

# Non-Clairvoyant Dynamic Mechanism Design: Experimental Evidence

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# Main Takeaways

## What do we do?

- ▶ Bring Non-Clairvoyant Environment (Mirrokni et al., 2020) into Lab.
- ▶ Test the optimal Non-Clairvoyant dynamic mechanism (NC).
- ▶ Compare the performance with Repeated Static optimal mechanism (RS).

## What do we find?

- ▶ Dynamic NC works well as theory predicts - more revenue.
- ▶ Participants overbid less in NC.
- ▶ Risk aversion  $\rightarrow$  No full participation  $\rightarrow$  Revenue loss in NC.

# Optimal Dynamic Mechanism Design

- ▶ How the principal (seller) establish the rules of allocation and price over **multi-period** as the agent (buyer) receives private information over time.
  - ▶ Long-term principal-agent relationship
  - ▶ **Repeated selling of perishable goods**
- ▶ Dynamic mechanism improves revenues and efficiency (Baron & Besanko, 1984).

# Non-Clairvoyance

Clairvoyance: Future demand distribution is known at the beginning.

- ▶ Form of the optimal dynamic mechanism depends on environment.
- ▶ Buyers tend to have biased forecast on future demand (DellaVigna & Malmendier, 2006).

Non-Clairvoyance: Future demand is not accessible at the beginning.

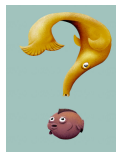
- ▶ No needs to share unbiased belief.
- ▶ General Form.



$F_2$  is unknown in Day 1



$v_1 \sim F_1$



$v_2 \sim F_2 ?$

# Mechanisms under Non-Clairvoyant Environment

$\Rightarrow$  Optimal clairvoyant revenue  $Rev^*$  is unachievable.

RS: Repeated Static optimal mechanism (Myerson, 1981)

- Rules in two days are independent of each other

Maximize **intra-period revenue** for each period separately.

$\Rightarrow \frac{Rev^{RS*}}{Rev^*}$  could be arbitrarily small (Papadimitriou et al., 2016)

NC: Non-Clairvoyant optimal dynamic mechanism (Mirrokni et al., 2020)

- Rules in Day 2 depends on bid in day 1

Best Revenue Guarantee:  $\Rightarrow \frac{Rev^{NC*}}{Rev^*} \geq \frac{1}{a}$

Achieve at least  $\frac{1}{2}$  revenue produced by optimal clairvoyant mechanism under all scenarios in **two-period single-buyer** case.

# When can Non-Clairvoyant dynamic mechanism do better?

Theoretically, Non-Clairvoyant mechanism can not always outperform.

	<b>Optimal Intra-period Revenue</b>	<b>Optimal Inter-period Revenue</b>
RS	100%	zero
NC	$\geq 50\%$	$\geq 50\%$

Relative size of optimal intra- and inter-period revenues is the key.

- ▶ Scenario A: Optimal inter - period revenue is larger  $\Rightarrow$  NC outperforms.
- ▶ Scenario B: Optimal intra - period revenue is larger  $\Rightarrow$  RS outperforms.

# Experimental Design 2 \* 2

## Two Mechanisms

- ▶ Non-Clairvoyant Dynamic Mechanism (NC)
- ▶ Repeated Static Mechanism (RS)

## Two Scenarios

$$F_A = \{v, p(v)\} = \{(2, \frac{1}{2}), (4, \frac{1}{2})\}, \mathbb{E}_A = 3.$$

$$F_B = \{v, p(v)\} = \{(2, \frac{1}{2}), (4, \frac{1}{4}), (8, \frac{1}{8}), (16, \frac{1}{16}), (32, \frac{1}{16})\}, \mathbb{E}_B = 6.$$

- ▶ Scenario A ( $S_A$ ): NC generates more revenue than RS.

$$F_1 = F_A, F_2 = F_B \Rightarrow REV^{RS} = 4, REV^{NC} = 4.5 \uparrow 12.5\%$$

- ▶ Scenario B ( $S_B$ ): NC generates less revenue than RS.

$$F_1 = F_B, F_2 = F_A \Rightarrow REV^{RS} = 4, REV^{NC} = 3.5 \downarrow 12.5\%$$

# Non-Clairvoyant Environment

- ▶ **Buyer:** Participant
- ▶ **Robot Seller:** Experimenter,  $c = 0$
- ▶ **Two periods :** Buyer can buy one item in each period from seller,  $t = 1, 2$ .
- ▶ **Non-clairvoyance :** The distribution of buyer's value ( $F_t$ ) is common knowledge **only in that period**
- ▶ **Incomplete Information :**
  1. **Only buyer** knows his value for the item in each period,  $v_t$ .
  2. Buyer's value is drawn **independently**.

## Variables for Environment

- ▶ **Endowment:**  $E = 50$



# Mechanism - Repeated Static (RS)

## Period 1

- ▶ Seller sets a reserve price  $r_1$  based on the distributional knowledge  $F_1$ .
- ▶ Buyer learns his value ( $v_1$ ), makes a bid :  $b_1$
- ▶ Buyer can get the item only when  $b_1 \geq r_1$  and pay  $p_1 = r_1$ .

## Period 2

- ▶  $F_2 \Rightarrow r_2$ ,  $v_2 \Rightarrow b_2$ , pays  $p_2 = r_2$  if  $b_2 \geq r_2$

## Myerson's Auction

monopoly price:  $r_1 = r_2 = 2$

$$r_A = 2 \in \{\arg \max_r r \cdot P(v_A > r)\}, \quad r_B = 2 \in \{\arg \max_r r \cdot P(v_B > r)\}$$

# Mechanism - Non-Clairvoyant Dynamic (NC)

How the dynamic mechanism work?



Half chance of free item in period 1

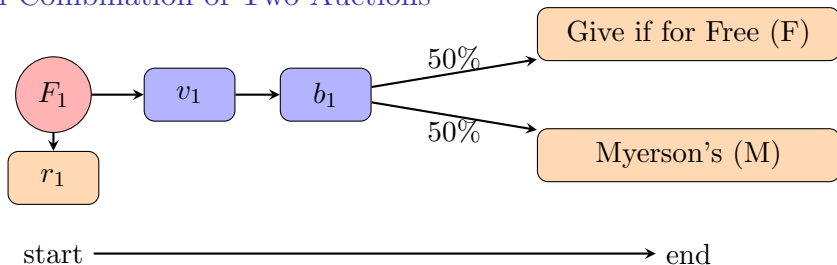


Half chance of upfront fee in period 2

# Non-Clairvoyant Mechanism in Period 1

- ▶ Seller sets a fixed reserve price  $r_1$  based on the distribution  $F_1$ .
- ▶ Buyer learns his value ( $v_1$ ), makes a bid :  $b_1$
- ▶ Buyer has 50% chance to get the item for free:  $p_1 = 0$ ;  
Otherwise, buyer can get the item only when  $b_1 \geq r_1$  and pay  $p_1 = r_1$ .

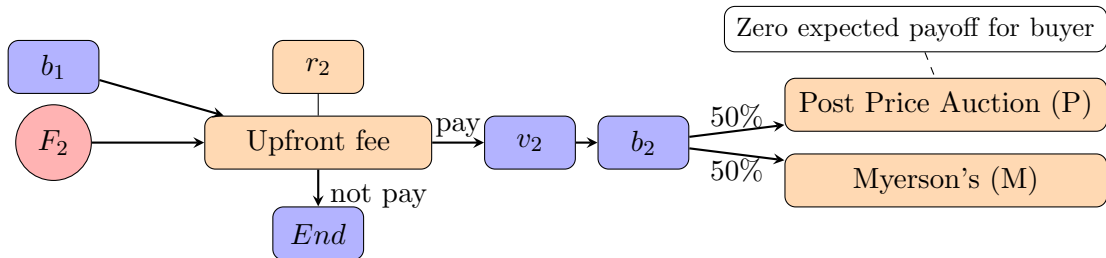
## Uniform Combination of Two Auctions



## Non-Clairvoyant Mechanism in Period 2

- ▶ Seller sets an upfront fee  $s_2 = \min(b_1, E(v_2))$ .
- ▶ Buyer decides pay or leave. If buyer leave ( $enter = 0$ ), game over.
- ▶ If buyer pays, ( $enter = 1$ ),
  - ▶ Buyer learns his value,  $v_2$ , and makes a bid:  $b_2$
  - ▶ Buyer has 50% chance to get refund on the upfront fee ( $luck = 1$ ).
  - ▶ Seller sets two reserve prices ( $r_2$ ) based on the  $F_2, luck$  for each given  $m_2$ ,  
Buyer can get the item only when  $b_2 \geq r_2$  and pay  $p_2 = r_2$

### Uniform Combination of Two Auctions



# Hypotheses

## Hypothesis 1 - On Revenue Comparison

- ▶ In Scenario A ( $S_A$ ), the non-clairvoyant mechanism (NC) generates greater revenue than the repeated static mechanism (RS);
- ▶ In  $S_B$ , NC generates less revenue than RS.

## Hypothesis 2 - On Individual Rationality

- ▶ Some buyers choose not to pay the upfront fee, such that the experimental revenue of the non-clairvoyant mechanism is less than its theoretical prediction.

## Hypothesis 3 - On Incentive Compatibility

- ▶ Participants' bids are closer to true value under NC than RS.

# Experiments

- ▶ 256 George Mason Students. September to November 2021.

Treatment	Scenario A		Scenario B	
	Non-Clairvoyant	Repeated Static	NC	RS
Age	21.6	22.3	21.9	22.7
Gender (Male=1)	0.48	0.44	0.52	0.47
Risk aversion	4.46	4.90	4.55	4.63
Observation	64	64	64	64

Table 1: Summary Statistic

# Results

## Result 1.

Experimental observations match theoretical predictions.

- ▶ In  $S_A$ , the non-clairvoyant dynamic mechanism gains more revenue than the repeated static mechanism.
- ▶ In  $S_B$ , the non-clairvoyant dynamic mechanism gains less revenue than the repeated static mechanism. mechanism.

## Experimental Revenue Comparison - Period 1

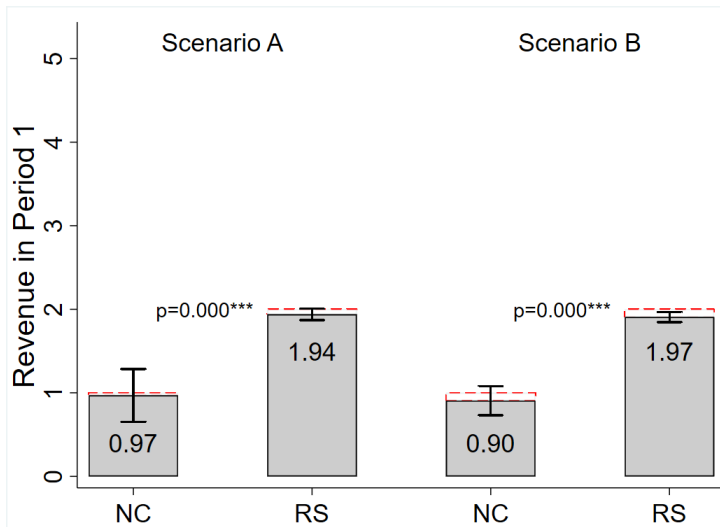


Figure 3: Revenues of Period 1 in each Treatment



## Experimental Revenue Comparison - Period 1 & Period 2

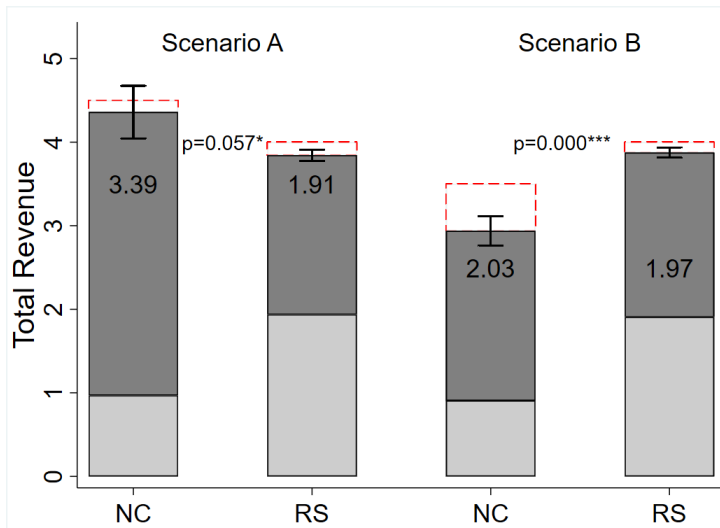


Figure 4: Revenues in each Treatment

# Results

## Result 2.

Risk aversion deters buyers from participating in the second period in NC.

- ▶ In  $S_A$ , 4 buyers quit the second period, and the number doubles in  $S_B$ .
- ▶ Revenue from NC being less than theoretically predicted.

# Revenue Loss Decomposition

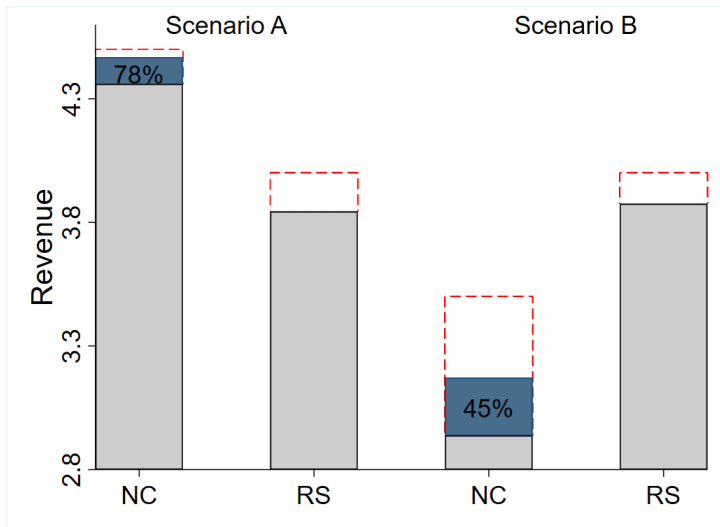


Figure 5: Revenues Increase if all Buyers enter in Period 2.

## Why not Pay the Upfront Fee (membership fee)

- ▶ “Since I got a profit the first time I didn’t want to go again with my luck”
- ▶ “Risk vs Reward..... I got lucky and did not have to pay.”
- ▶ “Based on the membership fee. ”
- ▶ “didn’t want to take any big risks so I just lowballed my offers and refused to take the membership”
- ▶ “i read the instructions carefully. i think the second period isn’t worth losing the points - i had to pay membership fee and could only get the item by bidding higher than the price set by the seller..... honestly, i haven’t been feeling lucky so i’d rather not take my chances. so i tried not to lose money in the first period and just left it as is.”

# Risk Aversion Affects Second-period Participation Indirectly

	DV: Enter in Period 2 (=1)	
	(1)	(2)
Scenario A (=1)	0.17** (0.08)	0.25* (0.13)
<i>notfree</i> <sub>1</sub> (= 1)	0.07 (0.07)	0.08 (0.11)
Scenario A * <i>notfree</i> <sub>1</sub>	-0.18* (0.10)	-0.14 (0.17)
risk aversion	-0.01 (0.01)	-0.03 (0.02)
<i>payoff</i> <sub>1</sub>	0.00 (0.01)	0.00 (0.01)
<i>upfront</i> <sub>2</sub>	-0.01 (0.03)	-0.03 (0.05)
Controls		✓

Standard errors in parentheses. \*\*\* $p < 0.01$ , \*\* $p < 0.05$ , \* $p < 0.1$ .

Table 2: Regression of Participation Choice on Risk attitude.

# Results

## Result 3.

- ▶ Generally overbid.
- ▶ Buyers overbid less under Non-Clairvoyant mechanism when the distribution of their valuation has low variance.

# Bid-Value Ratio Comparison

Bid/value	Non-Clairvoyant Dynamic	Repeated Static	(p-value) <sup>1</sup>
$F_A$ (Low variance)	1.264 (0.04)	1.379 (0.04)	<b>0.060*</b>
$F_B$ (High variance)	1.194 (0.05)	1.251 (0.04)	0.392
(p-value)	0.116	<b>0.008***</b>	

Table 3: Bid-Value Ratio Comparison

<sup>1</sup>We report two-sided p-value under t-test.

# Conclusions

- ▶ We find the experimental observations are consistent with theoretical predictions: the optimal Non-Clairvoyant dynamic mechanism outperforms the optimal Repeated Static mechanism when it is predicted to do so.
- ▶ Buyers' risk attitudes matter in the success of Non-Clairvoyant mechanism.
- ▶ Randomization in non-clairvoyant mechanism leads buyers to overbid less.



# Discussion

## How should sellers choose between mechanisms?

- ▶ NC generates more revenue when the scenario is “good”.
- ▶ NC encourages more accurate valuation information.
- ▶ NC works better when buyers are not risk-averse.

## Future work

- ▶ Can participants (human sellers) set up correct rules?
- ▶ Experiments on multi-buyer with more than 2 periods.

*Thank you!*

# Requirements of Mechanisms under Non-clairvoyant Environment

Seller sets up:

- ▶ Allocation rule  $x \in \{0, 1\}$  : whether buyer can get the item or not
- ▶ Price rule  $p \in \mathcal{R}$  : how much to pay if buyer gets the item

Buyer:  $\max_{\{b_1, b_2\}} u_1 + u_2 = (x_1 v_1 - p_1) + (x_2 v_2 - p_2)$

- ▶ Dynamic Incentive Compatibility (DIC)

For a buyer, it is optimal to bid true value in each period

- ▶ Ex-post Individual Rationality (EPIR)

$u_1 + u_2 \geq 0$ , for all realization of  $v_1, v_2$

## Intra-period Revenue & Inter-period Revenue

- ▶ Intra-period revenue: independent revenue, using information within that period  $\Rightarrow$  bounded by Myerson's revenue.
- ▶ Inter-period revenue: dependent revenue, linking past periods with current period  $\Rightarrow$  bounded by current-period expected value.

## Revenue Comparison in Scenario A

$$F_1 = F_A = \{v, p(v)\} = \{(2, \frac{1}{2}), (4, \frac{1}{2})\} \quad \mathbb{E}_1 = 3.$$

$$F_2 = F_B = \{v, p(v)\} = \{(2, \frac{1}{2}), (4, \frac{1}{4}), (8, \frac{1}{8}), (16, \frac{1}{16}), (32, \frac{1}{16})\}, \quad \mathbb{E} = 6.$$

- Non-Clairvoyant Mechanism increases revenue,  $\uparrow 12.5\%$

Revenue in $S_A$	Non-clairvoyant Dynamic		Repeated Static	
Period 1	<b>Give for Free (F)</b> Myerson's Auction (M)	0 2	Myerson's Auction (M)	2
Period 2	<b>Post Price Auction (P)</b> Myerson's Auction (M)	<b>5</b> 2	Myerson's Auction (M)	2
Total		<b>4.5</b>		<b>4</b>
Intra-period Revenue		2		4
<b>Inter-period Revenue</b>		2.5		0

Table 4: Theoretical Revenues in Scenario A.

## Revenue Comparison in Scenario B

$$F_1 = F_B = \{v, p(v)\} = \{(2, \frac{1}{2}), (4, \frac{1}{4}), (8, \frac{1}{8}), (16, \frac{1}{16}), (32, \frac{1}{16})\}, \quad \mathbb{E}_1 = 6.$$

$$F_2 = F_A = \{v, p(v)\} = \{(2, \frac{1}{2}), (4, \frac{1}{2})\}, \quad \mathbb{E}_2 = 3.$$

- Non-Clairvoyant Mechanism decreases revenue,  $\downarrow 12.5\%$

Revenue in $S_B$	Non-clairvoyant Dynamic		Repeated Static	
Period 1	<b>Give for Free (F)</b>	0	Myerson's Auction (M)	2
	Myerson's Auction (M)	2		
Period 2	<b>Post Price Auction (P)</b>	<b>3</b>	Myerson's Auction (M)	2
	Myerson's Auction (M)	2		
Total		<b>3.5</b>		<b>4</b>
Intra-period Revenue		2		4
<b>Inter-period Revenue</b>		1.5		0

Table 5: Theoretical Revenues in Scenario B.

## Reserve price $(r_1, r_2)$ in Scenario A

$$F_1 = F_A = \{v, p(v)\} = \{(2, \frac{1}{2}), (4, \frac{1}{2})\}, \quad \mathbb{E}_1 = 3.$$

$$F_2 = F_B = \{v, p(v)\} = \{(2, \frac{1}{2}), (4, \frac{1}{4}), (8, \frac{1}{8}), (16, \frac{1}{16}), (32, \frac{1}{16})\}, \quad \mathbb{E}_2 = 6.$$

### Period 1

- Myerson's Auction:  $r_1 = 2$

### Period 2

- If  $luck = 1$ , Myerson's Auction:  $r_2 = 2$
- If  $luck = 0$ , Posted Price Auction:  $r_2$  satisfies

$$E_{v_2}[(v_2 - r_2)^+] = \min(b_1, E(v_2)) = \text{upfront fee}.$$

Piece-wise function:  $r_2^P = 0$  if  $b_1 \geq 6$ ,  $r_2^P = 2$  if  $b_1 = 4$ ,  $r_2^P = 8$  if  $b_1 = 2$ , and  $r_2^P = 32$  if  $b_1 = 0$ .

## Reserve price $(r_1, r_2)$ in Scenario B

$$F_1 = F_B = \{v, p(v)\} = \{(2, \frac{1}{2}), (4, \frac{1}{4}), (8, \frac{1}{8}), (16, \frac{1}{16}), (32, \frac{1}{16})\}, \mathbb{E}_1 = 6.$$
$$F_2 = F_A = \{v, p(v)\} = \{(2, \frac{1}{2}), (4, \frac{1}{2})\}, \mathbb{E}_2 = 3.$$

### Period 1

- Myerson's Auction:  $r_1 = 2$

### Period 2

- If  $luck = 1$ , Myerson's Auction:  $r_2 = 2$
- If  $luck = 0$ , Posted Price Auction:  $r_2$  satisfies

$$E_{v_2}[(v_2 - r_2)^+] = \min(b_1, E(v_2)) = \text{upfront fee}.$$

Piece-wise function:  $r_2^P = 0$  if  $b_1 \geq 3$ ,  $r_2^P = 1$  if  $b_1 = 2$  and  $r_2^P = 4$  if  $b_1 = 0$ .

# Experimental Revenue Decomposition in Scenario A

Revenue in $S_A$	Non-clairvoyant Theory	Dynamic Experiment	Repeated Theory	Static Experiment
Period 1	Give it for free	0		
	Myerson's auction	2	1.94(0.06)	Myerson's 2 1.94(0.04)
Period 2	Post Price Auction	5	4.84(0.47)	
	Myerson's auction	2	1.94(0.06)	Myerson's 2 1.91(0.05)
Total		5	4.35(0.32)	4 3.84(0.07)

Table 6: Revenue decomposition in  $S_A$



# Experimental Revenue Decomposition in Scenario B

Revenue in $S_B$	Non-clairvoyant		Dynamic		Repeated Static	
	Theory		Experiment		Theory	Experiment
Period 1	Give it for free	0	0			
	Myerson's auction	2	1.93(0.06)	Myerson's	2	1.91(0.05)
Period 2	Post Price Auction	<b>3</b>	2.25(0.21)			
	Myerson's auction	2	1.75(0.12)	Myerson's	2	1.97(0.03)
Total		3.5	<b>2.91</b> (0.18)		4	<b>3.88</b> (0.06)

Table 7: Revenue decomposition in  $S_B$