Non-Clairvoyant Dynamic Mechanism Design: Experimental Evidence

Shan Gui, Daniel Houser

George Mason University

May 6th, 2022

Main Takeaways

What do we do?

- Bring Non-Clairvoyant Environment (Mirrokni et al., 2020) into Lab.
- Test 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 fully 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

Long-term contract

Repeated selling

- 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

Repeated Optimal Static Mechanism (Myerson, 1981)

- Rules in two days are independent of each other

  Maximize intra-period revenue for each period separately.

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

Optimal Non-clairvoyant Dynamic Mechanism (Mirrokni et al., 2020)

- Rules in Day 2 depends on bid in day 1

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

  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.

	Intra-period revenue	**Inter-period Revenue**
Repeated Static	optimal	zero
Non-clairvoyant Dynamic	$\frac{1}{2}$ of optimal	$\frac{1}{2}$ of optimal

Inter-period is the key.

- Good Senario: Expected value in 2nd period is high, Myerson's revenue in low.
- Bad Senario: Expected value in 2nd period is how.

Experimental Design $2 * 2$

Two Mechanisms

- Non-Clairvoyant Dynamic $*$ Repeated Static

Two Scenarios

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

- S1-Good Scenario: Non-Clairvoyant Dynamic has more revenue.

$$F_1 = F_A,\ F_2 = F_B \quad \Rightarrow REV^{static} = 4,\ REV^{Non} = 4.5\ \uparrow 12.5\%$$

- S2-Bad Scenario: Non-Clairvoyant has less revenue than Repeated Static.

$$F_1 = F_B,\ F_2 = F_A \quad \Rightarrow REV^{static} = 4,\ REV^{Non} = 3.5\ \downarrow 12.5\%$$

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**: $E = 50$

Institution-Static Optimal Mechanism

Period 1

- Seller sets a secret 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: $r_1 = r_2 = 2$

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

Optimal Non-clairvoyant Dynamic Mechanism

How the dynamic mechanism work?

Half chance of free in period 1

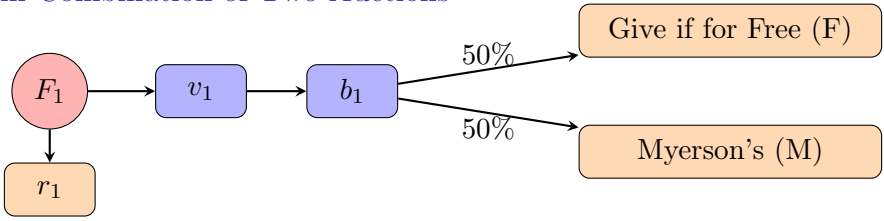
Half chance of membership fee in period 2

Non-clairvoyant Mechanism

Period 1

- Seller sets a fixed secret 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

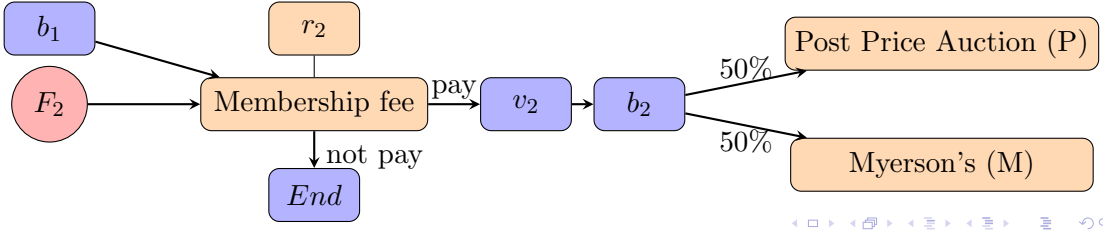


Institution-Non-clairvoyant Mechanism

Period 2

- Seller set a membership fee $m_2 = \min(b_1, E(v_2))$.
- 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 redeem the membership fee ($luck = 1$).
  - Seller sets a secret reserve price r_2 based on the $F_2, m_2, luck$.
    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 - Revenue Comparison

- In S1, Non-Clairvoyant mechanism has more revenue than repeated mechanism; has less revenue in S2.

Hypothesis 2 - Individual Rationality

- Risk-aversed buyers not paying membership fee hurts the revenue of non-clairvoyant mechanism.

Hypothesis 3 - Incentive Compatibility

- Randomization in NC lead participants overbid less.

Experiments

- 256 George Mason Students. September to November 2021.

Treatment	Scenario 1		Scenario 2	
	Non-clairvoyant	Static	Non-clairvoyant	Static
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 with theoretical prediction.

- In S1, Non-Clairvoyant mechanism has more revenue than repeated mechanism.
- In S2, Non-Clairvoyant mechanism has less revenue than repeated static mechanism.

Experimental Revenue Comparison - Period 1

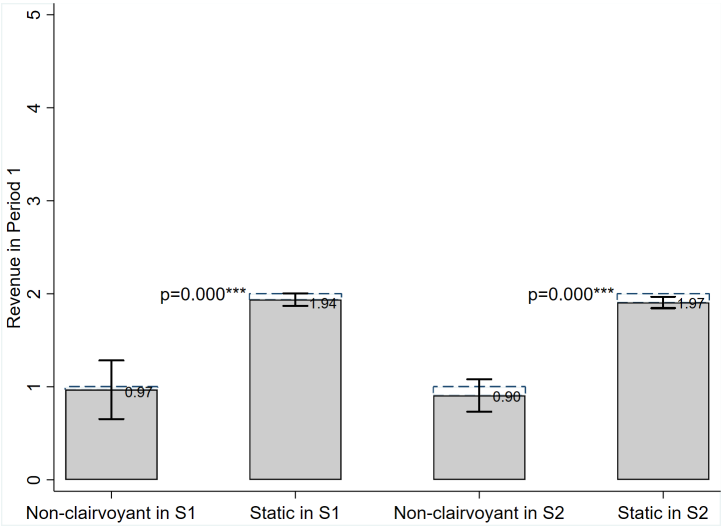


Figure 4: Revenues of Period 1 in each Treatment

Experimental Revenue Comparison - Period 2

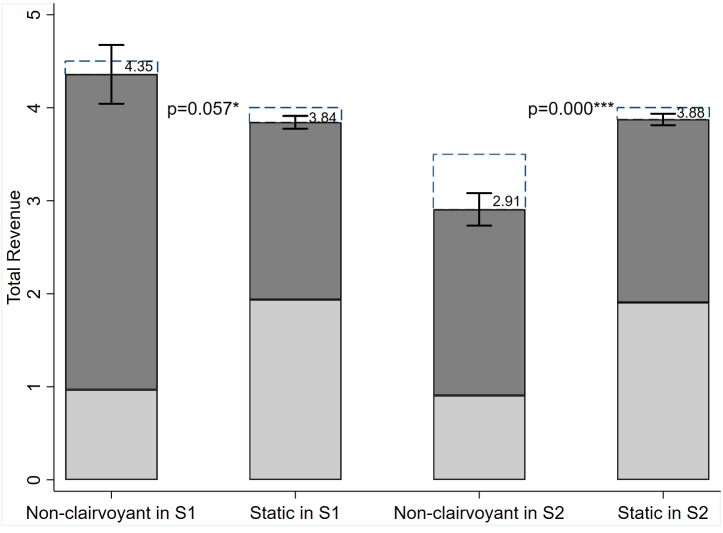


Figure 5: Revenues in each Treatment

Results

Result 2.

Risk aversion hurt the revenue of Non-clairvoyant mechanism.

- In good scenario (S1) 4 buyers quit the second period, and the number goes to 8 in bad scenario.
- The more risk-aversed the buyer is, the more likely they will refused to pay the membership fee and quit the second period.

Revenue Loss Decomposition

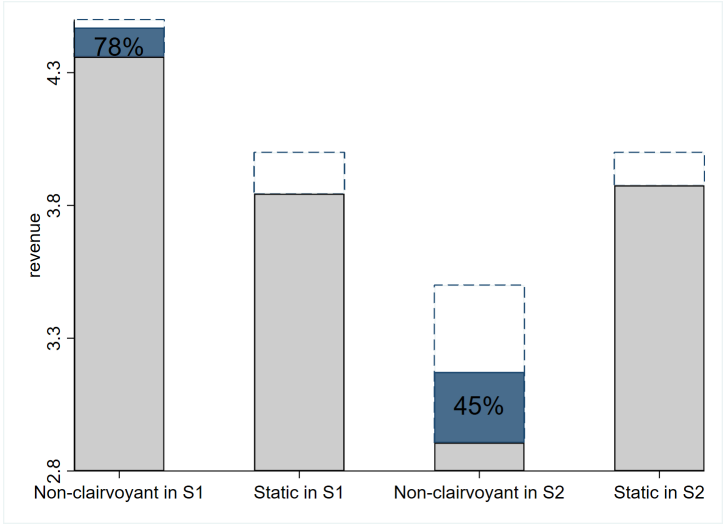


Figure 6: Revenues Increase if all Buyers enter in Period 2.

Why not pay the 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

	Enter in period 2 (=1)					
	S1 - Good Scenario			S2 - Bad Scenario		
	(1)	(2)	(3)	(1)	(2)	(3)
risk aversion	**-0.0279***	**-0.0281***	**-0.0465****	**-0.0909****	**-0.0825***	**-0.0938***
	(0.0161)	(0.0164)	(0.0199)	(0.0437)	(0.0462)	(0.0503)
$Free_1(=0)$	0.044	0.044	0.140*	-0.026	-0.013	0.004
	(0.0620)	(0.0629)	(0.0707)	(0.124)	(0.134)	(0.146)
Membership fee	-0.028	-0.003	-0.020	-0.243**	-0.203*	-0.232**
	(0.0215)	(0.0304)	(0.0227)	(0.107)	(0.109)	(0.111)
$Value_1$	0.046		0.029	0.0142*		0.008
	(0.0313)		(0.0342)	(0.00799)		(0.00955)
Male (=1)	0.014	0.007	-0.036	0.196	0.141	0.177
	(0.0607)	(0.0613)	(0.0681)	(0.123)	(0.124)	(0.140)
Age	-0.002	-0.004	0.006	-0.0637***	-0.0550**	-0.0590**
	(0.0104)	(0.0105)	(0.0122)	(0.0201)	(0.0204)	(0.0220)
Graduate (=1)	-0.145	-0.115	-0.110	0.016	-0.010	-0.042
	(0.0902)	(0.0915)	(0.103)	(0.124)	(0.131)	(0.155)
$Bid/Value_1$		-0.025			-0.007	
		(0.0300)			(0.0185)	
Constant	1.068***	1.139***	0.968***	2.971***	2.756***	2.907***
	(0.272)	(0.271)	(0.304)	(0.651)	(0.678)	(0.728)

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

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) [1]
F1(low variance)	1.264(0.04)	1.379(0.04)	**(0.060*)**
F2(High variance)	1.194(0.05)	1.251(0.04)	0.392
(p-value)	0.116	**(0.008***)**	

Table 3: Bid-Value Ratio Comparison

[1] We report two-sided p-value under t-test.

Conclusions

- We find the experimental observations match with theoretical predictions on revenue comparison between mechanisms.
- Buyer's risk aversion matters in the success of non-clairvoyant mechanism.
- Randomization in non-clairvoyant mechanism leads buyer to overbid less.

Discussion

- Experiment on multi-buyer with more than 2 periods.
- Can participants as Seller set up correct rules ?

Thank you!

Reserve price (r_1, r_2) for Scenario 1

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

Period 1

- Myserson's Auction: $r_1 = 2$

Period 2

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

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

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) for Scenario 2

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

Period 1

- Myserson's Auction: $r_1 = 2$

Period 2

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

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

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 $b_1 = 0$.

Mechanism Comparison for Scenario 1

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

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

E1-Revenue	Non-clairvoyant Dynamic		Repeated Static	
Period 1	Give for Free (F) Myerson's Auction (M)	0 2	Myerson's Auction (M)	2
Period 2	Post Price Auction (P) Myerson's Auction (M)	5 2	Myerson's Auction (M)	2
Total		**4.5**		**4**

Table 4: Theoretical Revenues in Scenario 1.

Mechanism Comparison for Scenario 2

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

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

E1-Revenue	Non-clairvoyant Dynamic		Repeated Static	
Period 1	Give for Free (F) Myerson's Auction (M)	0 2	Myerson's Auction (M)	2
Period 2	Post Price Auction (P) Myerson's Auction (M)	3 2	Myerson's Auction (M)	2
Total		**3.5**		**4**

Table 5: Theoretical Revenues in Scenario 2.

Experimental Revenue Decomposition in S1

E1 Revenue	Non-clairvoyant Dynamic Theory		Experiment	Repeated Static Theory		Experiment
Period 1	Give it for free	0	0	Myerson's	2	1.94(0.04)
	Myerson's auction	2	1.94(0.06)			
Period 2	Post Price Auction	**5**	4.84(0.47)	Myerson's	2	1.91(0.05)
	Myerson's auction	2	1.94(0.06)			
Total		5	**4.35**(0.32)		4	**3.84**(0.07)

Table 6: Revenue decomposition under E1 (Good Environment)

Experimental Revenue Decomposition in S2

E2 Revenue	**Non-clairvoyant Dynamic**			**Repeated Static**		
	Theory		**Experiment**	**Theory**		**Experiment**
Period 1	Give it for free	0	0	Myerson's	2	1.91(0.05)
	Myerson's auction	2	1.93(0.06)			
Period 2	Post Price Auction	**3**	2.25(0.21)	Myerson's	2	1.97(0.03)
	Myerson's auction	2	1.75(0.12)			
Total		3.5	**2.91**(0.18)		4	**3.88**(0.06)

Table 7: Revenue decomposition in S2 (Bad Scenario)