Pricing priorities in waitlists

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Motivation

- Waitlists are a common **alternative to market mechanisms**
  - Used for affordable housing, daycare places, camping permits...
- Natural choice when we **do not want to extract revenue** from participants
- But using waitlists instead of prices causes **allocative inefficiency**...

Motivation

- We should consider intermediate options: waitlists with some partial pricing!

My question:

How to optimally combine waitlists with prices while recognizing that charging participants is undesirable?

Literature

- **Mechanisms without money** (Hylland and Zeckhauser, 1979; Budish, 2011)
  - **This paper**: money allowed but transfers undesirable
- **Wasteful screening** (Hartline and Roughgarden, 2008; Yang, 2021)
  - **This paper**: combining wasteful and non-wasteful screening
- **Wait times 'acting as prices'** (Barzel, 1974; Leshno, 2022; Ashlagi et al., 2022)
  - **This paper**: but waiting screens only on relative values…
  - …while money screens on absolute values

Model

Agents

- The designer distributes two kinds of goods, $\boldsymbol{A}$ and $\boldsymbol{B}$
- Agents' values for A and B given by two-dimensional types $\boldsymbol{(a,b)} \in [0,1]^2$
- A type-(a,b) agent who gets a good, pays $\boldsymbol{p}$ and waits $\boldsymbol{t}$ gets utility:

$$
\begin{aligned}
&e^{-\rho \cdot t}(a-p) \quad \text{if she gets } A,\\
&e^{-\rho \cdot t}(b-p) \quad \text{if she gets } B.
\end{aligned}
$$

- NB: waiting **delays receipt** $\Rightarrow$ waiting cost **multiplies value** for the good!

Arrivals

- At every time $\tau \in \mathbb{R}$, flow masses $\boldsymbol{\mu_A, \mu_B} > 0$ of goods A and B arrive
    - Unit flow mass of goods arrives in total: $\mu_A + \mu_B = 1$
- At every time $\tau \in \mathbb{R}$, a unit flow mass of agents with types $(a, b) \sim \boldsymbol{F}$ arrives
    - F has full support and a differentiable pdf f
- Total good arrival rate = agent arrival rate

Waitlists

- Separate first-come-first-serve waitlists for goods A and B

- The designer chooses:

  1. **Prices for joining** the two waitlists
  2. A **menu of pay-to-skip options** for each waitlist

- Arriving agents choose:

  1. **At most one waitlist** to join
  2. Whether they want some **pay-to-skip** option from their waitlist's menu

Steady state

- We will consider **steady states** of the waitlists
- In SS, **all agents of the same type make the same choices**
- Thus, the designer chooses **steady state allocations** of:
  1. Payments $p : [0,1]^2 \to \mathbb{R}_+$
  2. Wait-times $t : [0,1]^2 \to \mathbb{R}_+$
  3. Goods: $x : [0,1]^2 \to \{A, B, \varnothing\}$

Designer's constraints

- Designer chooses allocation (p, t, x) subject to **IC, IR** and **supply** constraints:

$$\text{for every } (a,b),(a',b') \in [0,1]^2, \quad U[a,b,(p,t,x)(a,b)] \geq U[a,b,(p,t,x)(a',b')] \tag{IC}$$

$$\text{for every } (a,b) \in [0,1]^2, \quad U[a,b,(p,t,x)(a,b)] \geq 0 \tag{IR}$$

$$\int \mathbb{1}_{x(a,b)=A}\, \mathrm{d}F(a,b) \ \leq \ \mu_a, \qquad \int \mathbb{1}_{x(a,b)=B}\, \mathrm{d}F(a,b) \ \leq \ \mu_b \tag{S}$$

Designer's objective

- In SS, objective can be written in terms of **flows**. Choose (p, t, x) to maximize:

$$\gamma \cdot R + W$$

- $\gamma \in [0, 1]$ is the weight on revenue R:

$$R = \int p(a, b) \, \mathrm{d}F(a, b)$$

- W is the value for goods (net of payments) for agents getting them:

$$W = \int \underbrace{\mathbb{1}_{x(a,b)=A}(a - p(a, b))}_{\text{Agents getting good } A} + \underbrace{\mathbb{1}_{x(a,b)=B}(b - p(a, b))}_{\text{Agents getting good } B} \, \mathrm{d}F(a, b)$$

Designer's objective

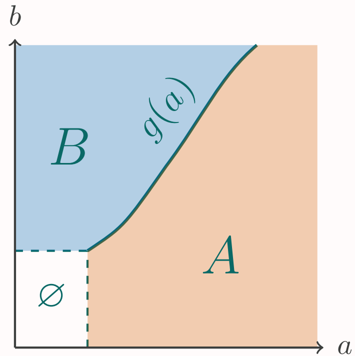
$$W = \int \underbrace{\mathbb{1}_{x(a,b)=A}\big(a - p(a,b)\big)}_{\text{Agents getting good } A} + \underbrace{\mathbb{1}_{x(a,b)=B}\big(b - p(a,b)\big)}_{\text{Agents getting good } B} \, \mathrm{d}F(a,b)$$

- When allocating, designer cares about agents' values, but **not** when they arrived
- Counterintuitive implication: **no wait times** in the objective!
  - Indeed, an agent's utility is $e^{-\rho \cdot t}(a - p)$ not $a - p(a,b)$...
  - ... but giving it to her earlier **pushes someone else back**
- Also means the designer is **indifferent about some types skipping ahead!**

Feasible mechanisms

Who chooses which waitlist?

- When joining both waitlists costs money, some types do not participate ($\varnothing$)
- Types on the **boundary $\boldsymbol{g}$** indifferent between their best options in both waitlists
- Types below g pick some option in A, types above g pick some option in B



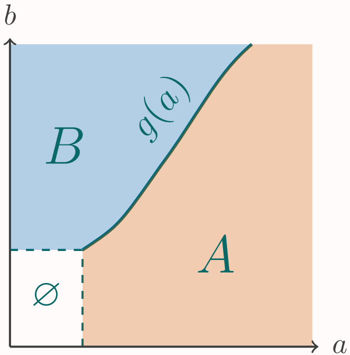
Who chooses which waitlist?

- Offering different **pay-to-skip** options alters the shape of boundary g

- Indeed, the designer is indifferent about some types skipping ahead...

- ...and offers pay-to-skip options precisely to **deform the boundary** $\boldsymbol{g}$...

- ...that is, to encourage certain types to join one or the other waitlist



Role of payments:

Two extreme cases

No payment benchmark

No payment benchmark

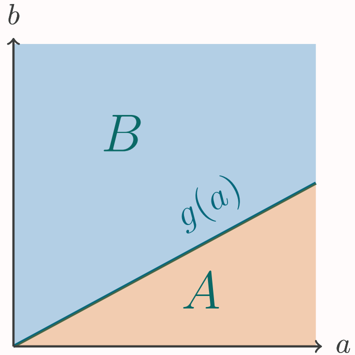
- Suppose joining is free and there are no pay-to-skip options

- Then everyone joins and wait-times 'clear the market'

- Type (a, b) chooses A if:

$$e^{-\rho \cdot t_A} \cdot a > e^{-\rho \cdot t_B} \cdot b$$

- **Ratio** $\frac{a}{b}$ determines choice of waitlist



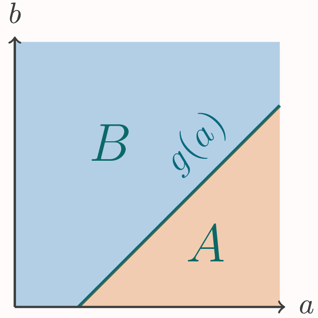
Non-wasteful payments ($\gamma = 1$)

Non-wasteful payments ($\gamma = 1$)

Proposition 1

If payments are not wasteful ($\gamma = 1$), the optimal mechanism offers **no pay-to-skip** options and prices entry to only one waitlist. The price is chosen to **equate wait-times** in both waitlists.

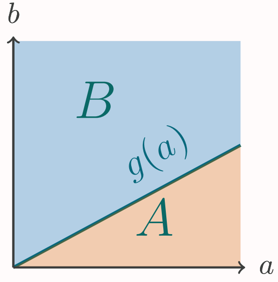
- This achieves the first-best!
- A-goods go to those with **highest $\boldsymbol{a - b}$**



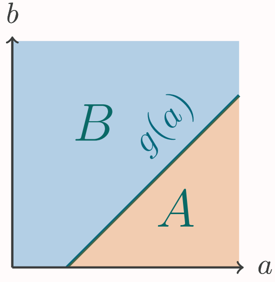
Role of payments: intuition

- Without payments, agents self-select only based on **relative values**

- Payments are wasteful, but let us screen on agents' **absolute values**



No payments



Payments + equal wait-times

- In general, payments create a **better allocation** but **are wasteful**

General case ($\gamma \in [0, 1]$)

General case

- **Assumption**: consider piece-wise continuously diff'able wait-time allocation rules

Theorem 1

The optimal mechanism prices entry to only one waitlist and offers finitely many pay-to-skip options.

Conjecture 1

For *sufficiently well-behaved distributions*, the optimal mechanism prices entry to only one waitlist and offers **no pay-to-skip options**.

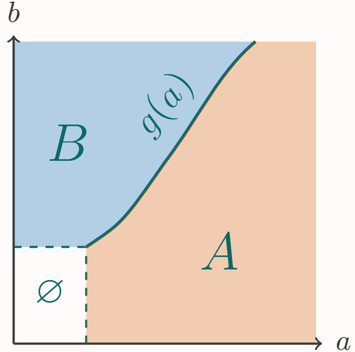
- Conjecture 1 holds in simulations for uniform, normal, Beta, etc…

Proof intuition

Indirect utilities

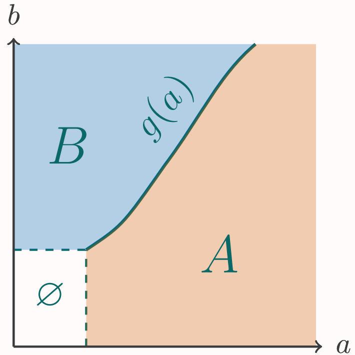
- Agents in the A-region choose some pay-to-skip options in waitlist A...

- ...and agents in the B-region choose one in waitlist B



Indirect utilities

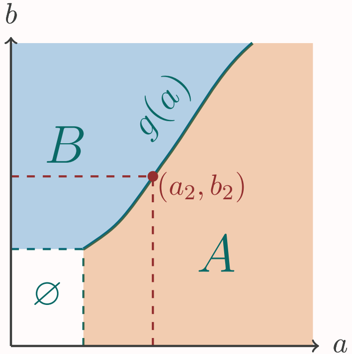
- Agents in the A-region choose some pay-to-skip options in waitlist A...
- ...and agents in the B-region choose one in waitlist B
- Moreover, agents' pay-to-skip choice in their waitlist **does not depend** on their value for the other good!
- Therefore, we can write indirect utilities cond. on joining waitlists A and B as $\boldsymbol{U_A(a), U_B(b)}$



Indirect utilities

- $U_A(a), U_B(b)$ are the indirect utilities cond. on joining waitlists A and B
- We thus have two 1D screening problems (one for each wailtist)...
- ...connected by the boundary types' indifference conditions:

$$U_A(a_2) = U_B(g(a_2))$$



Proof strategy

1. Rewrite the problem in terms of U_A, U_B, and the g they induce
2. Fix any g and find the optimal U_A, U_B that implement it
3. Find the optimal g among optimally implemented boundaries

Objective in terms of U_A and U_B

1. Recall the objective is:

$$\int \underbrace{\mathbb{1}_{x(a,b)=A}(p(a,b)\cdot\gamma + a - p(a,b))}_{\text{Agents getting } A} + \underbrace{\dots}_{\text{Agents getting } B} \mathrm{d}F(a,b)$$

2. To express $p(a,b)$ using $U_A(a)$, notice that:

$$U_A(a) = e^{-\rho\cdot t(a,b)}(a - p(a,b)) \quad \text{and} \quad U_A'(a) = e^{-\rho\cdot t(a,b)}$$

3. This gives $\frac{U_A(a)}{U_A'(a)} = a - p(a,b)$ and thus:

$$\int \mathbb{1}_{x(a,b)=A}\left(a\cdot\gamma + (1-\gamma)\cdot\frac{U_A(a)}{U_A'(a)}\right) + \underbrace{\dots}_{\text{Agents getting } B} \mathrm{d}F(a,b)$$

Optimal U_A, U_B inducing a given boundary

- Fix some boundary g

- Pick indirect utilities U_A, U_B to maximize the objective:

$$\int \mathbb{1}_{x(a,b)=A}\left(a \cdot \gamma + (1-\gamma)\frac{U_A(a)}{U_A'(a)}\right) + \mathbb{1}_{x(a,b)=A}\left(b \cdot \gamma + (1-\gamma)\frac{U_B(b)}{U_B'(b)}\right) \mathrm{d}F(a,b)$$

- Subject to:

  1. U_A, U_B being convex, increasing, and Lipschitz
  2. U_A and U_B being 0 for lowest participating types
  3. Agents at the boundary being indifferent: $U_A(a) = U_B(g(a))$

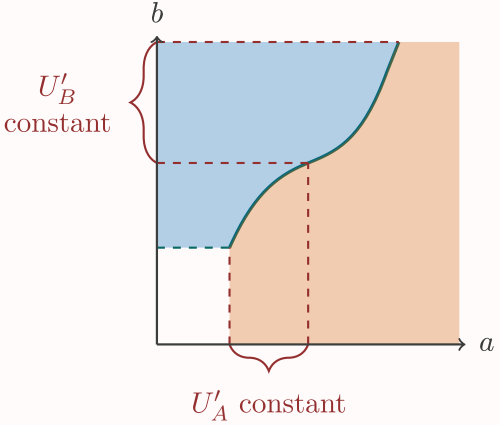
- Can see that **'more convex' $\boldsymbol{U_A, U_B}$ bad for objective**

How flat can we make U_A and U_B?

- U_A more convex $\rightarrow$ different wait-times $\rightarrow$ larger payments!
- Role of payments: **affect area split** by deforming the boundary
- So **pointless to charge more** than required **for particular area split**!
- How flat can we make U_A and U_B? Diff'ing boundary indifference gives:

$$U'_A(a) = U'_B(g(a)) \cdot g'(a)$$

- Wherever $g(a)$ convex, set $U'_A(a)$ **constant** and $U'_B(b(a)) \propto g'(a)$!



Picking the optimal boundary

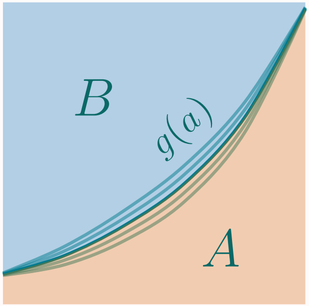
- These conditions tell us **how to optimally implement** each boundary g

- Now, look at any convex region of g...

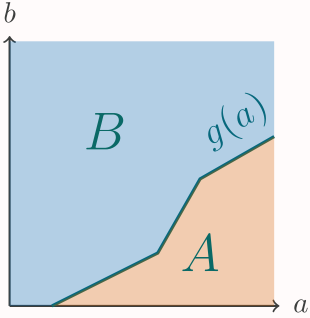
- ...and find necessary conditions for the **optimal shape** of g on it

- Turns out the optimal g has to be **linear on every such region**!

- Else, there is an improving perturbation

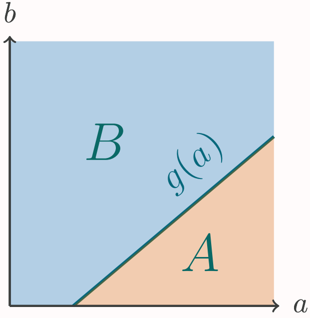


Optimal boundaries



Theorem 1

Entry price for only one waitlist
Finite pay-to-skip options



Conjecture 1

Entry price for only one waitlist
No pay-to-skip options

Conclusions

Conclusions

- The literature notes wait-times can to some extent **‘act like prices’**
- Distinguish **waitlists** (waiting delays receipt) and **queues** (waiting wastes time)
- For waitlists, **wait-times only screen on relative preferences**
- Payments screen on **absolute preferences**, and could be useful even when wasteful

Thank you!

Ashlagi, I., J. Leshno, P. Qian, and A. Saberi (2022): "Price Discovery in Waiting Lists," *Available at SSRN 4192003*.

Barzel, Y. (1974): "A theory of rationing by waiting," *The Journal of Law and Economics*, 17, 73–95.

Budish, E. (2011): "The combinatorial assignment problem: Approximate competitive equilibrium from equal incomes," *Journal of Political Economy*, 119, 1061–1103.

Hartline, J. D. and T. Roughgarden (2008): "Optimal mechanism design and money burning," in *Proceedings of the fortieth annual ACM symposium on Theory of computing*, 75–84.

Hylland, A. and R. Zeckhauser (1979): "The efficient allocation of individuals to positions," *Journal of Political economy*, 87, 293–314.

Leshno, J. D. (2022): "Dynamic Matching in Overloaded Waiting Lists," *American Economic Review*, 112, 3876–3910.

Yang, F. (2021): "Costly multidimensional screening," *arXiv preprint arXiv:2109.00487*.