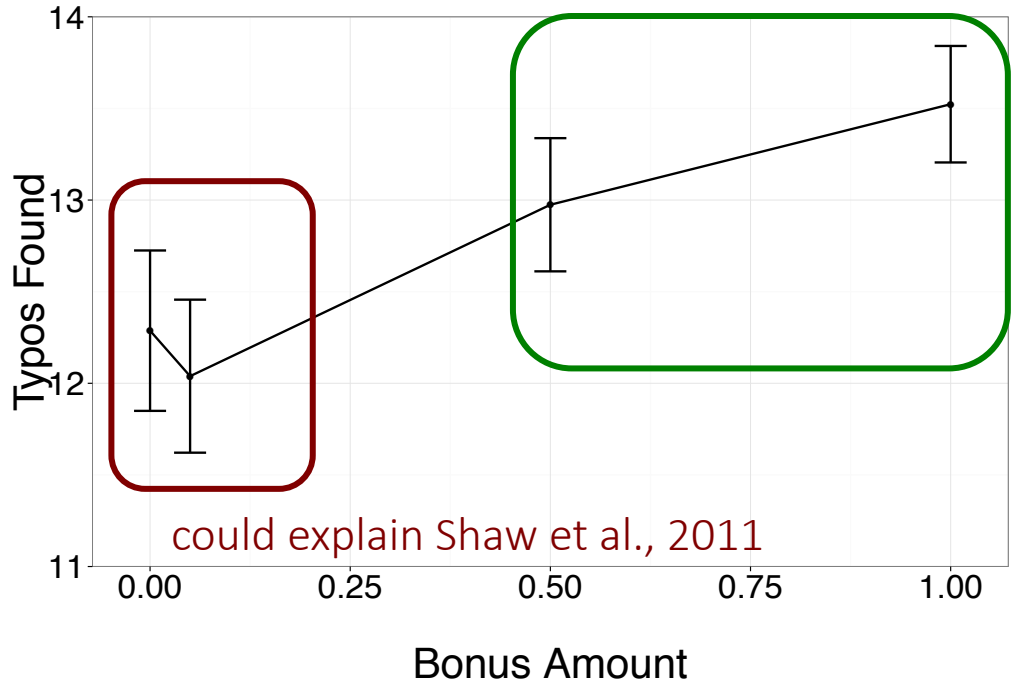


- PBPs work for a wide range of thresholds
- Subjective beliefs (5 typos vs. 25% of typos) can improve quality

Experiment 2: When does PBP work?

Bonus amounts (451 unique workers)

- $0.50 base + $*X* bonus for finding 75% of typos
- PBPs work as long as the bonus is large enough



could explain Yin et al., 2013

Experiment 3: Why does PBP work?

Possible explanations:

- Workers are rational and aim to maximize their expected payoff (expected payment - cost)
- Workers work harder when being paid more
- Workers work harder when receiving unexpected bonuses for the work [G14]
  - To avoid selection bias, our bonus description is announced *after* a worker accepts the task.

Experiment 3: Why does PBP work?

Can we separate the unexpected bonus effects?

- Goal: Give workers full payment description before they accept our tasks while avoiding selection bias
- Use qualifications for random treatment assignment
  - Post recruitment tasks to recruit a pool of workers
  - Randomly assign workers to different treatments
  - Invite workers to complete tasks
  - Ensure workers cannot see other tasks using qualifications

Experiment 3: Why does PBP work?

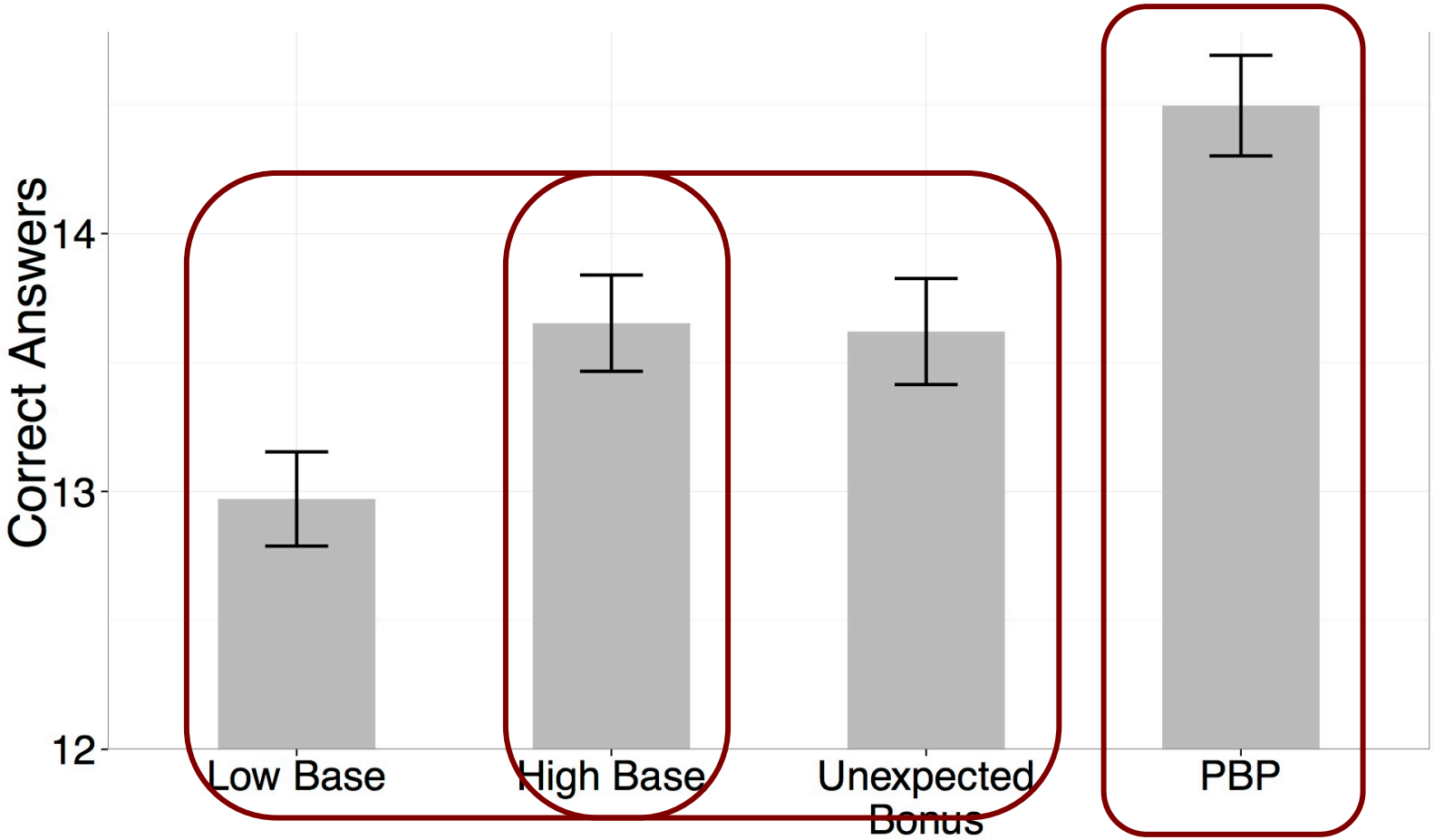
Task: Determining whether or not there are differences between 20 pairs of images [Y13]

Four treatments:

- *Low base*: $0.50 base payment
- *High base*: $1.50 base payment
- *Unexpected bonus*: $0.50 base + $1.00 unconditional (unexpected) bonus
- *PBP*: $0.50 base + $1.00 bonus if accuracy >= 80%

Experiment 3: Why does PBP work?

- **Results** (542 unique workers)



No unexpected bonus effects

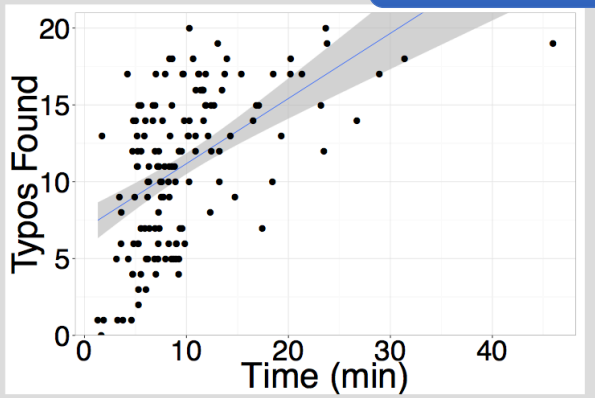
Paying more works,
but PBP works even better

Experiment 4: Where does PBP work?

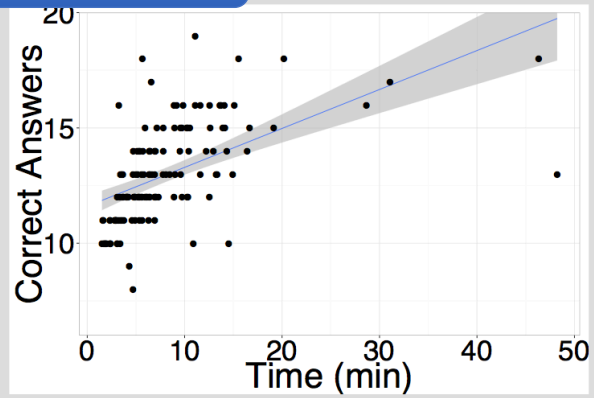
- What properties of a task allow PBP to improve quality?
- Some pilot experiments suggested that
  - PBPs improve quality for effort-responsive tasks
  - It is not always straightforward to guess which tasks are effort-responsive.
- Examine the correlation between effort-responsiveness and whether PBPs work.
  - Use time as a proxy for effort

Experiment 4: Where does PBP work?

Effort Responsive

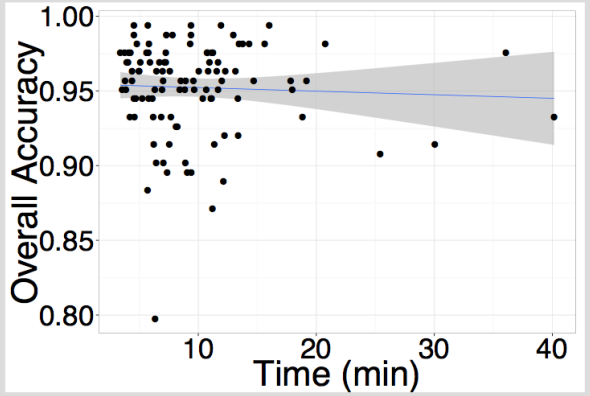


proofreading

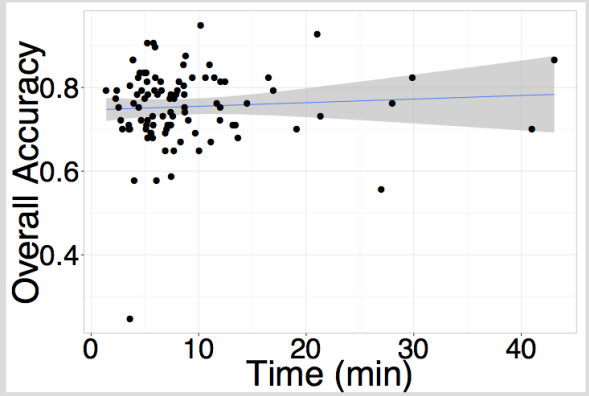


Spotting differences

Not Effort Responsive



Handwriting recognition

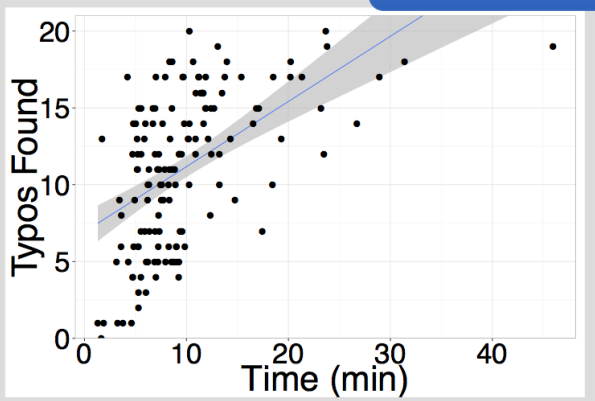


Audio transcription

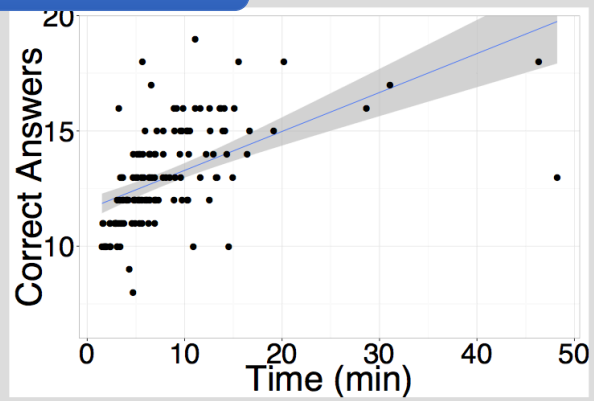
Experiment 4: Where does PBP work?

PBP works

Effort Responsive



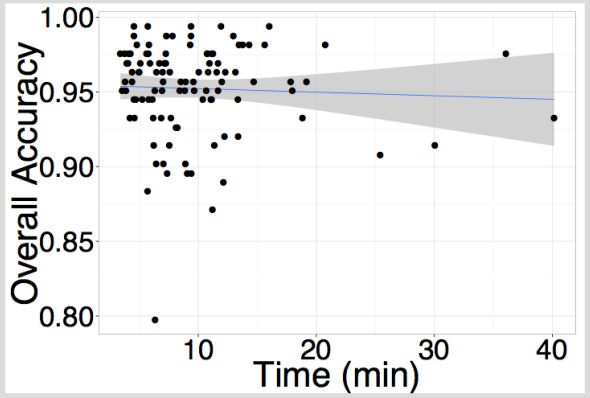
proofreading



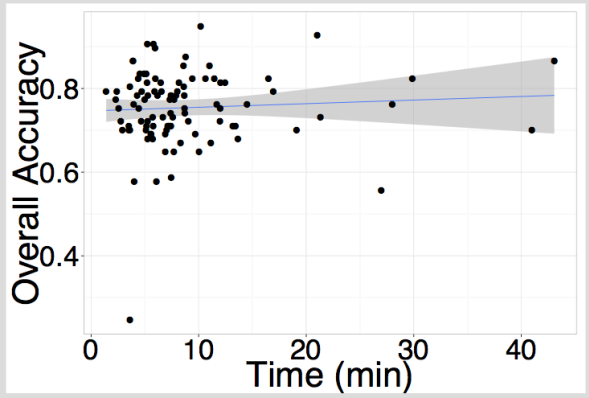
Spotting differences

PBP doesn't work

Not Effort Responsive



Handwriting recognition



Audio transcription

Worker Model

- Standard economic assumption (principal-agent model): each worker chooses to produce work of the quality q that maximizes their expected utility:

$$\text{BasePayment} + \text{BonusPayment} \times \Pr(\text{GetBonus} \mid q) - \text{Cost}(q)$$

true probability of receiving the bonus

(*positive or negative*) intrinsic cost of performing the work

Worker Model

- In our model, workers choose q to maximize:

subjective probability of receiving the base

$$\text{BasePayment} \times \Pr(\text{GetBase} \mid q)$$
$$+ \text{BonusPayment} \times \Pr(\text{GetBonus} \mid q)$$
$$- \text{Cost}(q)$$

subjective probability of receiving the bonus

Worker Model

This model can be used to explain key observations from our experiments:

- Subjective beliefs about acceptance increase quality.
- Higher payments increase quality. (Not true for PA!)
- Performance-based payments (significantly) increase quality when
  - the task is effort-responsive
  - there are no ceiling effects
  - the bonus payment is sufficiently high
  - the bonus is not too easy to obtain

Results from HSV14 still apply under this model!

Conclusion

- We explore whether, when, why, and where performance-based payments improve the quality of crowdwork and propose a novel but simple worker model coherent with our results.

- More in this line of research
  - Can we use empirical insights to inform the algorithmic theory of human computation?
  - What can this informed algorithmic theory give back to the crowdsourcing research?

Discussion

- We have read several papers so far and they have made various assumptions about humans. What assumptions do you think might be questionable (maybe just in some particular applications)?

- Can you think of ways to examine the assumption, for example, by designing behavioral experiments or crawling data from the Web for analysis?