

Fair Allocation of Vaccines, Ventilators and Antiviral Treatments: Leaving No Ethical Value Behind in Health Care Rationing

Parag Pathak
MIT

Tayfun Sönmez
Boston College

Utku Ünver
Boston College

Bumin Yenmez
Boston College

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Synopsis

- COVID-19 pandemic has spurred renewed interest in guidelines for rationing scarce medical resources.
 - Guidelines written for a wide range of public health emergencies.
 - Scarce items: ventilators, ICU beds, anti-virals, vaccines, etc.
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- This paper:
 - 1) We argue a priority system is too restrictive; we show how existing guidelines struggle to integrate or balance ethical considerations.
 - 2) To increase flexibility, we propose and analyze a **reserve system**.
 - 3) We develop a general theory of reserve design, introduce cutoff equilibrium, smart reserves, and extend sequential reserve matchings.
 - 4) We relate these concepts to current debates.

Background

- COVID-19 pandemic has motivated policymakers to revisit existing or issue new guidelines on allocating medical resources (Emanuel et al. *NEJM* 2020, Truog et al. *NEJM* 2020).
- These guidelines appeal to various ethical principles including:
 - Saving the most lives
 - Saving the most life-years
 - The life-cycle principle
 - Instrumental value
 - Reciprocity
 - Equal access

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- These guidelines appeal to various ethical principles including:
 - Saving the most lives
 - Saving the most life-years
 - The life-cycle principle
 - Instrumental value
 - Reciprocity
 - Equal access
- These principles can compete with one another:
 - E.g., equal access ignores patient age while the life-cycle principle explicitly considers it.
- An **allocation mechanism** must implement the desired balance of ethical values.

Ethical Values with Cardinal Measures

- For some of these principles,
 - only individual attributes are relevant, and
 - they either have a natural or a well-established cardinal measure.
- Metric for **life-cycle principle**: Age
- Metric for **saving the most lives**: Sequential Organ Failure Assessment (SOFA) score

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- Metric for **life-cycle principle**: Age
- Metric for **saving the most lives**: Sequential Organ Failure Assessment (SOFA) score
 - The SOFA score numerically quantifies the number and severity of failed organs.
 - Each of six organ groups **lungs, liver, brain, kidneys, blood clotting** and **blood pressure** is assigned a score of 1 to 4, with higher scores for more severely failed organs.

Pandemic Resource Allocation Mechanisms Worldwide

- By and large, most pandemic allocation guidelines worldwide rely on versions of the priority system in an attempt to accommodate their desired balance of ethical values.
- **Vaccine Allocation:** Priority systems based on priority tiers.
- **Ventilator/ICU Allocation:** Priority point systems.

Priority Point System for Ventilator/ICU Allocation

- The SOFA score is considered a good **proxy for mortality risk**.
- So **if** the sole ethical value under consideration is the utilitarian goal of saving the most lives, a single-principle point system based on SOFA scores may be a good choice for ventilator/ICU allocation.
- But if there are multiple ethical values, and many argue that should be the case, then a priority point system is **too restrictive** to reach an ethically-compelling balance between the desired values.
- It maps **individual attributes** to a **numeric scale**, and therefore cannot even incorporate principles which lack a cardinal and monotonic representation, let alone aggregate them.

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Example: It cannot accommodate distributional objectives such as proportional representation of disadvantaged groups.

Priority Point System for Ventilator/ICU Allocation

- While recognizing the need to consider multiple ethical values, many states adopted a priority point system based on SOFA scores only.
- Others have adopted multi-principle point systems to accommodate multiple ethical values.
- For ventilator allocation, the point system emerged as the mechanism of choice in the US, adopted in the following states:
 - **Single-Principle Point System:** NY, MN, NM, AZ, NV, UT, CO, OR, IN, KY, TN, KS, VT
(SOFA or mSOFA based)
 - **Multi-Principle Point System:** CA, CO, MA, NJ, OK, PA, SC, MD
- Vast majority were adopted in haste after the COVID-19 pandemic.

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- Aggregation across ethical values raises question of **incommensurability** – “apples vs. oranges”
- We next illustrate some of the consequences of these shortcomings, focusing on recent debates on Essential Personnel priority.

Illustrative Debate on Prioritizing Essential Personnel

- Many argue that essential personnel should receive priority under pandemic resource allocation systems.
- This view is also strongly endorsed by medical ethicists based on:
 - the backward-looking principle of **reciprocity**,
 - the forward-looking principle of **instrumental value**, and
 - due to the **incentives** it creates:

“... but giving them priority for ventilators [...] may also discourage absenteeism.” (Emanuel et al. NEJM 2020)

Illustrative Debate on Prioritizing Essential Personnel

- In an attempt to issue their guidelines in a timely manner during the COVID-19 crisis, some states remained vague about essential personnel priority, despite being precise on other dimensions.
- MA recommends a priority point system that relies on rigorous clinical criteria, but casually suggests “heightened priority” for essential personnel without detailing its implementation.
- The Pittsburgh guideline specifies two tie-breakers, one based on age and the other based on essential personnel status. However, it is silent on how to use these tie-breakers.
- The **vagueness** in these cases sharply contrasts with widely-accepted calls for clarity in rationing guidelines.

Confusion & Frustration due to Vague Descriptions

Who gets a ventilator? New gut-wrenching state guidelines issued on rationing equipment

Preference given to medical personnel, people who are healthy, younger

By [Liz Kowalczyk](#) Globe Staff, Updated April 7, 2020, 2:49 p.m.

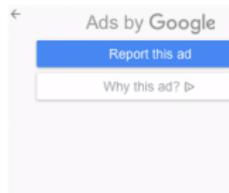
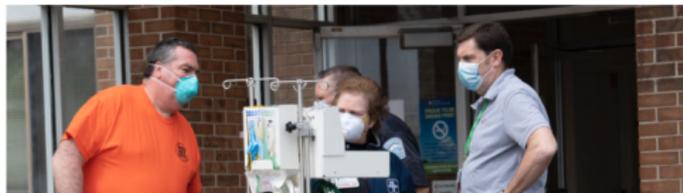


OPINION

I helped write Maryland's ventilator guidelines in 2017. Pa.'s rules are too vague. | Expert Opinion

Updated: April 27, 2020 - 11:33 AM

[Darren P. Mareiniss](#), For The Inquirer



Illustrative Debate on Prioritizing Essential Personnel

- Yet worse, states such as NY and MN had to give up on essential personnel priority, largely due to concerns about extreme scenarios where no units remain for the rest of the society.
 - “[. . .] *it is possible that they [essential personnel] would use most, if not all, of the short supply of ventilators; other groups systematically would be deprived access.*”
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 - “[...] *may mean that only health care workers obtain access to ventilators in certain communities. This approach may leave no ventilators for community members, including children; this alternative was unacceptable to the Task Force.*”
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- **Bottomline:** A limitation of the allocation mechanism designed to implement these values resulted in giving up these values!

Increasing Flexibility with a Reserve System

- It is clear that many challenges stem from the fact that a priority system relies on a single priority ranking of patients that is identical for all units.
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 - A remedy has to break this limiting characteristic.
- A **reserve system** divides resources into **multiple categories** and uses different criteria for allocation of units in each category.
- These **category-specific criteria** reflect the balance of ethical values guiding allocation of units in the given category.

Real-Life Applications of Reserve Systems

- Deceased donor kidney allocation in the U.S.
Categories: Higher quality kidneys (20%), other kidneys (80%)
- Assignment of slots for Boston and NYC marathons
- H-1B visa allocation in the U.S.
- School choice
 - Boston
 - Chicago
 - New York
 - Chile
- Affirmative Action in India
- College Admissions in Brazil

Reserve System: A Compartmentalized Priority System

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- In many applications, one may also need to specify what to do when a patient qualifies for a unit through **multiple** reserve categories.
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 - Since units are homogenous, the patient does not care about the category through which she receives a unit.
 - However, this choice influences the outcome for other patients.
- This last point is often misunderstood in real-life applications, resulting in unintended (distributional) consequences:
 - Boston schools 50-50 neighborhood reserve (Dur et al. 2018)
 - H-1B visa allocation (Pathak et al. 2020)

Theoretical Agenda

- We therefore present a general theory of reserve systems.
- Plan for Theory:
 - Formulate **three intuitive axioms** and examine their implications.
 - Formulate a **cutoff equilibrium** solution concept, linking our axioms to real-life practices.
 - Provide a procedure to construct **all** cutoff equilibria.
 - Extend the prior analysis of **sequential reserve matching** policies which dominate real-life practices.
 - Formulate potential shortcomings of sequential reserve matching policies, and introduce/analyze **smart reserve matching** policies.

A General Model of Reserve Systems

- I : set of patients each in need of one unit
- q : # of identical medical units in short supply
- \mathcal{C} : set of reserve categories
- r_c : # of units subject to category- c allocation criteria s.t.

$$\sum_{c \in \mathcal{C}} r_c = q$$

- π_c : strict priority order of patients for units in category c
 - $i \pi_c j$ Patient i has higher priority for category- c units than patient j
 - $i \pi_c \emptyset$ Patient i is **eligible** for category c
 - $\emptyset \pi_c c$ Patient i is **ineligible** for category c

$\underline{\pi}_c$: weak order induced by π_c

Outcome: A Matching of Patients to Categories

- A **matching** $\mu : I \rightarrow \mathcal{C} \cup \{\emptyset\}$ is an assignment of each patient to either a category or \emptyset such that no category is assigned to more patients than the number of its units.

$\mu(i) = c$ Patient i receives a unit reserved for category c

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- **Important Modeling Choice:** Why do we need to specify how a patient receives her assignment?
 - Because, even though patients are indifferent between all units, their “claims” over units in different categories are potentially different.

Primary Axioms

- A matching **complies with eligibility requirements** if patients only receive units from categories for which they are eligible.

$$\forall i \in I, \forall c \in \mathcal{C} \quad \mu(i) = c \quad \implies \quad i \pi_c \emptyset$$

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- A matching is **non-wasteful** if no unit from any category remains idle despite the presence of an eligible patient who remains unserved.

$$\forall i \in I, \forall c \in \mathcal{C} \quad i \pi_c \emptyset \quad \text{and} \quad \mu(i) = \emptyset \quad \implies \quad |\mu^{-1}(c)| = r_c$$

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- A matching **respects priorities** if no patient remains unserved while a unit from some category $c \in \mathcal{C}$ is awarded to another patient with lower category- c priority.

$$\forall i, i' \in I, \forall c \in \mathcal{C} \quad \mu(i) = c \quad \text{and} \quad \mu(i') = \emptyset \quad \implies \quad i \pi_c i'$$

Cutoff Equilibria

- We next formulate a natural counterpart of the standard competitive equilibrium for our model.
- For any category $c \in \mathcal{C}$, a **cutoff** f_c is an element of $I \cup \{\emptyset\}$ s.t.

$$f_c \underline{\pi}_c \emptyset$$

- Expressed in terms of a "cutoff" individual.
- Plays the same role as a non-negative price.
- For a given a cutoff vector $f = (f_c)_{c \in \mathcal{C}}$, the **budget set** of patient i is

$$\mathcal{B}_i(f) = \{c \in \mathcal{C} : i \underline{\pi}_c f_c\}$$

Cutoff Equilibria

- A **cutoff equilibrium** is a cutoff vector-matching pair (f, μ) s.t.
 1. For any patient $i \in I$,
 - (a) $\mu(i) \in \mathcal{B}_i(f) \cup \{\emptyset\}$, and
 - (b) $\mathcal{B}_i(f) \neq \emptyset \implies \mu(i) \in \mathcal{B}_i(f)$.
 2. For any category $c \in \mathcal{C}$,

$$|\mu^{-1}(c)| < r_c \implies f_c = \emptyset.$$

Here,

- the first condition corresponds to **utility maximization** within the budget set, whereas
- the second one corresponds to the **market-clearing** condition.

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- A matching μ is a **cutoff matching** if it is supported by some cutoff vector f at a cutoff equilibrium (f, μ) .

Cutoff Equilibria in Real-Life Applications

- It is widespread practice to describe the outcome of a reserve system through its cutoff equilibrium, often utilizing a metric that is used to construct the priority order at each category.
- **India-Allocation of public jobs and seats at public schools:**
 - Outcome defined by **cutoff exam scores** for each category.
- **Chicago-Admission to Selective Enrollment High Schools:**
 - Outcome defined by **cutoff composite scores** for the merit-only seats and for each of the four socioeconomic tiers.
- **US-Assignment of H-1B visas:**
 - 2005-2008: Outcome defined by **cutoff application arrival dates** for the general category and the advanced degree category (with ties broken with an even lottery within each category).

Cutoff Equilibria in Real-Life Applications

RAJASTHAN PUBLIC SERVICE COMMISSION, AJMER

DATE: 23-11-2012

THE CANDIDATES BEARING THE FOLLOWING ROLL NO. FOR THE RAJASTHAN STATE & SUBORDINATE SERVICES COMBINED COMPETITIVE (PRELIMINARY) EXAMINATION, 2012 HELD ON 14-06-2012 ARE DECLARED PROVISIONALY QUALIFIED FOR ADMISSION TO THE MAIN EXAMINATION IF ANY CANDIDATE IS FOUND THAT HE/SHE DOES NOT FULFILL THE CONDITIONS OF ELIGIBILITY PRESCRIBED AS PER ADVERTISEMENT/RULES, THE COMMISSION SHALL REJECT HIS/HER CANDIDATURE AT ANY STAGE.

CUT OFF MARKS

CATEGORY	CUT OFF MARKS	CUT OFF MARKS
GEN	GEN	218.89
	FEM	185.22
	WD	141.80
	DV	162.31
SC	GEN	210.79
	FEM	151.73
	WD	123.68
TSP SC	DV	141.94
	GEN	184.02
	FEM	
ST	GEN	218.91
	FEM	168.86
	WD	138.16
	DV	191.59
TSP ST	GEN	162.10
	FEM	140.59
OBC	GEN	218.91
	FEM	185.22
	WD	142.16
	DV	164.76
SBC	GEN	207.74
	FEM	171.36
BL/V	140.68	
LD	Already pass in respective category	
HI	140.91	
NG	Already pass in respective category	
DC	140.27	
EX	143.09	



CUTOFF SCORES

SELECTIVE ENROLLMENT
HIGH SCHOOLS

2020-2021



School	Selection Method	Min	Mean	Max
Brooks	Rank	806	837.39	894
	Tier 1	884	799.43	804
	Tier 2	775	775.59	800
	Tier 3	759	782.01	800
Tier 4	704	758.79	800	

School	Selection Method	Min	Mean	Max
Hancock	Rank	808	848.51	900
	Tier 1	722	754.21	814
	Tier 2	770	802.41	820
	Tier 3	764	804	820
Tier 4	700	782.95	820	

School	Selection Method	Min	Mean	Max
Jones	Rank	807	895.02	900
	Tier 1	799	838.11	890
	Tier 2	843	868.11	890
	Tier 3	855	872.53	890
Tier 4	883	886.90	890	

School	Selection Method	Min	Mean	Max
King	Rank	684	724.34	846
	Tier 1	600	639.03	684
	Tier 2	600	642.51	684
	Tier 3	601	635.24	683
Tier 4	624	647.63	677	

School	Selection Method	Min	Mean	Max
Lane	Rank	875	885.58	900
	Tier 1	747	788.16	874
	Tier 2	810	820.36	875
	Tier 3	808	805.81	875
Tier 4	802	869.39	875	

School	Selection Method	Min	Mean	Max
Lindholm	Rank	771	815.38	895
	Tier 1	667	712.85	769
	Tier 2	710	754.78	769
	Tier 3	707	733.65	769
Tier 4	603	669.78	771	

School	Selection Method	Min	Mean	Max
Northside	Rank	894	897.61	900
	Tier 1	785	819.38	894
	Tier 2	843	871.38	894
	Tier 3	875	884.00	894
Tier 4	889	891.63	894	

School	Selection Method	Min	Mean	Max
Rayton	Rank	894	898.44	900
	Tier 1	803	849.11	894
	Tier 2	800	862.34	894
	Tier 3	802	869.13	894
Tier 4	895	896.61	899	

School	Selection Method	Min	Mean	Max
South Shore	Rank	684	724.62	862
	Tier 1	620	624.69	682
	Tier 2	600	636.91	684
	Tier 3	600	633.78	682
Tier 4	613	646	677	

School	Selection Method	Min	Mean	Max
Westgrove	Rank	794	821.27	882
	Tier 1	718	764.43	793
	Tier 2	724	785.00	795
	Tier 3	724	779.82	795
Tier 4	601	693.78	784	

School	Selection Method	Min	Mean	Max
Young	Rank	883	901.28	900
	Tier 1	804	841.55	883
	Tier 2	811	852.84	883
	Tier 3	804	870.11	883
Tier 4	870	878.63	883	

Note: The 'Rank' score denotes students selected by their point score only, outside of their tiers. The 'Min' score is the cutoff score.

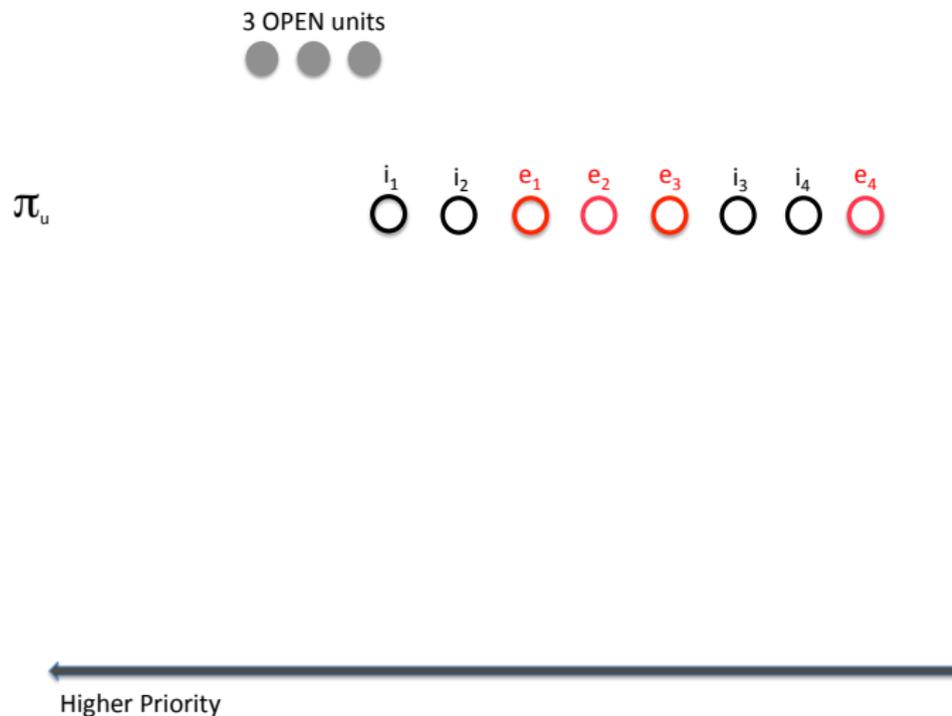
Characterization through Cutoff Equilibria

- Our first result shows a strong link between our three axioms and the proposed solution concept.

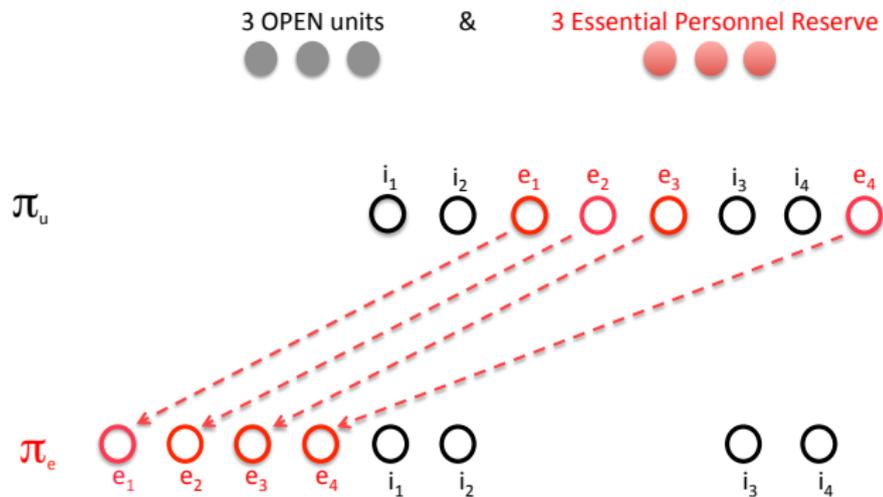
Characterization through Cutoff Equilibria

- Our first result shows a strong link between our three axioms and the proposed solution concept.
- **Theorem 1.** A matching
 - *complies with eligibility requirements*,
 - is *non-wasteful*, and
 - *respects priorities*if, and only if, it is a **cutoff matching**.

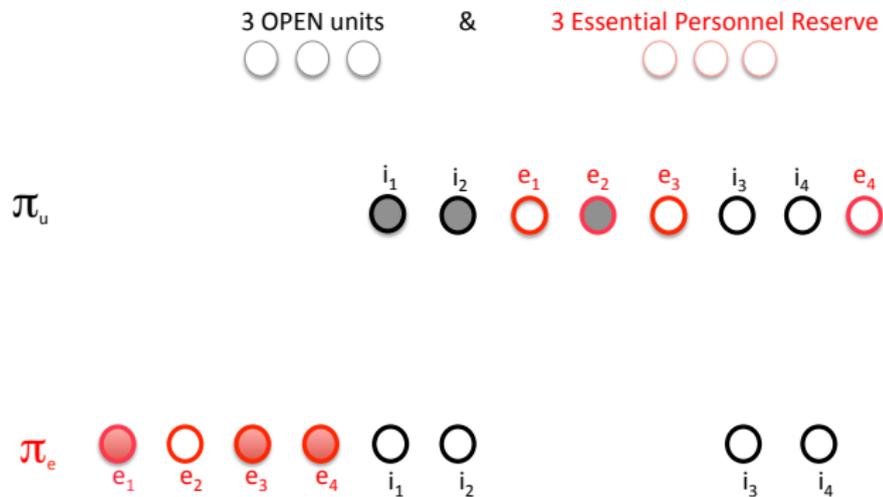
Cutoff Vector Construction



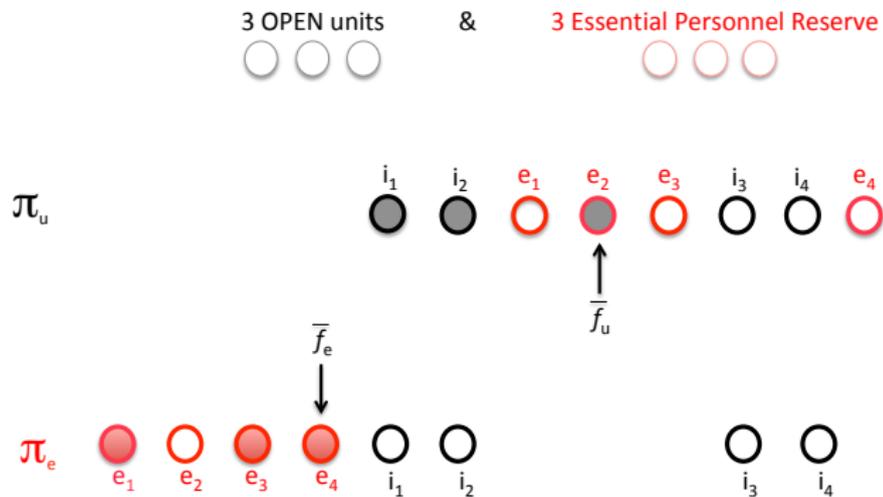
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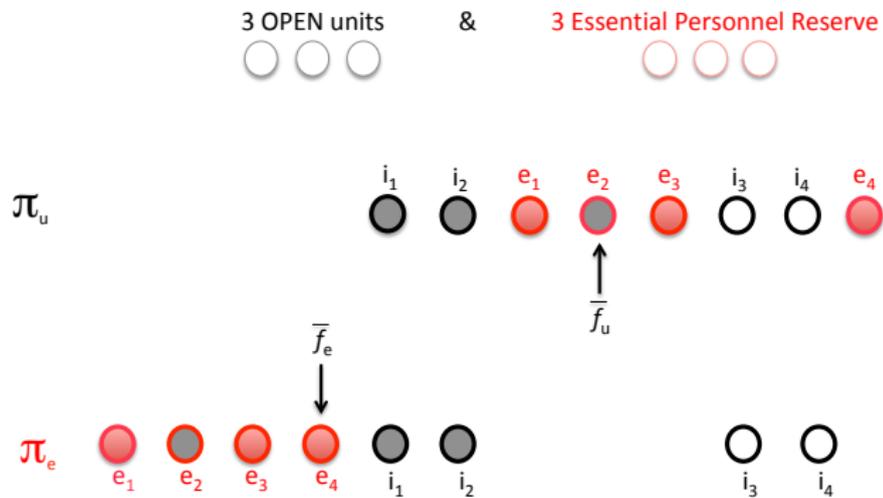


Cutoff Vector Construction

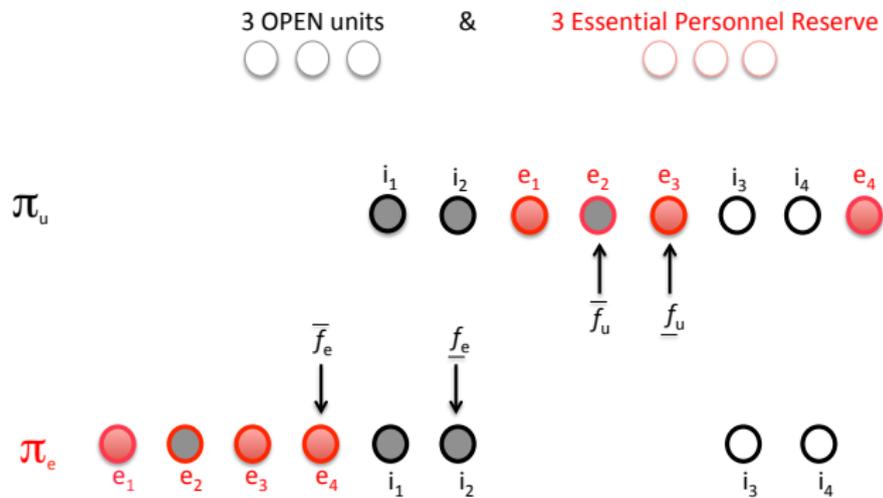


← Higher Priority

Cutoff Vector Construction



Cutoff Vector Construction



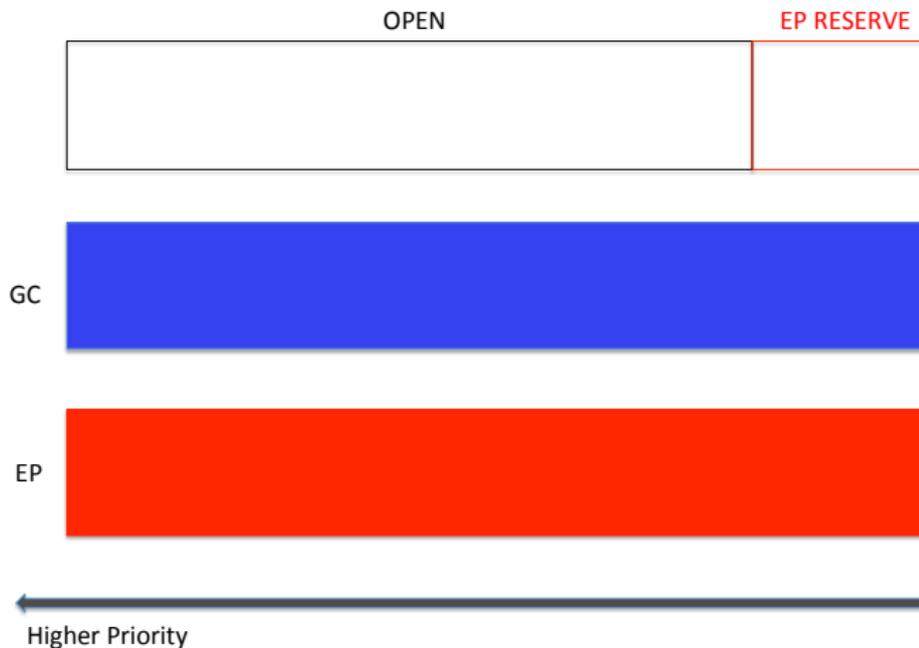
Cutoff Equilibria Properties

- We focus on the **maximum cutoff vector** $\bar{f} = (\bar{f}_c)_{c \in \mathcal{C}}$
 - For any category $c \in \mathcal{C}$, it is given by the lowest π_c -priority patient matched to category c if units in category exhausted, and \emptyset otherwise.
 - Other cutoffs are **artificially** lower and without any clear interpretation.
- The maximum cutoff indicates the **selectivity** of a category.
 - The higher priority the cutoff patient is, the more competitive the category is.

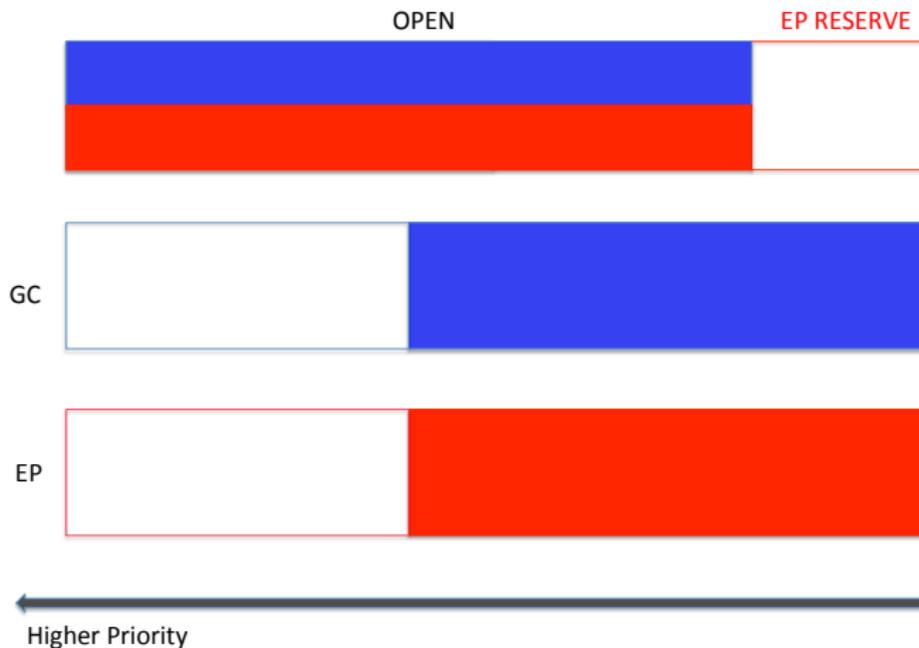
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- The maximum cutoff indicates the **selectivity** of a category.
 - The higher priority the cutoff patient is, the more competitive the category is.
- How do you find cutoff equilibrium matchings?
 - We start with a situation where we process categories sequentially.
 - Most widespread practice in real-life applications.

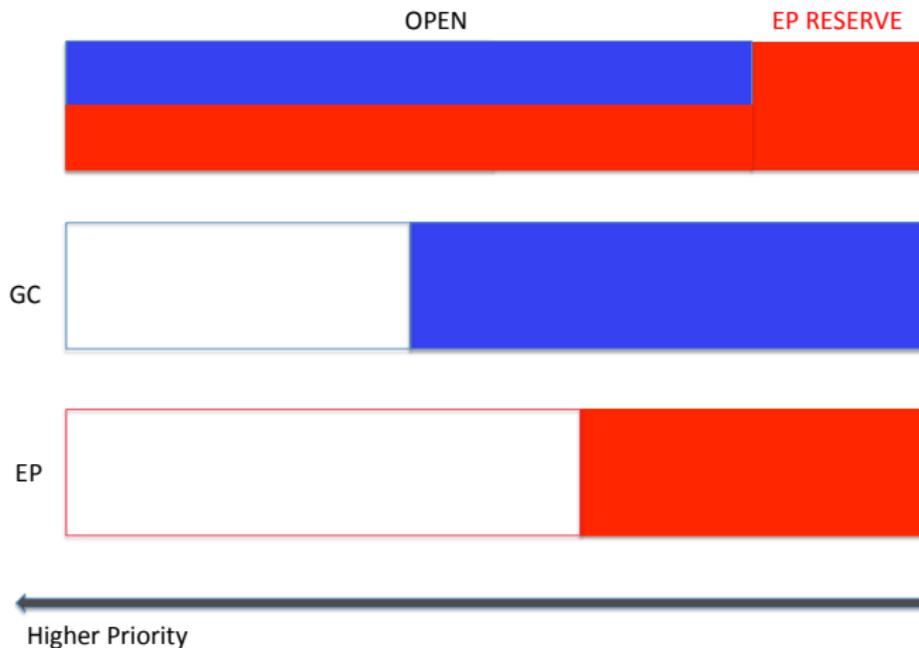
Sequential Category Processing: Open-Reserved



Sequential Category Processing: Open-Reserved



Open First - Reserved Next = Over & Above Policy



Sequential Category Processing: Reserved-Open



Sequential Category Processing: Reserved-Open



Sequential Category Processing: Reserved-Open



Reserved First - Open Next = Minimum Guarantee Policy



Construction of Cutoff Equilibria

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 - there may be several cutoff matchings, and
 - reserves may sometimes be redundant (minimum guarantee).
- We next present a procedure to construct **all** cutoff matchings
 - using the celebrated **deferred acceptance algorithm** (Gale & Shapley 1962)
 - on a **hypothetical many-to-one matching market** that relates to the original rationing problem.

Hypothetical Two-Sided Matching Market $\langle I, \mathcal{C}, r, \pi, \succ \rangle$

- I : The set of patients
- \mathcal{C} : The set of categories
- r_c : Capacity of category c
- π_c : Strict preferences of category c over $I \cup \{\emptyset\}$

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- **Observation:** All primitives **except the strict patient preferences** over categories naturally follow from the primitives of the original problem.

Characterization through Deferred Acceptance Algorithm

- A matching is **DA-induced** if it is the outcome of the Individual-Proposing Deferred Acceptance algorithm for **some** preference profile \succ .

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- Theorem 2 can be used to construct the set of cutoff equilibria or a selection from it.

Sequential Reserve Matching

- The hypothetical two-sided matching market relies on an artificial preference profile $(\succ_i)_{i \in I}$ of patients over categories.
 - Patient i is considered for her eligible categories in **sequence**, following the ranking of these categories under her artificial preferences \succ_i .

Sequential Reserve Matching

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 - Patient i is considered for her eligible categories in **sequence**, following the ranking of these categories under her artificial preferences \succ_i .
- Critically, this sequence can differ between patients.
- Without a systematic way to construct these preferences, it may be difficult to motivate this methodology.

Sequential Reserve Matching

- Not all reserve systems have to process categories sequentially, but in most real-life practices they do.
- An **order of precedence** \triangleright is a linear order over the set of categories \mathcal{C} , interpreted as the **processing sequence of categories**.
- $c \triangleright c'$: Category- c units are to be allocated before category- c' units.

Sequential Reserve Matching

- **Sequential Reserve Matching:** Fix a processing sequence \triangleright of the categories. Following this sequence, allocate units in each category $c \in \mathcal{C}$ to highest π_c -priority patients.

Sequential Reserve Matching

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- **Proposition 1.** Fix an order of precedence \triangleright . Let the preference profile \succ^{\triangleright} be such that for each patient i and pair of categories c, c' ,

$$c \succ_i^{\triangleright} c' \iff c \triangleright c'.$$

Then the resulting sequential reserve matching φ_{\triangleright} is DA-induced from the preference profile \succ^{\triangleright} .

Order of Precedence & Cutoff Comparative Static

- **Proposition 2.** Fix a pair of categories $c, c' \in \mathcal{C}$ and a pair of orders of precedence $\triangleright, \triangleright' \in \Delta$ such that:
 - $c' \triangleright c$,
 - $c \triangleright' c'$, and
 - for any $\hat{c} \in \mathcal{C}$ and $c^* \in \mathcal{C} \setminus \{c, c'\}$

$$\hat{c} \triangleright c^* \iff \hat{c} \triangleright' c^*.$$

That is, \triangleright' is obtained from \triangleright by only changing the order of c with its immediate predecessor c' . Then,

$$\overline{f}_c^{\varphi \triangleright'} \underline{\pi}_c \overline{f}_c^{\varphi \triangleright}$$

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- **Interpretation:** The earlier a category is processed, the more selective it becomes.

Reserve Systems with a Baseline Priority Order

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- Any other category c provides **preferential treatment** to a **beneficiary** group I_c .

π_c : Prioritizes beneficiaries of category c over others and π_u is used to break ties internally within the two groups.

- **Hard Reserves**: Eligibility is restricted to beneficiaries only
- **Soft Reserves**: Everyone is still eligible

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- **Hard Reserves**: Eligibility is restricted to beneficiaries only
 - **Soft Reserves**: Everyone is still eligible
- The set of **general-community** patients I_g are those who are beneficiaries of the unreserved category only.

$$I_g = I \setminus \bigcup_{c \in \mathcal{C} \setminus \{u\}} I_c$$

Comparative Statics Under a Baseline Priority Order

- Proposition 3.** Assuming there are at most five categories and each patient is a beneficiary of at most one preferential-treatment category, consider a soft reserve system induced by a baseline priority order. Fix a preferential treatment category $c \in \mathcal{C} \setminus \{u\}$, any other category $c' \in \mathcal{C} \setminus \{c\}$, and a pair of orders of precedence $\triangleright, \triangleright' \in \Delta$ such that:
 - $c' \triangleright c$,
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- Interpretation:** The later a preferential-treatment category is processed, the better it is for its beneficiaries (set inclusion-wise).

Over & Above Reserve Processing

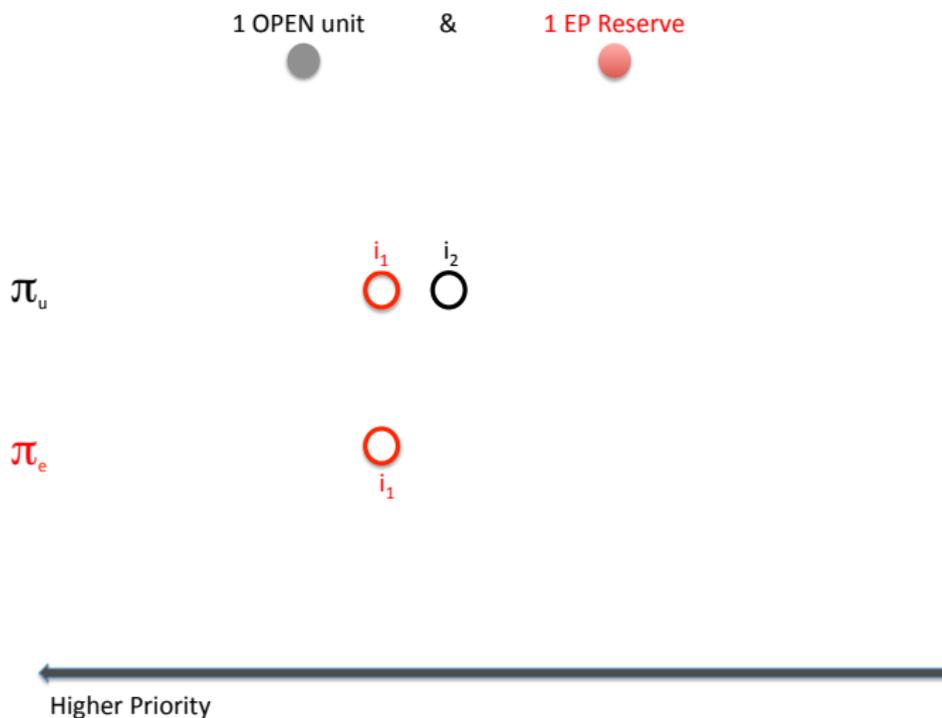
Over & Above Reserve Processing

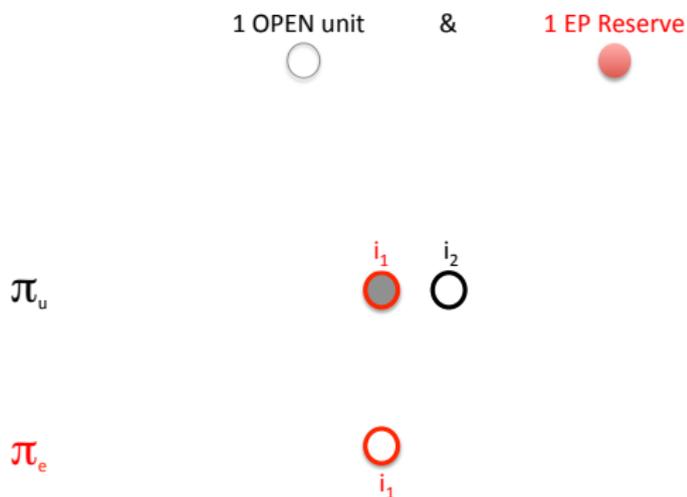
- **Over & Above** implementation:
 - Reserve category processed after the open category
 - Provides stronger benefit
 - Best suited for situations that warrants an **extra boost**
- **Real-Life Examples of Over & Above Implementation:**
 - **Public Positions in India:** Scheduled Castes, Scheduled Tribes, OBC
 - **School Choice in Chicago:** 4 Distinct Socioeconomic tiers (17.5% each)
 - **Post-2020 H1-B Visa Allocation in the US:** Advanced Degree Cap

Minimum Guarantee Reserve Processing

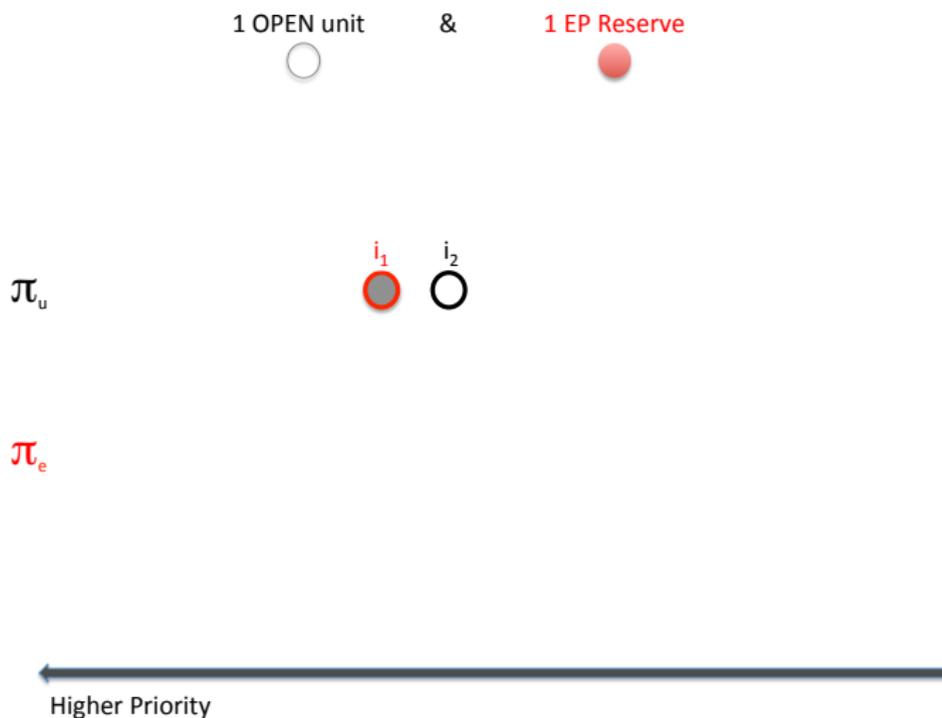
- **Minimum Guarantee** implementation:
 - Reserve category processed prior to open category
 - Provides weaker benefit compared to O&A implementation
 - May provide no benefit at all if target minimum already reached in the absence of reserve
 - Best suited for situations that warrants a **protective measure**
- **Real-Life Examples of Minimum Guarantee Implementation:**
 - **Public Positions in India:** Persons with Disabilities
 - **School Choice in Boston:** Neighborhood (Accidental: **O&A Intended!**)
 - **School Choice in Chile:** Low Income, Special Needs, High-Achieving

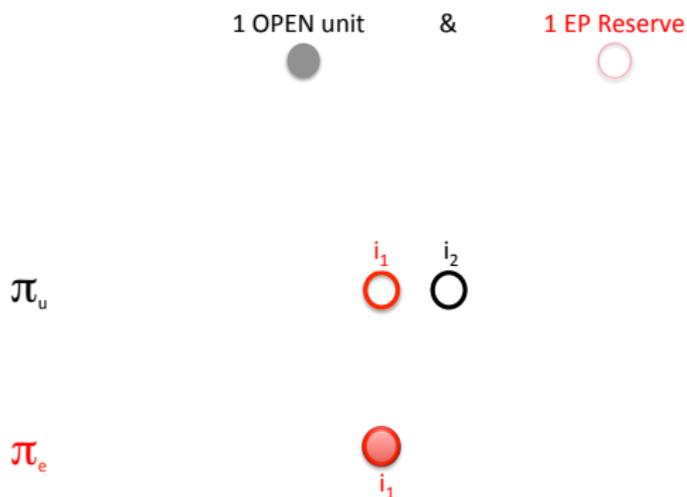
Example 2: Possible Efficiency Loss



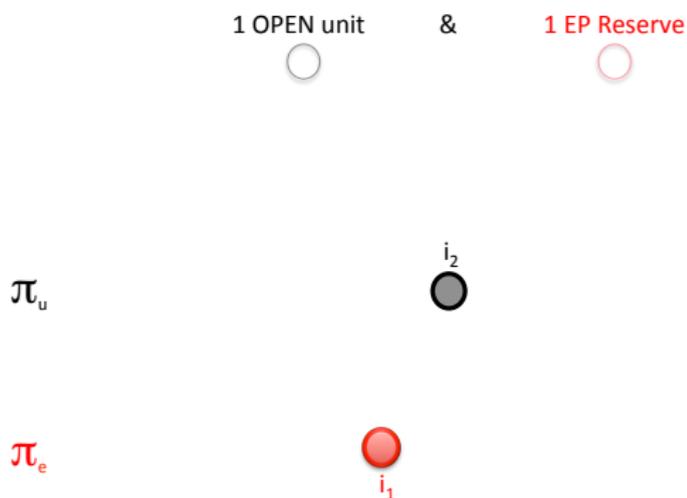
Example 2: Open \triangleright Reserved

← Higher Priority

Example 2: Open \triangleright Reserved \implies Idle Unit

Example 2: Reserved \triangleright Open

← Higher Priority

Example 2: Reserved \triangleright' Open \implies Maximal Match

Example 2: Possible Efficiency Loss

- There are two individuals i_1, i_2 , a single-unit unreserved category u , and a single-unit preferential-treatment category c .

The baseline priority order π_u is s.t.

$$i_1 \pi_u i_2 \pi_u \emptyset$$

and the sole beneficiary of category c (which has **hard reserves**) is individual i_1 . Hence category c priority order π_c is s.t.

$$i_1 \pi_c \emptyset \pi_c i_2$$

Case 1 (Inefficient Reserve Processing): $u \triangleright c$

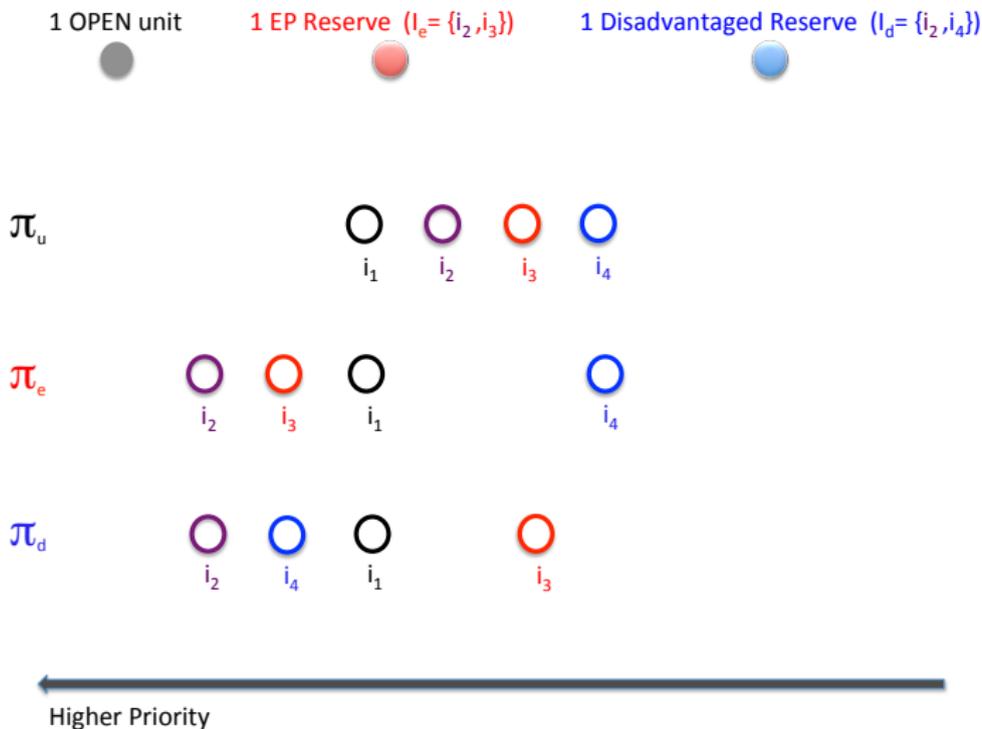
- i_1 receives the unreserved unit and category- c unit is left **idle**.

Case 2 (Efficient Reserve Processing): $c \triangleright' u$

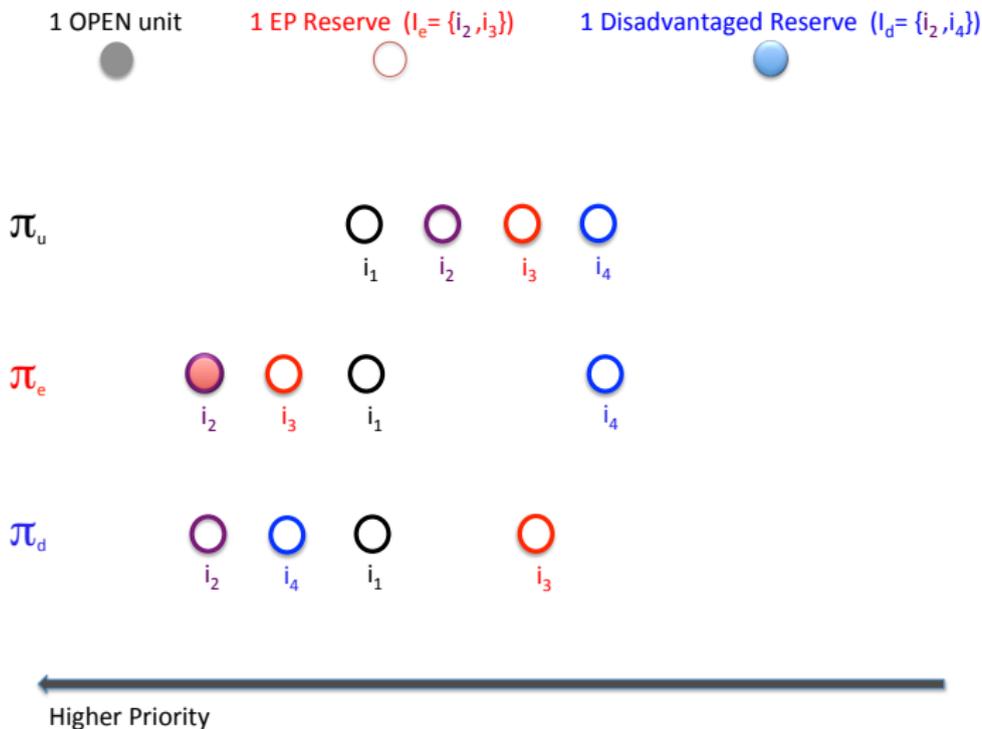
- i_1 receives the category- c unit and i_2 receives the unreserved unit.

- Issue with Case 1:** The more flexible unreserved unit is allocated to patient i_1 , who is the only beneficiary of category c ; this results in suboptimal utilization of reserves.

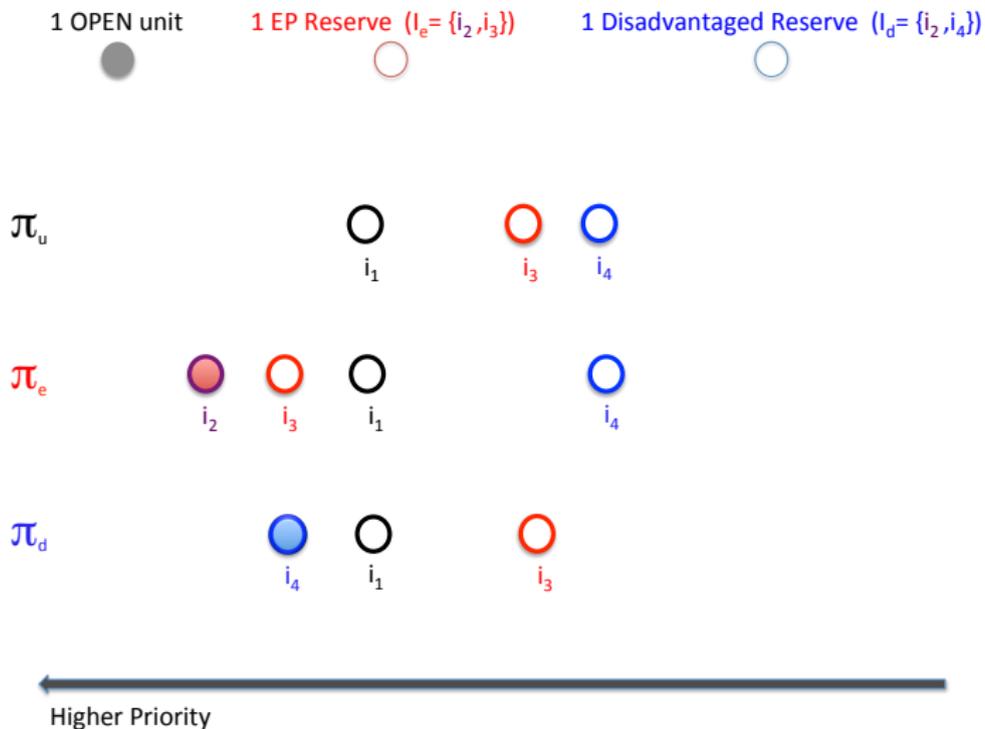
Example 3: Needless Rejection of High-Priority Individuals



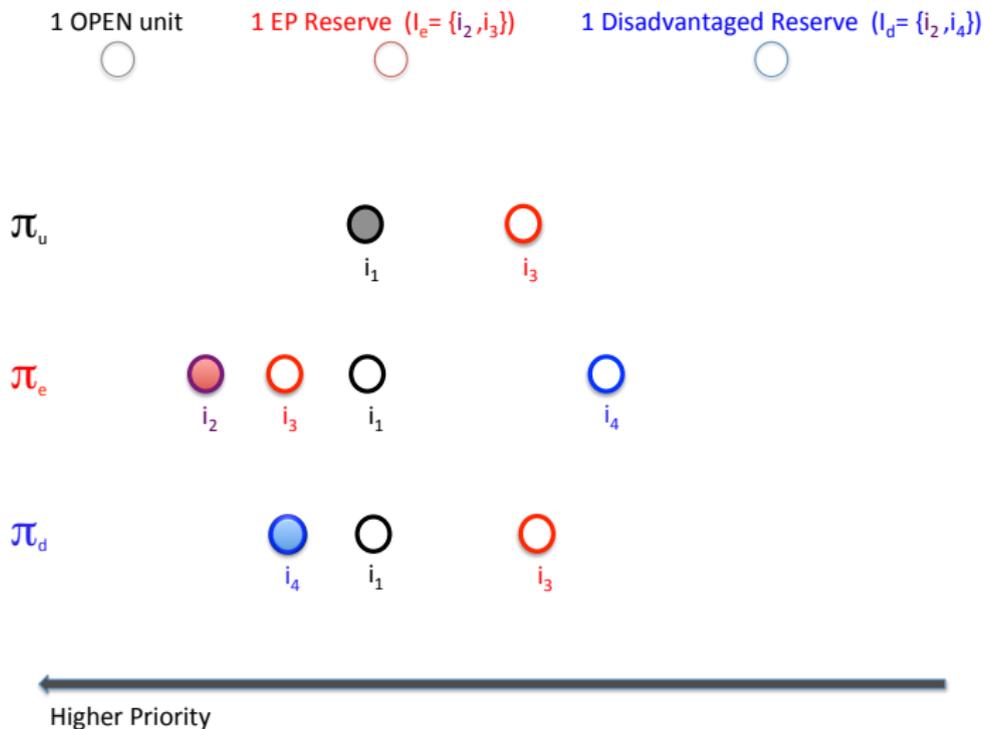
Example 3: EP Reserve \triangleright Disadvantaged Reserve \triangleright Open



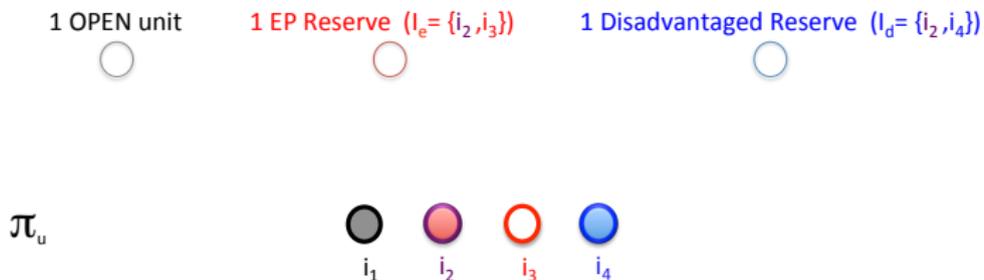
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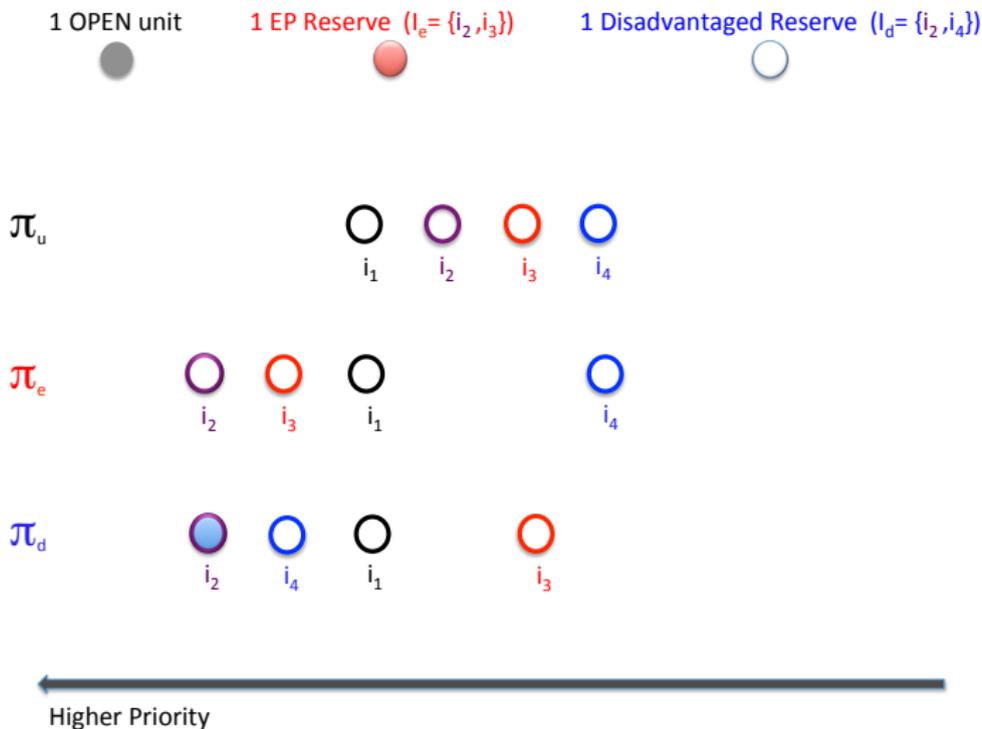


Example 3: i_4 Receives a Unit at the Expense of i_3

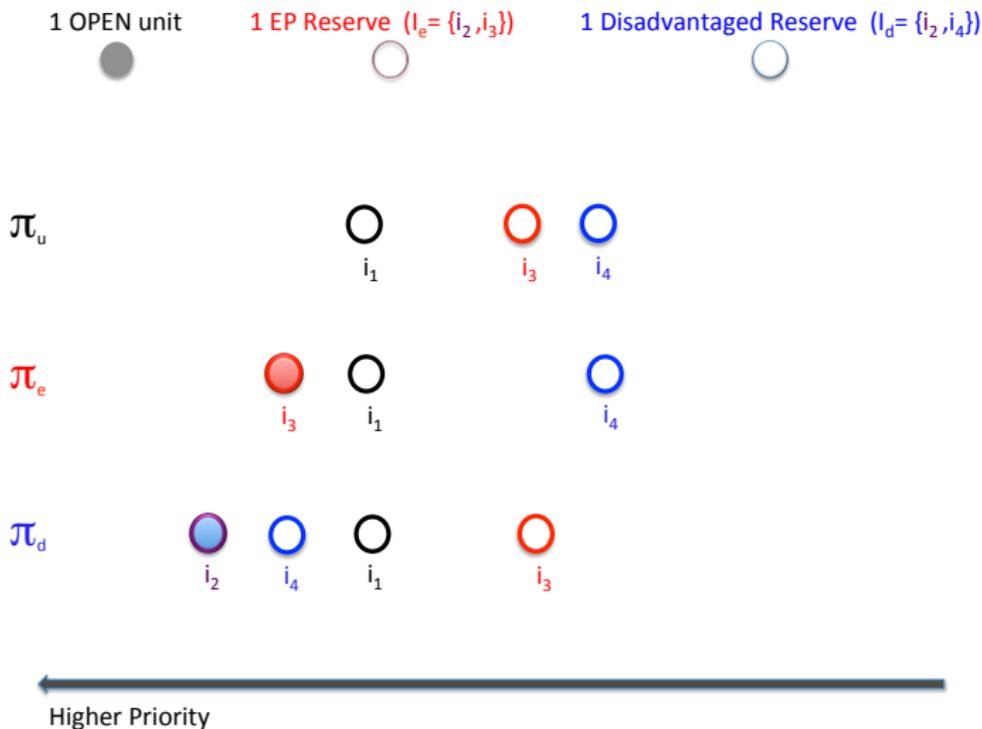


Higher Priority

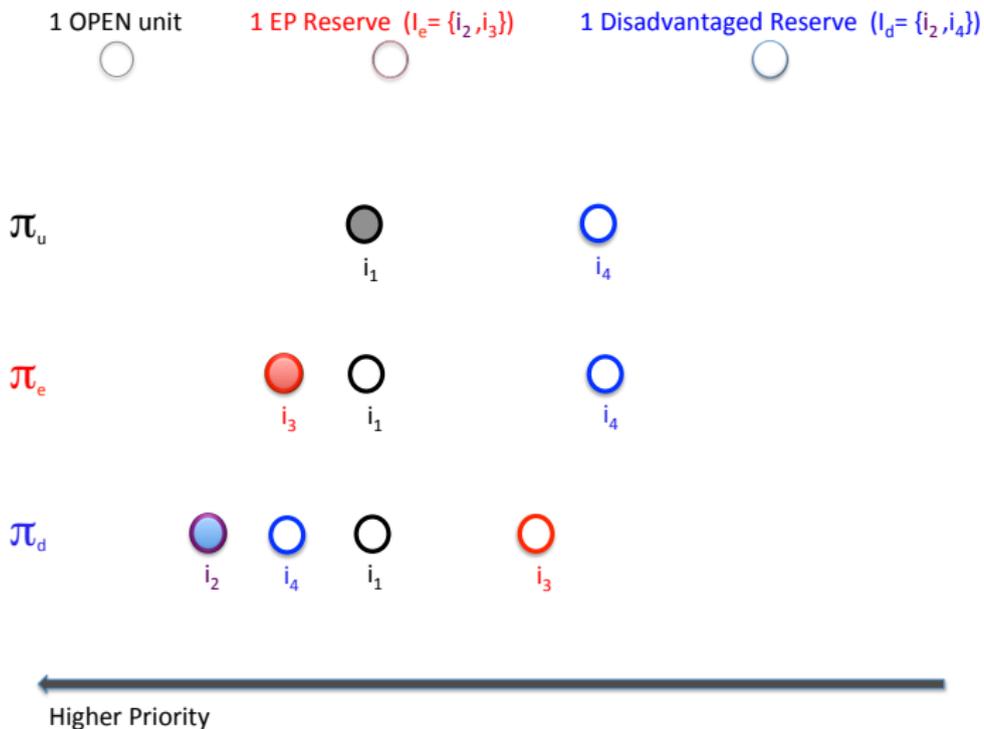
Example 3: Disadvantaged Reserve \triangleright' EP Reserve \triangleright' Open



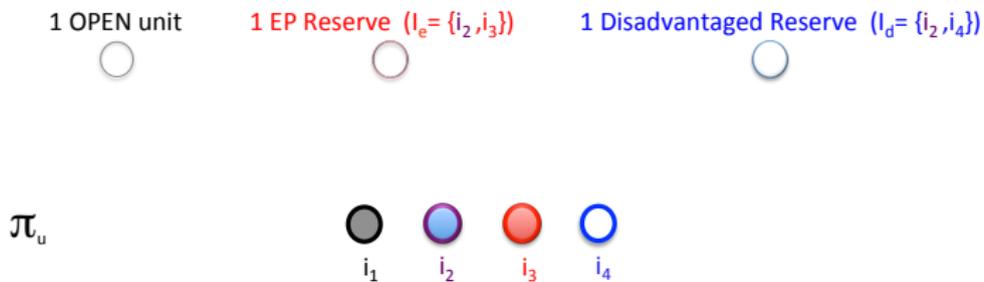
Example 3: Disadvantaged Reserve \triangleright' EP Reserve \triangleright' Open



Example 3: Disadvantaged Reserve \triangleright' EP Reserve \triangleright' Open



Example 3: A More Just Allocation of Units



Higher Priority

Example 3: Needless Rejection of High-Priority Individuals

- There are four individuals i_1, i_2, i_3, i_4 , a single-unit unreserved category u and two single-unit preferential-treatment categories d, e .

The baseline priority order π_u is s.t.

$$i_1 \pi_u i_2 \pi_u i_3 \pi_u i_4 \pi_u \emptyset$$

The preferential-treatment categories d and e have **soft** reserves each, and have sets of beneficiaries $I_d = \{i_2, i_4\}$ and $I_e = \{i_2, i_3\}$. Hence:

$$i_2 \pi_d i_4 \pi_d i_1 \pi_d i_3 \pi_d \emptyset \quad \text{and} \quad i_2 \pi_e i_3 \pi_e i_1 \pi_e i_4 \pi_e \emptyset$$

Case 1 ($e \triangleright d \triangleright u$): i_2 receives the category-e unit, i_4 receives the category-d unit, and i_1 receives the unreserved unit.

Case 2 ($d \triangleright' e \triangleright' u$): i_2 receives the category-d unit, i_3 receives the category-e unit, and i_1 receives the unreserved unit.

- Issue with Case 1:** Higher baseline priority i_3 is rejected at the expense of lower baseline priority i_4 due to mechanical reserve processing.

Additional Axiom: Maximality in Beneficiary Assignment

- The following requirement helps us to avoid any efficiency loss by precluding the myopic assignment of patients to categories.
- A matching is **maximal in beneficiary assignment** if it maximizes the total number of units awarded to “target” beneficiaries of categories.
- **Observation:** Together with non-wastefulness, maximality in beneficiary assignment implies Pareto efficiency.

Smart Reserve Matching

- **Intuition:** The main idea is, determining which agents are to be matched (with **some** category) in a greedy manner following their baseline priorities **while assuring maximality in beneficiary assignment**.
- This can be done in multiple ways, depending on when unreserved units are processed.
- If all unreserved units are processed at the end, this extreme case of our algorithm generates a **minimum guarantee** version of the smart reserve matchings.
- If all unreserved units are processed at the beginning, this other extreme of our algorithm generates an **over & above** version of the smart reserve matchings.

Smart Reserve Matching

- **Proposition 4.** Any smart reserve matching *complies with eligibility requirements, is non-wasteful, respects priorities and maximal in beneficiary assignment.*

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- **Theorem 3.** Let
 - ω be any **over & above** smart reserve matching,
 - μ be any **minimum guarantee** smart reserve matching, and
 - ν be any matching that *complies with eligibility requirements, is non-wasteful, respects priorities and maximal in beneficiary assignment.*

Then

$$\bar{f}_u^{\omega} \pi_u \bar{f}_u^{\nu} \pi_u \bar{f}_u^{\mu}$$

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$$\bar{f}_u^\omega \preceq_u \bar{f}_u^\nu \preceq_u \bar{f}_u^\mu$$

- **Interpretation:** Of all matchings that satisfy our four axioms,
 - over & above smart matchings are the most selective, and
 - minimum guarantee smart matchings are the least selective ones for the unreserved category.

Most Related Literature

- **Reserve Systems:** Hafalir, Yenmez & Yildirim (*TE* 2013), Echenique & Yenmez (*AER* 2015)
- **Sequential Reserve Matching:** Kominers & Sönmez (*TE* 2016)
- **Smart Reserves:** Sönmez and Yenmez (2020)
- **Impact of Reserve Processing Sequence:** Dur, Kominers, Pathak & Sönmez (*JPE* 2018), Dur, Pathak & Sönmez (*JET* 2020), Sönmez & Yenmez (2019), Pathak, Rees-Jones & Sönmez (2020)
- **Additional Applications:** Aygün and Bó (2016), Aygün and Turhan (2016, 2017), Correa et. al (2019)

Reserve System in Pittsburgh (UPMC)

A MODEL HOSPITAL POLICY FOR FAIR ALLOCATION OF MEDICATIONS TO TREAT COVID-19

HOME (/) • A MODEL HOSPITAL POLICY FOR FAIR ALLOCATION OF MEDICATIONS TO TREAT COVID-19



Available now online:

To assist hospitals and health systems to implement a transparent and fair approach to allocate scarce medications to treat patients with COVID-19, we have created a model hospital policy and allocation framework. Hospitals and health systems are welcome to adapt the policy for their specific needs. Click here to download a PDF (<https://ccm.pitt.edu/sites/default/files/2020-05->

- Designed by a team of diversity and inclusion experts, ethicists, economists, and medical specialists from the University of Pittsburgh, Harvard University, University of Denver, Boston College and MIT.
- “The model policy uses a weighted lottery or categorical reserve system to fairly allocate drug supplies if there is insufficient supply to treat all eligible patients.”

Pittsburgh Model Policy for Antiviral Medications

- Reserve categories based on the combinations of the following three considerations:
 - Hardest hit (ADI of 8-10)
 - Essential worker (using PA state definition)
 - Is patient expected to die in one-year?
- Priorities are based on lottery
 - In this case, reserve system simplifies to stratified lottery (25% boost for each of the first two considerations, 50% reduction for the third).
 - Used for rationing of Remdesivir.
 - Outcome determined dynamically through cutoff lottery points for each category.
- After its initial deployment at UPMC in May 2020, **endorsed by the Commonwealth of Pennsylvania.**

CDC Priority System for Vaccines from 2018

- Place individuals into one of four tiers based on:
 - 1) Providing homeland and national security
 - 2) Providing health care and community support services
 - 3) Maintaining critical infrastructure
 - 4) Being a member of the general population

CDC Priority System for Vaccines from 2018

- Place individuals into one of four tiers based on:
 - 1) Providing homeland and national security
 - 2) Providing health care and community support services
 - 3) Maintaining critical infrastructure
 - 4) Being a member of the general population
- Since the beginning of the pandemic, there has been a vigorous debate on equitable vaccine allocation.
 - Until recently, these debates were purely focused on the structure of priority tiers.
- Melinda Gates in June 2020:

"We care about this vaccine getting out equitably. The first people that need this vaccine are the 60 million health care workers around the world. They deserve to get it before anybody else. Then you start tiering. In the U.S. that would be black people next, quite honestly, and many other people of color. They are having disproportionate effects from Covid-19."

Inability to Accommodate Compromises via Priority System

Who should get coronavirus vaccine first? U.S. weighs early access for some

July 9, 2020 at 4:45 am | Updated July 9, 2020 at 7:51 am



Dr. Francis Collins, director of the National Institutes of Health (NIH), holds up a model of COVID-19 during a Senate hearing on the plan to research... (Saul Loeb / The Associated Press) [More](#) ✓

By Megan Twohey

The New York Times

Federal health officials are already trying to decide who will get the first doses of any effective coronavirus vaccines, which could be on the market this winter but could require many additional months to become widely available to Americans.

The Centers for Disease Control and Prevention and an advisory committee of outside health experts in April began working on a ranking system for what may be an extended rollout in the United States. According to a preliminary plan, any approved vaccines would be offered to vital medical and national security officials first, and then to other essential workers and those considered at high risk — the elderly instead of children, people with underlying conditions instead of the relatively healthy.

Agency officials and the advisers are also considering what has become a contentious option: putting Black and Latino people, who have disproportionately fallen victim to COVID-19, ahead of others in the population.

OPINION

The lunatic drive for racial quotas for COVID-19 vaccines

By Betty McCaughey

July 16, 2020 | 7:38pm



At least two COVID-19 vaccines are scoring major successes in trials. APF via Getty Images

Sign up for our [special edition newsletter](#) to get a daily update on the coronavirus pandemic.

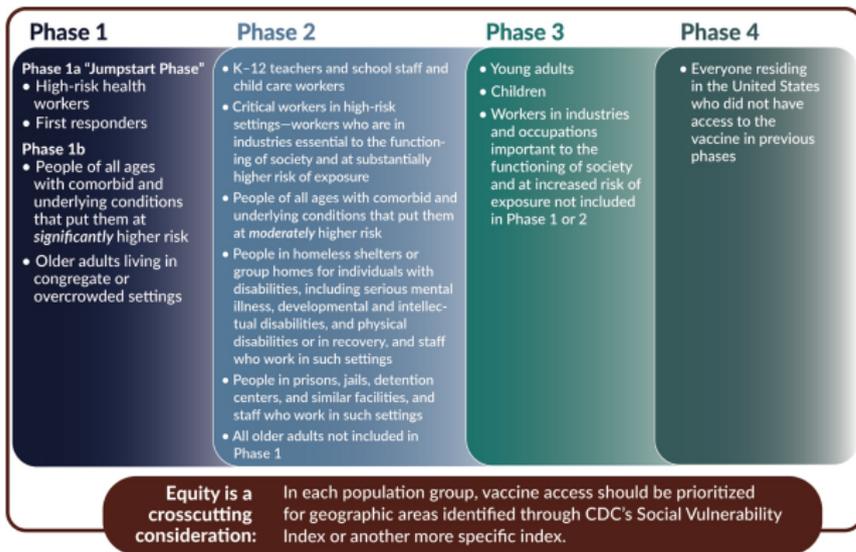
At least two COVID-19 vaccines are scoring major successes in trials. That means a vaccine might be ready by year's end, but not in sufficient quantity to vaccinate more than 300 million Americans. Frontline health workers and national-security personnel will be top priority, but after that, who comes next?

A federal committee is considering pushing blacks, Hispanics and Native Americans to the front of the line, ahead of whites.

NASEM Framework for Equitable Vaccine Allocation

- **July 2020:** CDC and NIH commissioned the National Academies of Sciences, Engineering, and Medicine (NASEM) to formulate their recommendations on the equitable allocation of a COVID-19 vaccine.
 - NASEM appoints committee of distinguished experts.

- **September 2020:** A discussion draft of the preliminary *Framework for Equitable Allocation of COVID-19 Vaccine* is made public.



- Comments from the public are solicited.
- In his written and oral comments, University of Pennsylvania bioethicist Harald Schmidt inquired about the recommended mechanism to prioritize members of hard-hit communities, bringing our proposed reserve system to the committee's attention as a possibility.

NASEM Framework for Equitable Vaccine Allocation

- **September 2020:** In response to the NASEM discussion draft, *JAMA* published the viewpoint “Fairly Prioritizing Groups for Access to COVID-19 Vaccines,” endorsing our proposed reserve system (Persad, Peek & Emanuel 2020).

NASEM Framework for Equitable Vaccine Allocation

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*“Dividing the initial vaccine allotment into priority access categories and using medical criteria to prioritize within each category is a promising approach. For instance, half of the initial allotment might be prioritized for frontline health workers, a quarter for people working or living in high-risk settings, and the remainder for others. Within each category, preference could be given to people with high-risk medical conditions. **Such a categorized approach would be preferable to the tiered ordering previously used for influenza vaccines,** because it ensures that multiple priority groups will have initial access to vaccines.”*

NASEM Framework for Equitable Vaccine Allocation

- **October 2020:** NASEM published their final **Framework for Equitable Allocation of COVID-19 Vaccine (2020)**, based on the ethical values formulated in (Emanuel et al. 2020), whose lead authors later on endorsed our proposed reserve system.

“Fair Allocation of Scarce Medical Resources in the Time of COVID-19

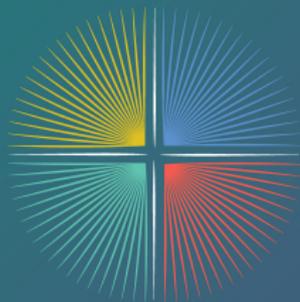
In May 2020, an article in The New England Journal of Medicine proposed a set of ethical values to underpin recommendations for allocating scarce medical resources during the COVID-19 pandemic (Emanuel et al. NEJM 2020). Drawing on previous proposals about how to allocate resources during scenarios of absolute scarcity, such as pandemics, the authors identify four fundamental ethical values: (1) maximize benefit, (2) treat people equally, (3) promote and reward instrumental value (i.e., providing benefit to others), and (4) give priority to the worst off.”

NASEM Framework for Equitable Vaccine Allocation

The National Academies of
SCIENCES · ENGINEERING · MEDICINE

CONSENSUS STUDY REPORT

FRAMEWORK FOR EQUITABLE ALLOCATION OF COVID-19 VACCINE



NATIONAL ACADEMY OF MEDICINE

- The final NASEM framework formally recommends a **10 percent reserve** for people from hard-hit areas.

“The committee does not propose an approach in which, within each phase, all vaccine is first given to people in high SVI areas. Rather the committee proposes that the SVI be used in two ways. First as previously noted, a reserved 10 percent portion of the total federal allocation of COVID-19 vaccine may be reserved to target areas with a high SVI (defined as the top 25 percent of the SVI distribution within the state).”

TN Adopts a Reserve System for Vaccine Allocation

- States are finalizing their Covid-19 vaccine allocation guidelines.
 - Tennessee already announced it will use a reserve system.

Tennessee Infrastructure Plan for COVID-19 Vaccine Distribution

Wednesday, October 21, 2020 | 01:39pm

NASHVILLE, Tenn. – The Tennessee Department of Health today announced the state's infrastructure plan for distribution of COVID-19 vaccines once they become available. TDH in coordination with other state and local agencies submitted an initial draft of the [COVID-19 Vaccination Plan](#) for Tennessee to the Centers for Disease Control and Prevention on October 16, 2020.

"We assure Tennesseans that safe, effective and approved COVID-19 vaccines will be released in Tennessee when they are available to reduce the spread of the virus," said Tennessee Health Commissioner Lisa Piercey, MD, MBA, FAAP. "Our vaccine distribution plan will be modified as more is understood about the virus and the availability of approved vaccines currently in development."

TDH has developed a preliminary structure for the allocation and distribution of COVID-19 vaccines:

- Five percent of Tennessee's allocation of COVID-19 vaccines will be distributed equitably among all 95 counties
- Ten percent of Tennessee's allocation of COVID-19 vaccines will be reserved by the state for use in targeted areas with high vulnerability to illness and death from the virus
- 85 percent of Tennessee's allocation of COVID-19 vaccines will be distributed among all 95 counties based on their populations

TDH modeled this approach to allocation and distribution of COVID-19 vaccines after review of the CDC's [COVID-19 Vaccination Program Interim Playbook for Jurisdictional Operations](#) and the National Academies of Sciences, Engineering and Medicine's [Framework for Equitable Allocation of COVID-19 Vaccine](#), and in consultation with Tennessee's Unified Command Group and a stakeholder group of more than 28 partner agencies and offices.

Vaccine Allocation Phases

Equity is a crosscutting consideration:

In each population group, vaccine access should be prioritized for geographic areas identified through CDC's Social Vulnerability Index or another more specific index.



Adapted from <https://www.nap.edu/catalog/25917/framework-for-equitable-allocation-of-covid-19-vaccine>

Conclusion

- In the first few months of the COVID-19 pandemic, many societies were caught unprepared when they needed guidelines for a possible ventilator rationing.
- At present, there is a worldwide need for policies and mechanisms for vaccine allocation.
- Poorly designed rationing mechanisms may damage the social contract between different segments of the society.
- Widely accepted but potentially competing ethical values for pandemic rationing require an allocation mechanism to implement the desired balance of values.
- Finding the right mechanism to honor these principles is therefore important for **maintaining the social fabric**.

Conclusion

- Because the mechanism is a tool to realize ethical values and not an end in itself, it should permit a wide range of options.
- The exclusion or inadequate balancing of certain ethical principles may do more harm than good.

“Maybe you end up saving more people but at the end you have got a society at war with itself. Some people are going to be told they don’t matter enough.”

Quote attributed to Christina Pagel in New York Times

- When revising or modifying guidelines during or after the COVID-19 pandemic, a reserve system should be part of the arsenal.