Using Market Mechanisms to Increase the Take-up of Improved Sanitation in Senegal[1]

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Motivation

- Almost 2 million people in peri-urban Dakar are not connected to the sewage system, so human fecal sludge is stored in underground tanks at residences
- Two options to remove fecal sludge from a residence:
  - *Mechanical:* Truck uses a gasoline-powered vacuum pump to empty the pit, and then dump the waste in a treatment center
  - *Manual:* Hired worker (25%) or family member (27%) empties the pit and disposes of the waste in the neighborhood
- Only 47% of desludgings are performed mechanically: this has negative health consequences, particularly for children
- Manual desludgings prices is $28 on average, while mechanical is $46 on average.
  1. Decentralized search market comprised largely of independent operators
  2. Trade associations and collusion
  3. Renegotiation and price discrimination

Intervention

1. Frequent, centralized, anonymous auctions reduce search times, undermine collusion, and mitigate price discrimination
2. Implement just-in-time procurement auctions for desludging services: invite 8-20 desludgers to over 4,000 between 2013-2016
3. The platform randomizes how many and which desludgers are invited: auction "laboratory", but is not socially optimal
4. Desludgers know the neighborhood and how many opponents they face (for half of the auctions), but not who they are bidding against

Just-in-time Auctions

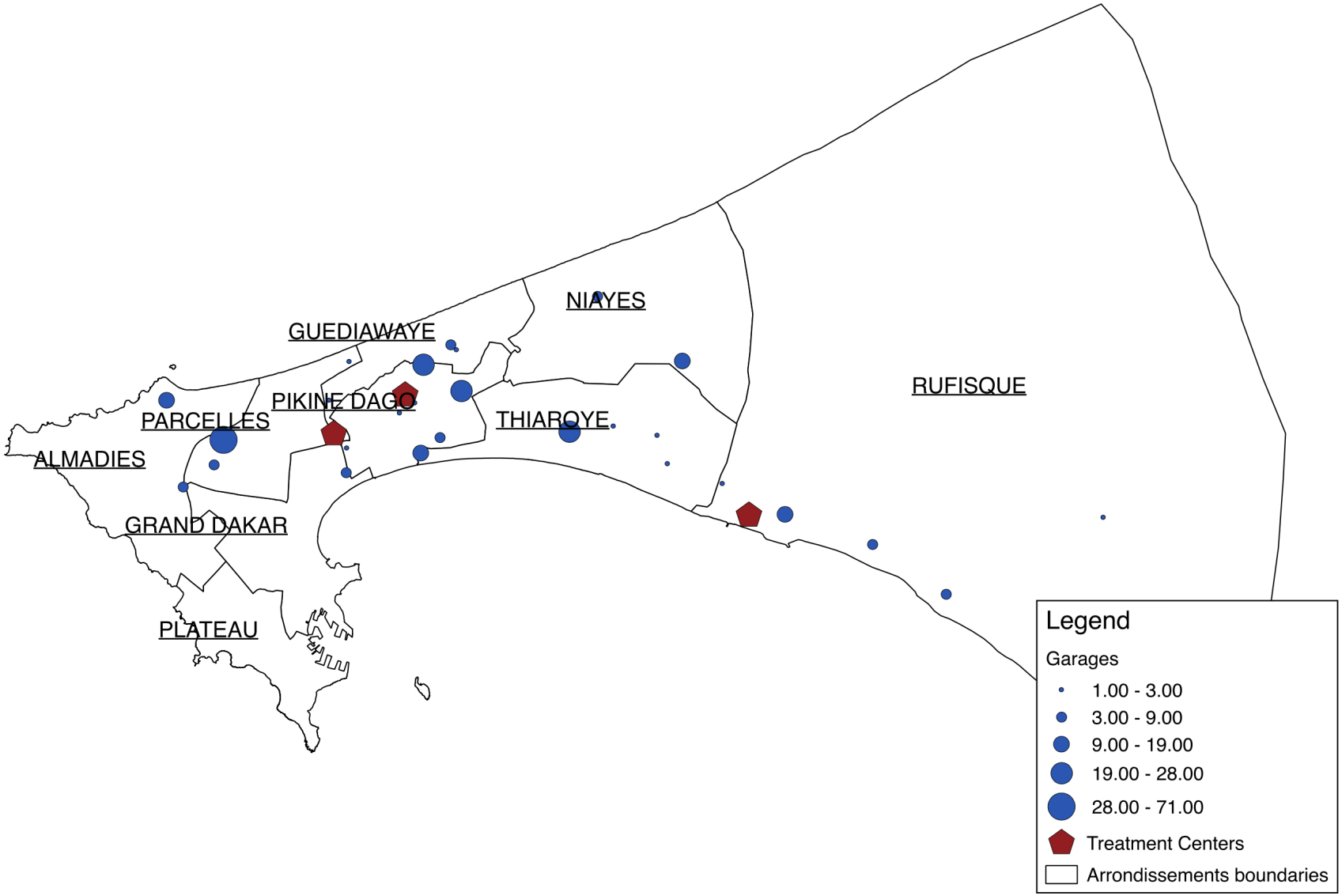
- Households call the center when they need a desludging
- Call center operators send out a request for bids by SMS with basic information on the job to 8-20 operators
- Invitation SMS includes: nearest landmark and number of invited bidders (half the auctions).
- Desludgers have 60 minutes to bid by SMS
- The lowest bid is passed to the household, who can accept that price and contract with the firm, or reject



Problem: 25% of calls lead to a transaction, and auction prices $\approx$ market prices. How to improve this?

- **Salient features:**
  - Highly elastic consumers
  - Strategic entry
  - Heterogeneous desludgers
- **Research questions:**
  - How do we optimally trade off encouraging participation (higher profits) with reducing prices (inviting more firms)?
  - How can we target the most efficient service providers and match them to the right households?
  - What are the costs of private information and strategic entry?

Example: Distance



Sketch of Model/Estimation Strategy

1. **Demand:** Use randomization in auctions and observed household accept/reject decisions to estimate an IV probit model
2. **Strategic bidding:** Follow Guerre-Perrigne-Vuong in recovering psuedo-cost estimates for desludger i in neighborhood n in auction t, $\hat{c}_{int}$
3. **Decomposition:** Regress cost estimates on observables to recover the observable and private information components:

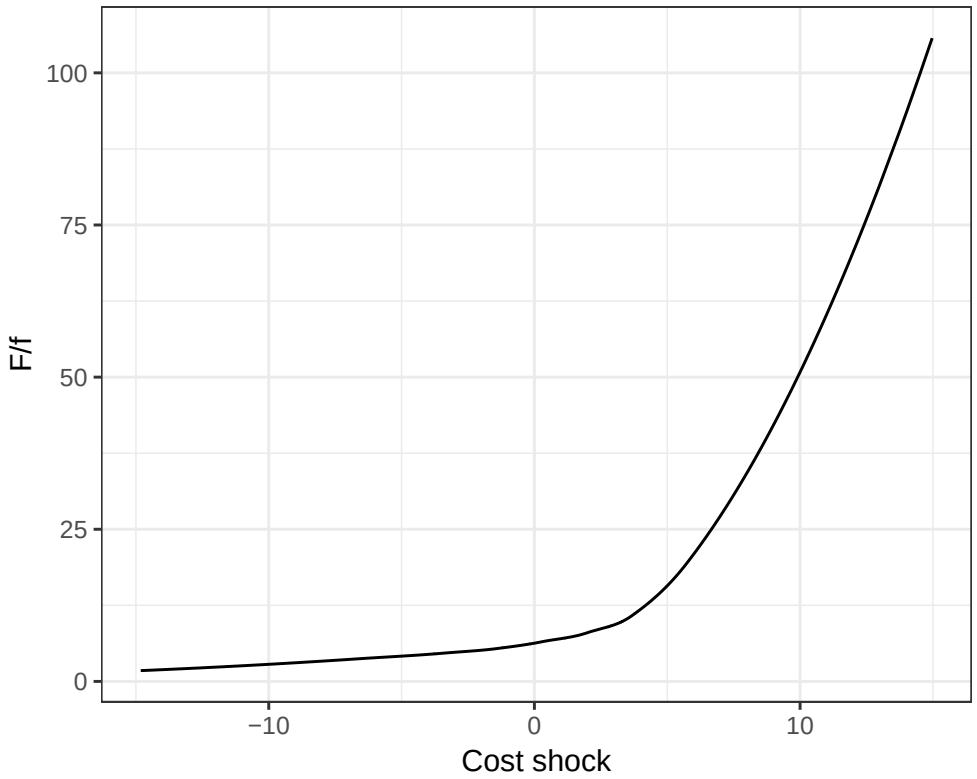
$$\hat{c}_{int} = \underbrace{\bar{c}_{in}}_{\text{Observable mean cost}} + \underbrace{\gamma_{int}}_{\text{Private information}}$$

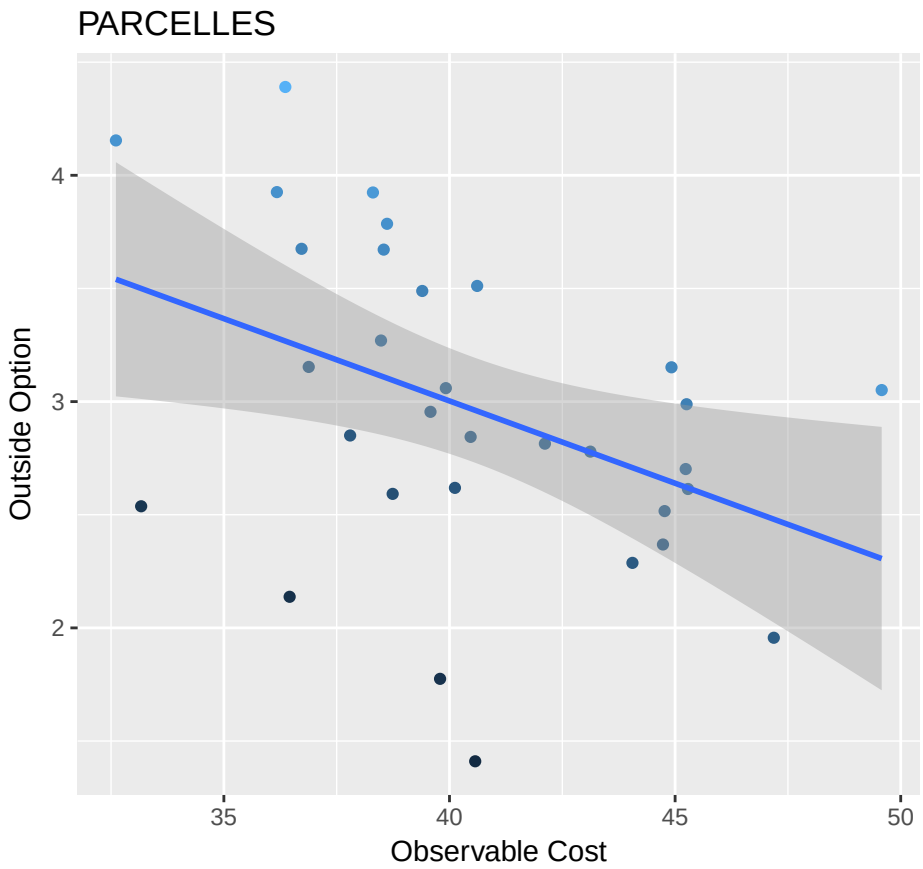
4. **Strategic entry:** firms enter the auction (learn their cost c_{int} and prepare a bid) if

$$\underbrace{\bar{\pi}_{in}}_{in\text{-average profits}} \geq \underbrace{\kappa_i}_{\text{Outside option}} + \underbrace{\sigma\varepsilon_{int}}_{\text{Entry shock}}$$

and otherwise stay out

Empirical Market Design





Main Results

		Avg. Net Surplus	Accept Probability
First-best	Desludgers bid truthfully in all auctions	\$9.29	0.72
Mandatory-entry	Bidders must compensated to reveal their private information	\$7.48	0.64
Second-best	Optimal targeted invitations, strategic entry, and private information cost.	\$3.87	0.37
Initial platform	Re-sample the distribution of winning bids.	\$2.10	0.34

Main Takeaway: The reduction in completion probability from private information alone is 14%, while the loss from strategic entry and private information is 48.6% (see Klemperer 2002) – but better design could increase the likelihood of success by as much as 35%.

Roadmap

We'll work backwards through the game/estimation, then discuss the counterfactuals:

1. Demand estimation
2. Bidding strategies
3. Entry decisions
4. Invitation (re-)design

Step 1: Demand Estimation

- **Goal:** Estimate the distribution of WTP from Accept/Reject decisions of clients:

$$\ln \text{WTP}_{jt} = x_{jt}\beta + u_{jt}/\alpha, \quad u_{jt} \sim \mathcal{N}(0,1)$$

$$\Rightarrow \Pr(\text{Accept}|b^*_{jt}, x_{jt}) = 1 - \Phi\left(\alpha \ln b^*_{jt} - x_{jt}\tilde{\beta}\right)$$

- **Identification problem:** In equilibrium, the winning bid can be correlated with u_{jt}
- **Solution:** Use randomization in the invitation rule to construct an instrumental variable for b^*_{jt} (Rivers and Vuong, 1988)
  - **IV**: Any variable that shifts the clearing prices but is unobserved by the household is a valid instrument: use number of bidders invited who participate at least 70% of the time in that neighborhood

Demand Estimation Results

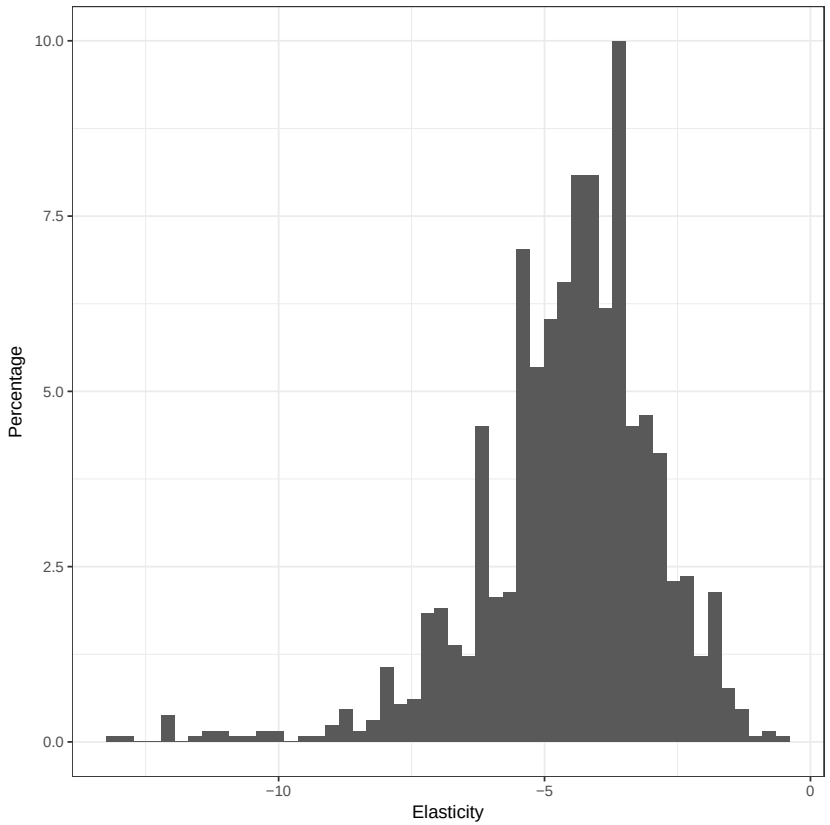
	Dependent Variables		
	$\ln b^*_{jt}$	$1(\text{Accept}_{jt})$	
	First stage	Second stage	Probit
	(1)	(2)	(3)
IV: Nb. active bidders	-0.011^{***}		
	(0.002)		
$\ln b^*_{jt}$		-3.740^{**}	-2.342^{***}
		(1.758)	(0.002)
tanh(rho)	0.181		
	(0.237)		
log(sigma)	-2.095		
	(0.02)		
F-statistic	19.212		

*p<0.1; **p<0.05; ***p<0.01

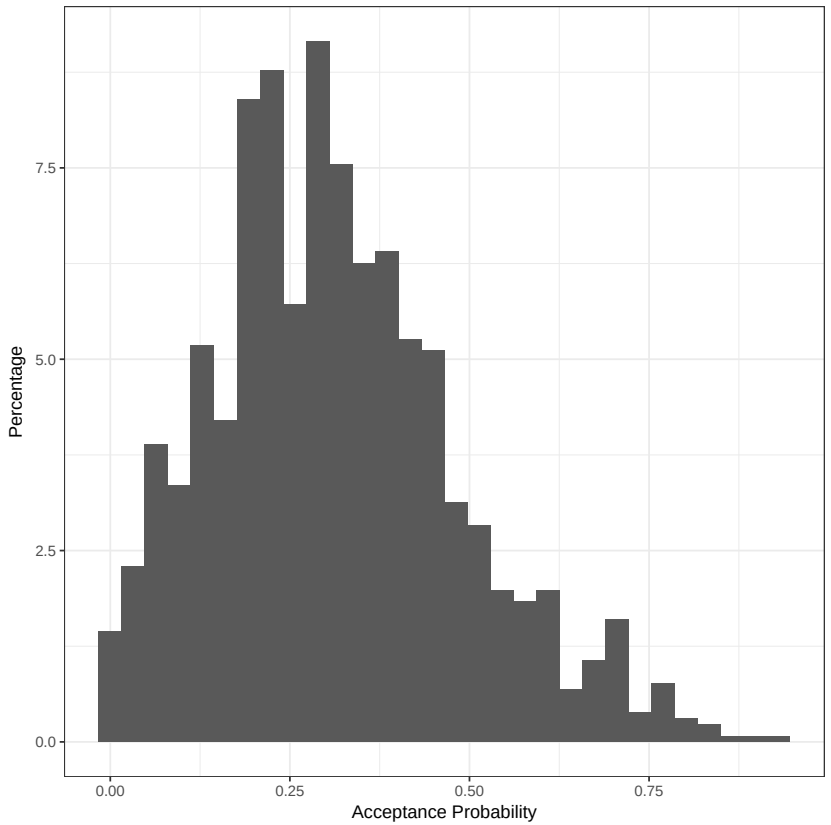
Additional controls: Month and year fixed-effects, neighborhood fixed-effects, hour of the day.

Demand Estimation Results

Platform demand elasticity



Acceptance probabilities



- Due to low A/WTP and availability of outside options, consumers are very price elastic: average probability of acceptance at the winning bid (given at least one bid) is .31

Part 2: Bidding Strategies

- **Expected profits:** Bidder i's expected profits from submitting a bid b with cost c_{int} with information set I_{int}:

$$\pi_i(b, c_{int}, I_{int}) = \underbrace{\Pr[\text{Win}|b, I_{int}]}_{\Pr(\text{Winning})} \underbrace{D[b|I_{int}]}_{\text{Demand}} \underbrace{(b - c_{int})}_{\text{Margin}}$$

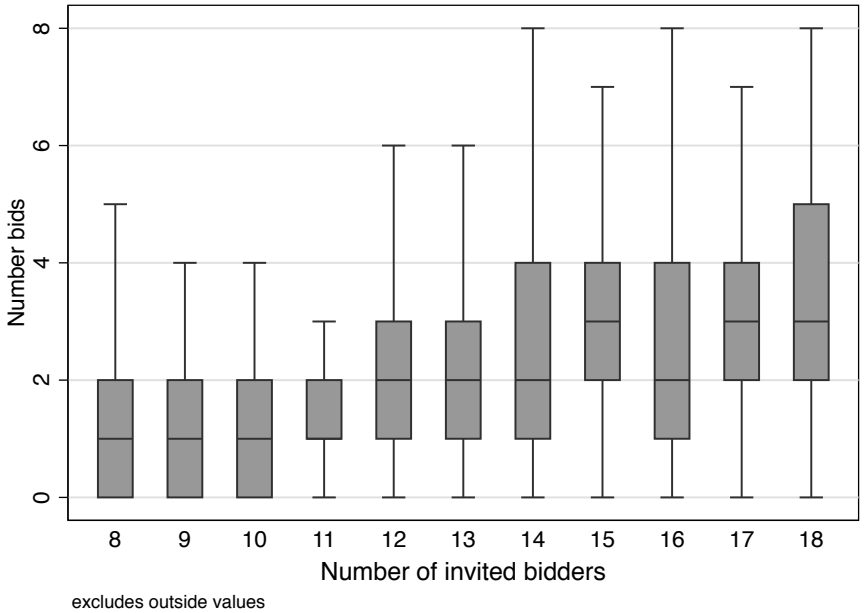
- **Probability of winning:** Let $\tilde{A}_{-i}$ be the number of active bidders besides i, so

$$\Pr[\text{Win}|b, I_{int}] = \underbrace{\Pr[\tilde{A}_{-i} = 0|I_{int}]}_{\text{Monopolist}} + \underbrace{(1 - \Pr[\tilde{A}_{-i} = 0|I_{int}])}_{\text{Contested auction}} \underbrace{\Pr[\min b_{-i} > b|\tilde{A}_{-i} > 0, I_{int}]}_{\text{Lowest bidder}}$$

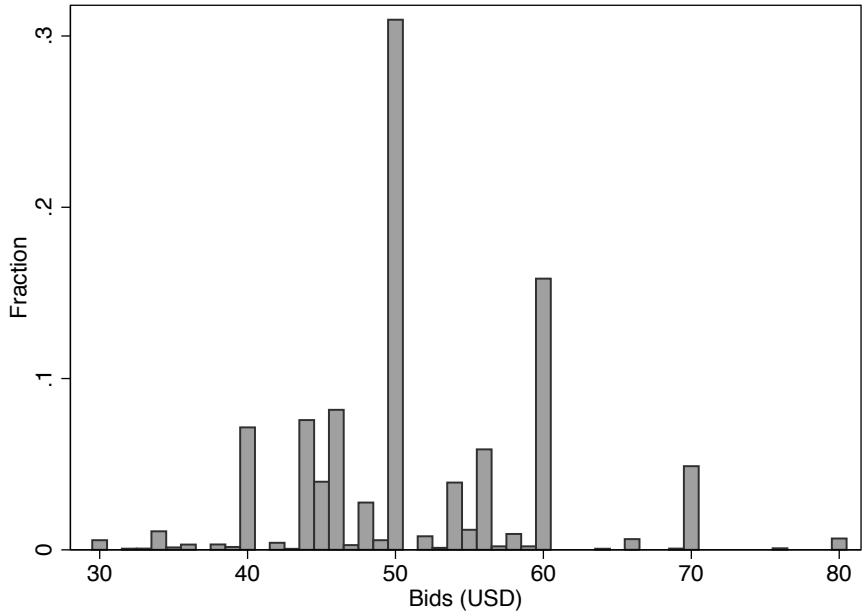
- **Cost estimation:** Adapt Guerre, Perrigne and Vuong (2000) [GPV], by estimating beliefs about the winning probability of i using his/her own *past experience* and the *client's location* (i.e. I_{int}).

Winning Probability Estimation: Two Features

Participation is independent of N



Ties and round bids are very common



$$\frac{n_{jt}}{N_{jt}} = \underset{(0.017)}{-0.013} \ln N_{jt} - \underset{(0.017)}{0.057} \ln \overline{\text{Dist}}_{jt}, \; E\left[\frac{n_{jt}}{N_{jt}}\right] = 0.16$$

# ties	1	2	3	4
%	0.825	0.143	0.028	0.004

Cost Estimation

- **Belief estimation:** Calculate the frequency $\widehat{\Pr}[\text{Win}|b', I_{int}]$ by re-sampling rivals' bids/participation decisions in past auctions from neighborhood j, in which i was invited. Beliefs
- **Bid inversion:**
  - Let $\mathcal{B}$ denotes the grid of observed bids
  - Profit maximization implies:

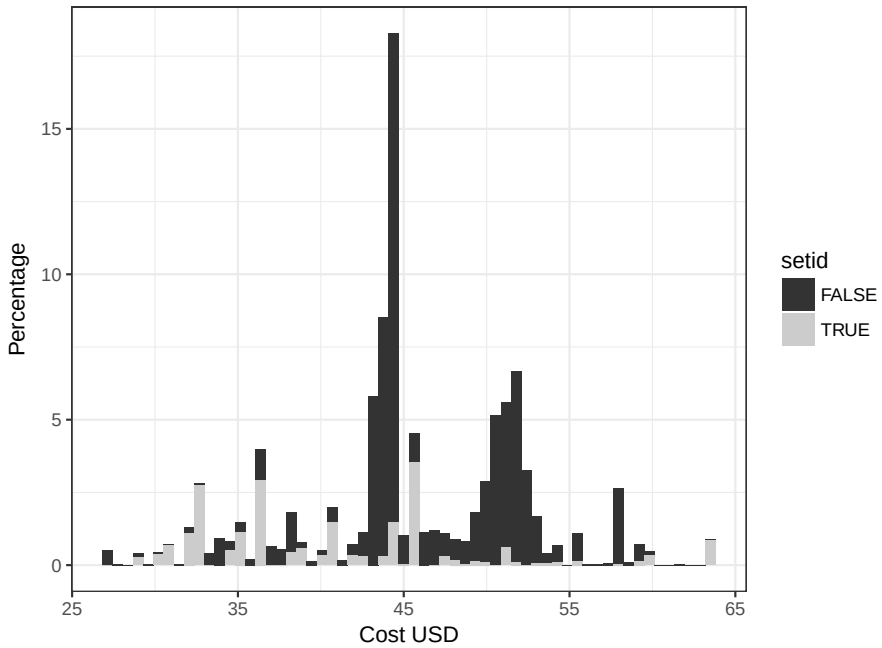
$$\begin{aligned}&\widehat{\Pr}[\text{Win}|b_{int}, I_{int}]\hat{D}[b_{int}|I_{int}](b_{int} - c_{int}) \\ &\quad \geq \widehat{\Pr}[\text{Win}|b', I_{int}]\hat{D}[b'|I_{int}](b' - c_{int}), \quad b' \in \mathcal{B}\end{aligned}$$

  - For each b_{int}, $\hat{c}_{int}$ is the **largest** marginal-cost such that this inequality is satisfied for all $b' \neq b_{int}$.
- With smooth beliefs and dense grid, this is equivalent to GPV:

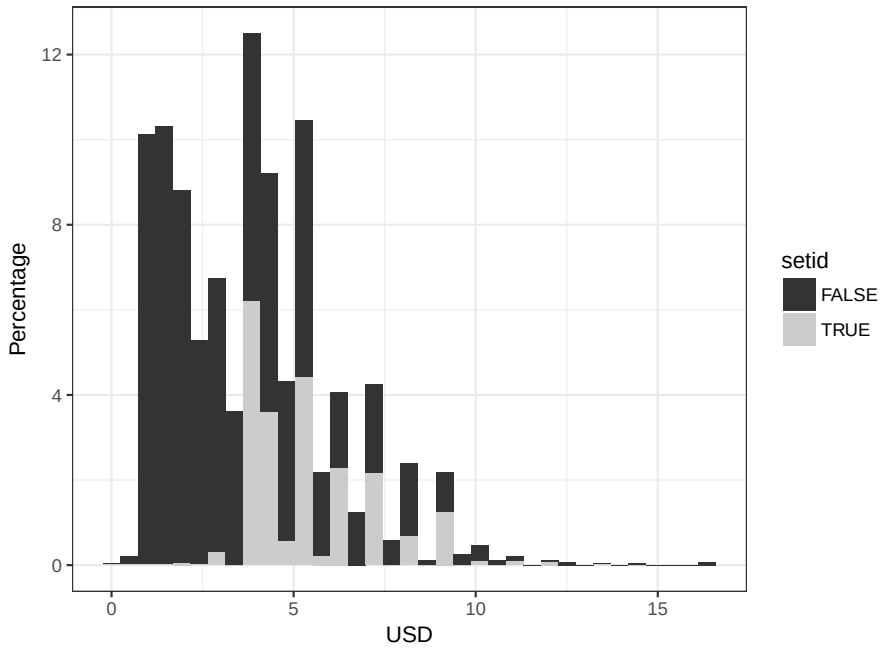
$$\frac{b_{int} - \hat{c}_{int}}{b_{int}} \approx -\left[\frac{d\text{Prob. Transaction}}{d\text{Bid}}\right]^{-1} \frac{\widehat{\Pr}[\text{Win}|b_{int}, I_{int}]\hat{D}[b_{int}|I_{int}]}{b_{int}}$$

Estimated Costs and Profit Margins

Distribution of Marginal Cost



Distribution of Ex-Post Profit Margins



While the expected ex-post profit margin is \$4.37 for low bids, the expected profit is only \$0.54

Decomposition: Observed and Unobserved Heterogeneity

- **Goal:** Separate the private value (γ_{int}) and deterministic component ($\bar{c}_{in}$).
- Regression model:

$$\hat{c}_{int} = \lambda \text{Dist.}_{in} + \underbrace{x_i\beta}_{\mu_i} + \gamma_{int}$$

- We estimate (λ, μ) with and without FE.

	Dependent variable: Cost	
	(1)	(2)
Dist. × Diesel price	0.0004***	0.001***
	(0.00003)	(0.00003)
Nb. Trucks (cie)	0.335***	
	(0.045)	
Size	1.010**	
	(0.501)	
AAAS	−1.668***	
	(0.315)	
Experience	0.140***	
	(0.038)	
1(Driver bid)	3.523***	
	(0.472)	
Truck FE	NO	YES
Observations	2,766	2,766
R^2	0.336	0.474

*p<0.1; **p<0.05; ***p<0.01

Additional controls: Quarter and year fixed-effects, neighborhood fixed-effects, hour of the day.

Part 3: Strategic Entry

- **Entry game:** Invited bidders submit a bid if *expected profit* (before observing γ_{int}) is larger than their outside option:

$$E[\pi_{int}|\bar{c}_{in}] = \bar{\pi}_{in} \geq \kappa_i + \sigma\epsilon_{in}, \quad \epsilon_{it} \sim \mathcal{N}(0,1)$$

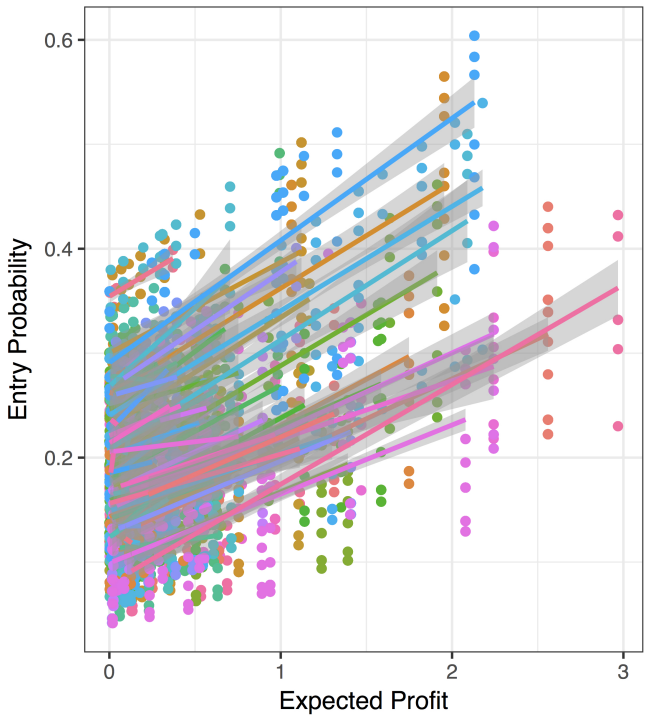
$$\Rightarrow \Pr[\text{Bid placed}_{int} = 1] = \Phi\left(\frac{\bar{\pi}_{in} - \kappa_i}{\sigma}\right)$$

  where κ_i is a vidangeur mean outside option/fixed-effect.
- To estimate $\{\kappa_1, \ldots, \kappa_I, \sigma\}$, we replace $\bar{\pi}_{in}$ with the average profits of bidder i in neighborhood j across all invited auctions (estimated from the bidding model).

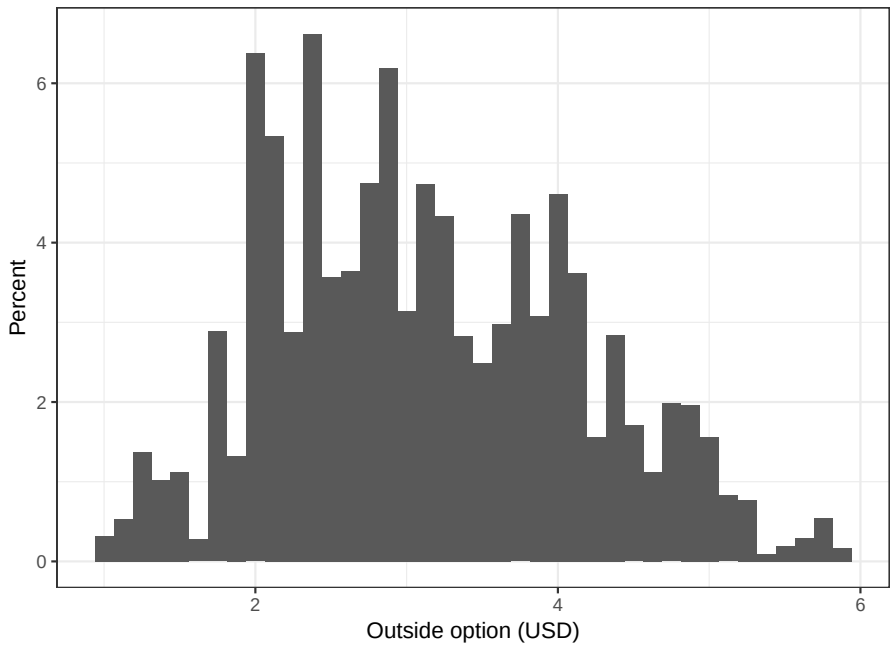
Probit Results: Predicted Entry Probilities

$\hat{\sigma} = 3.41$ USD

Entry probability and expected profits



Distribution of outside options – $\hat{\kappa}_i$



Step 4: Invitation Design

Let A_n be the set of (or probability distribution over) desludgers invited to the auction, and $\tilde{A}_t$ the random subset of A_n which actually participates. The platform selects $A_n \subset \{1, 2, ..., I\}$ (or $\Delta\{1, 2, ..., I\}$) and the conditional allocation rule $P_i(w_{nt}, \gamma_t | \tilde{A}_t)$ to maximize

$$\mathbb{E}_{w_{nt}, \gamma_t, \tilde{A}_n} \left[\sum_{i \in \tilde{A}_n} P_i(w_{nt}, \gamma_t | \tilde{A}_t) \left\{ w_{nt} - \bar{c}_{in} - \underbrace{\left(\gamma_{int} + \frac{F(\gamma_{int})}{f(\gamma_{int})} \right)}_{\text{Virtual cost}} \right\} \middle| A_n \right]$$

subject to $P_i(w_{nt}, \gamma_{int}, \gamma_{-int}, \tilde{A}_n)$ non-decreasing in γ_{int}, and entry probabilities determined by

$$Pr[i \in \tilde{A}_n | i \in A_n] = \Phi \left(\frac{\bar{\pi}_{in}(A_n) - \kappa_i}{\sigma} \right).$$

(Key assumptions: outside option is foregone by placing a bid [true], and cost shock is realized after entry [debatable])

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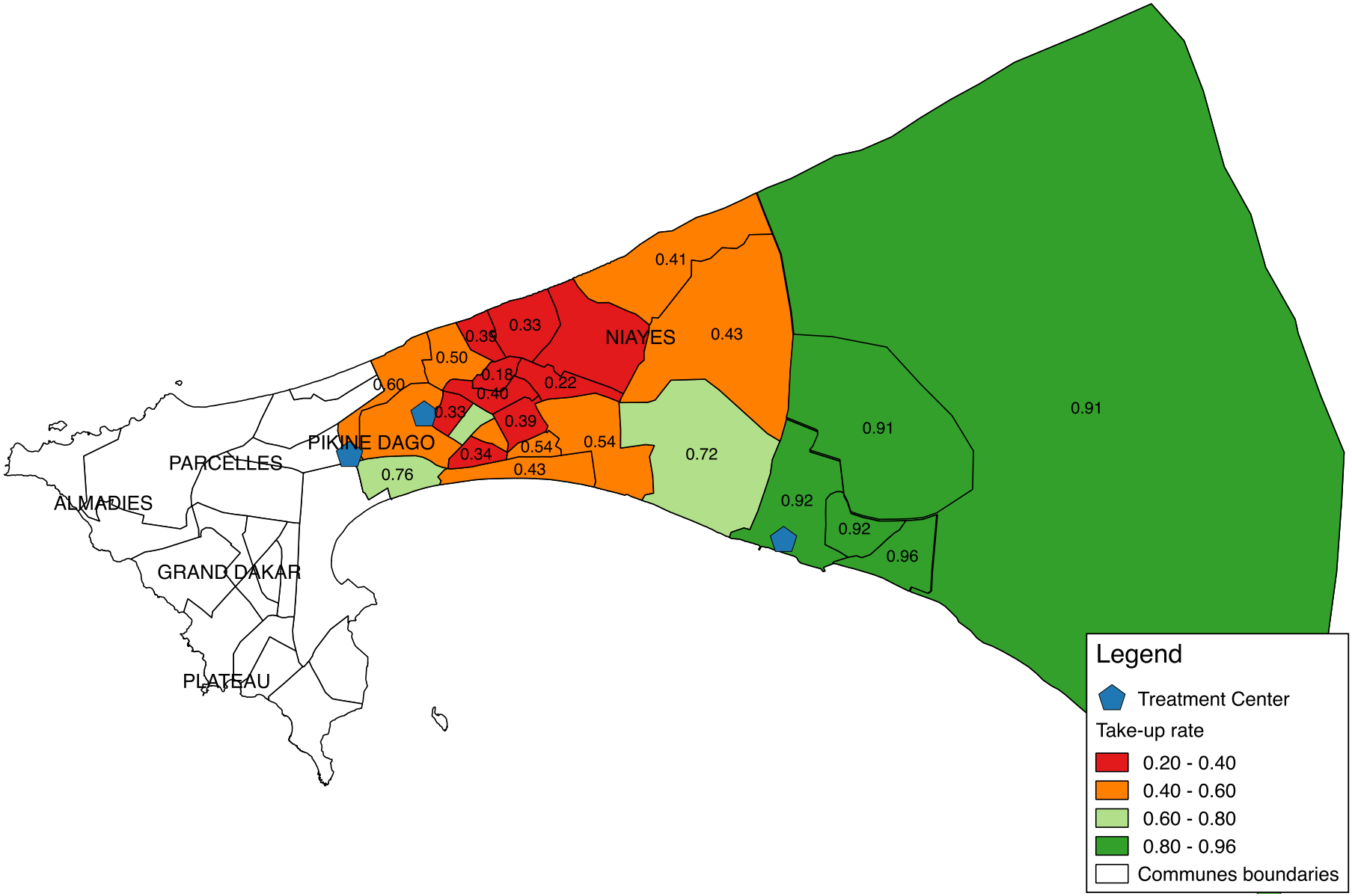
Counter-Factual Results: Consumer Surplus

	CS_{FB}	CS_{ME}	CS_{SB}	CS_0	% invited
Almadies	13.43	11.29	6.431	3.733	0.558
Grand Dakar	6.675	4.706	2.133	0.884	0.429
Plateau	10.306	8.308	4.529	2.802	0.8
Parcelles	12.718	10.182	5.964	3.585	0.719
Pikine Dago	10.625	8.543	4.139	2.158	0.426
Guediawaye	9.166	7.428	3.944	1.861	0.434
Niayes	8.676	7.297	3.36	1.235	0.371
Thiaroye	10.176	8.582	4.176	2.258	0.358
Rufisque	1.833	1.026	0.58	0.407	0.794
Average	9.289	7.485	3.873	2.103	0.465

Counter-Factual Results: Acceptance Probabilities

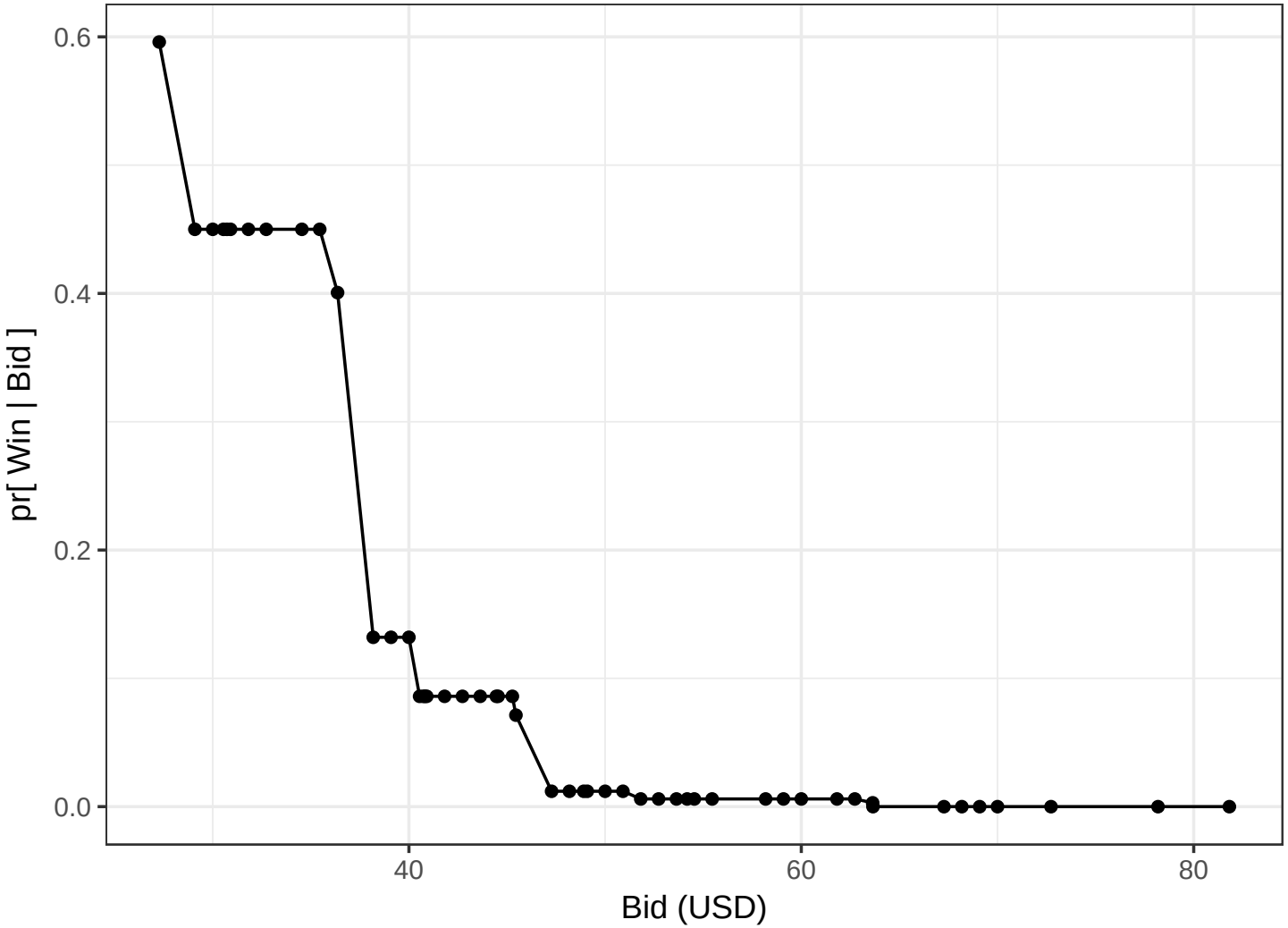
	Pr_{FB}	Pr_{ME}	Pr_{SB}	Pr_0	% invited
Almadies	0.883	0.797	0.539	0.335	0.558
Grand Dakar	0.664	0.512	0.238	0.125	0.429
Plateau	0.737	0.641	0.385	0.266	0.8
Parcelles	0.884	0.792	0.545	0.377	0.719
Pikine Dago	0.838	0.74	0.442	0.26	0.426
Guediaqaye	0.772	0.677	0.405	0.227	0.434
Niayes	0.708	0.63	0.342	0.14	0.371
Thiaroye	0.789	0.722	0.415	0.247	0.358
Rufisque	0.289	0.182	0.088	0.061	0.794
Average	0.729	0.633	0.371	0.226	0.465

Market share of mechanical services across neighborhoods



Conclusion

- Market-based solution to a development problem
- Randomization provides great instruments for measuring demand
- Firms make low expected profits, driving low participation, but have high margins, and consumers are very elastic
- The lowest cost firms have high outside option value, drop out of the market relatively quickly
  - *Some rents must be left on the table in order to convince the highest productivity firms to continue to participate.*
- Continuing to work on the extent to which firms must be compensated in order to reveal their private information on costs.
- Government of Senegal has already scaled up the call center: we are currently working on implementing new auction formats to improve the system.
- Counterfactuals: linear projection, heuristic rules (e.g. distance), optimal SPAR/FPAR



Cost Estimation