

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

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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
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  - Saving the most lives
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  - 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 **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.
- The total SOFA score is shown to be useful in predicting the clinical outcomes of critically ill patients.

## 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

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  - 1) Providing homeland and national security
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  - 3) Maintaining critical infrastructure
  - 4) Being a member of the general population
- Currently, there is a vigorous debate on vaccine allocation.
- 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.”*

# Limitation: Inability to Accommodate Compromises

## 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.

# Single-Principle vs. Multi-Principle Priority Point Systems

- 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.

## Example for Science Fiction Fans: Doomsday Scenario

- Consider a future pandemic so devastating that it threatens a significant portion of the human race.
- In this hypothetical crisis, a principle based on **survival of the species** may suggest a gender balance constraint: Assign at least 40% of the ventilators to female patients and at least 40% to male patients.
- Clearly, considerations based on group composition cannot be represented with a function that relies on individual attributes only.

## Emergence of the Priority Point System in the U.S.

- 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.

## Recap: Limitations of a Priority (Point) System

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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 a recent debates on Essential Personnel.

## 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 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.

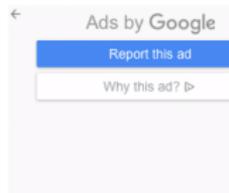
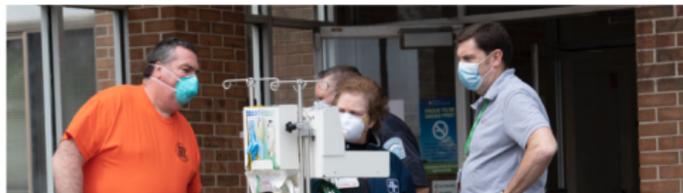


### OPINION

## 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.*”  
MN Pandemic Ethics Project, MN Dept. of Health 2010

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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

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  - A remedy has to break this limiting characteristic.

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- 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.
  - 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:
  - 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:**
  - Propose three intuitive axioms and examine their implications.
  - Formulate cutoff equilibrium solution concept, linking axioms to real-world.
  - Show multiplicity of equilibrium and a way to compute.
  - Extend the prior analysis of sequential reserve matching policies which dominate practical applications.
  - Formulate potential shortcomings of sequential reserve matching policies, and introduce/analyze smart reserve matching policies.

# Formal Model

- $I$ : 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.

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

- $\pi_c$ : 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  $\pi_c$

# Outcome and Its Properties

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

## 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  $(f, \mu)$  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
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  - the second one corresponds to the **market-clearing** condition.
- A matching  $\mu$  is a **cutoff matching** if it is supported by some cutoff vector  $f$  at a cutoff equilibrium  $(f, \mu)$ .

# 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
TSP ST	DV	191.59
	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	790.43	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	800	848.51	900
	Tier 1	722	754.21	814
	Tier 2	770	802.41	820
	Tier 4	700	782.95	820

School	Selection Method	Min	Mean	Max
Jones	Rank	801	895.02	900
	Tier 1	799	838.11	890
	Tier 2	843	868.11	890
	Tier 3	855	872.53	890
	Tier 6	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	805.84	875
Tier 4	802	869.39	875	

School	Selection Method	Min	Mean	Max
Lindholm	Rank	771	815.38	895
	Tier 1	661	712.85	769
	Tier 2	710	754.76	769
	Tier 3	707	733.65	769
Tier 4	603	669.76	771	

School	Selection Method	Min	Mean	Max
Northside	Rank	894	897.60	900
	Tier 1	785	819.59	894
	Tier 2	843	871.94	894
	Tier 3	875	884.00	894
Tier 4	884	881.63	894	

School	Selection Method	Min	Mean	Max
Rayton	Rank	894	898.44	900
	Tier 1	803	849.11	894
	Tier 2	805	862.74	894
	Tier 4	801	869.13	894

School	Selection Method	Min	Mean	Max
South Shore	Rank	684	724.62	862
	Tier 1	620	624.69	682
	Tier 2	602	636.91	684
	Tier 3	600	633.74	682
Tier 4	613	640	677	

School	Selection Method	Min	Mean	Max
Westgrove	Rank	794	821.27	883
	Tier 1	718	764.43	793
	Tier 2	724	765.08	795
	Tier 3	724	759.82	795
Tier 4	601	693.76	794	

School	Selection Method	Min	Mean	Max
Young	Rank	883	891.28	900
	Tier 1	806	841.55	883
	Tier 2	813	852.65	883
	Tier 3	804	850.11	883
Tier 4	870	876.63	883	

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

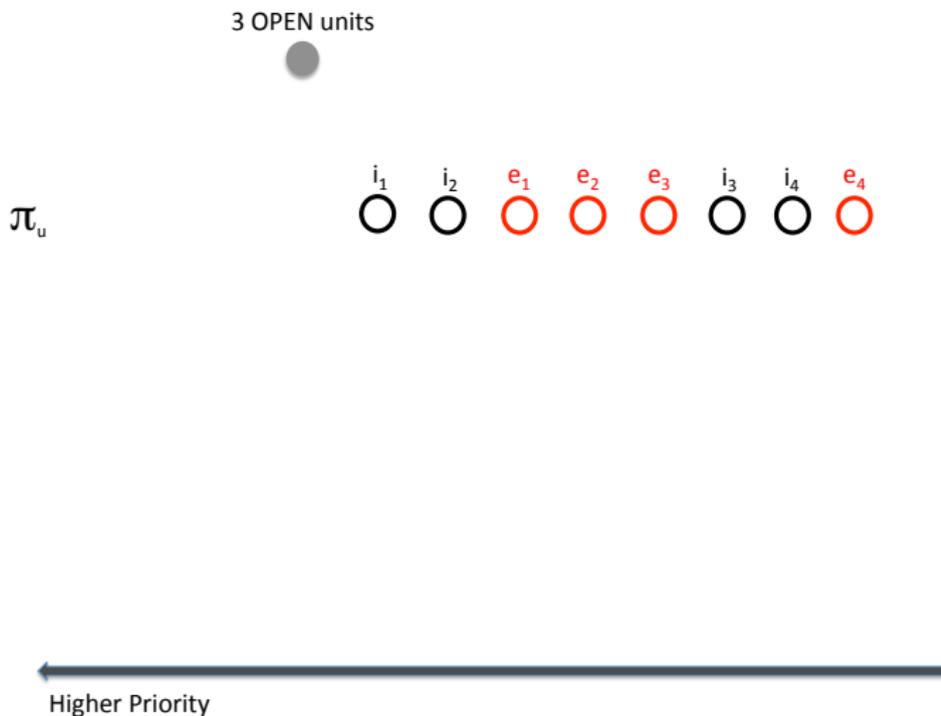
# Characterization through Cutoff Equilibria

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

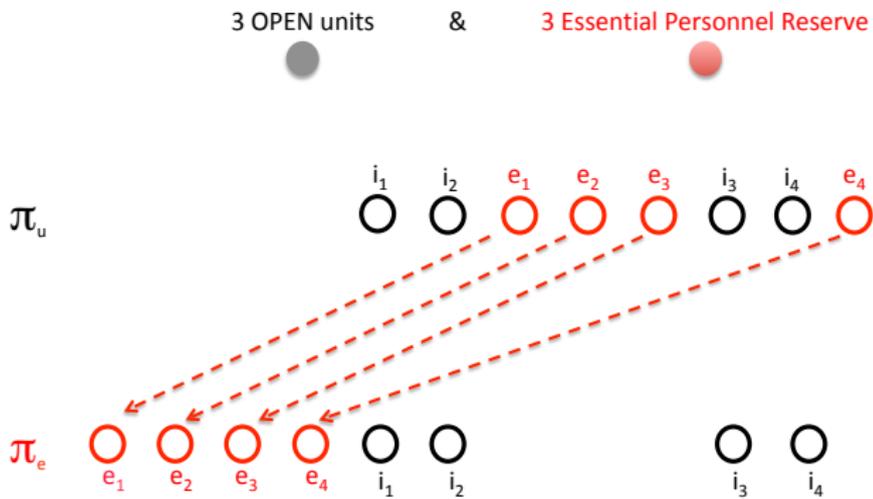
# Characterization through Cutoff Equilibria

- Our first result shows a strong link between our three axioms and 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**.

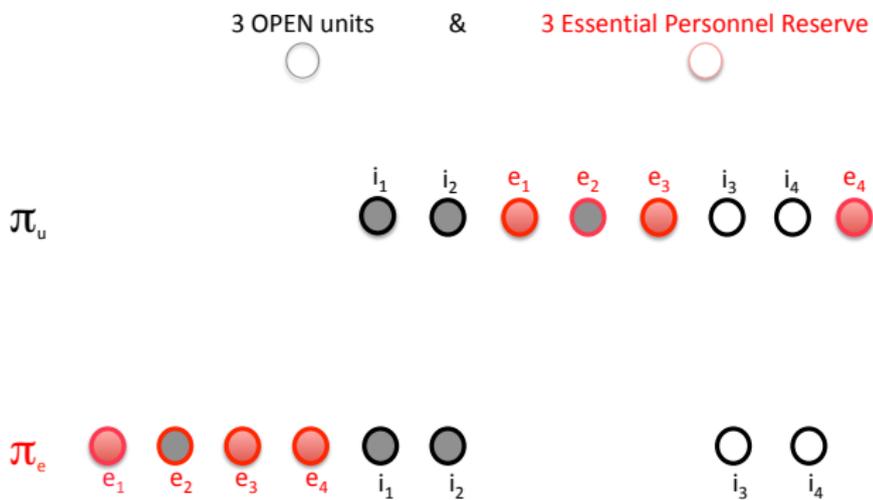
# Cutoff Vector Construction



# Cutoff Vector Construction

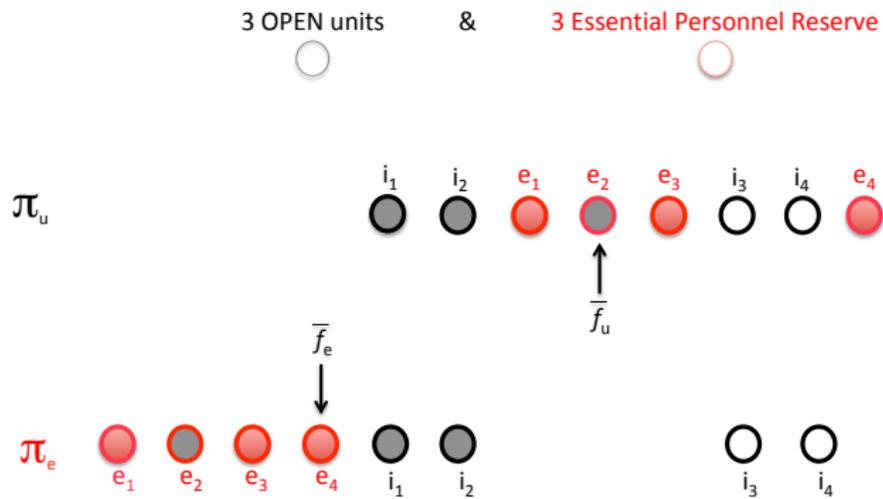


# Cutoff Vector Construction

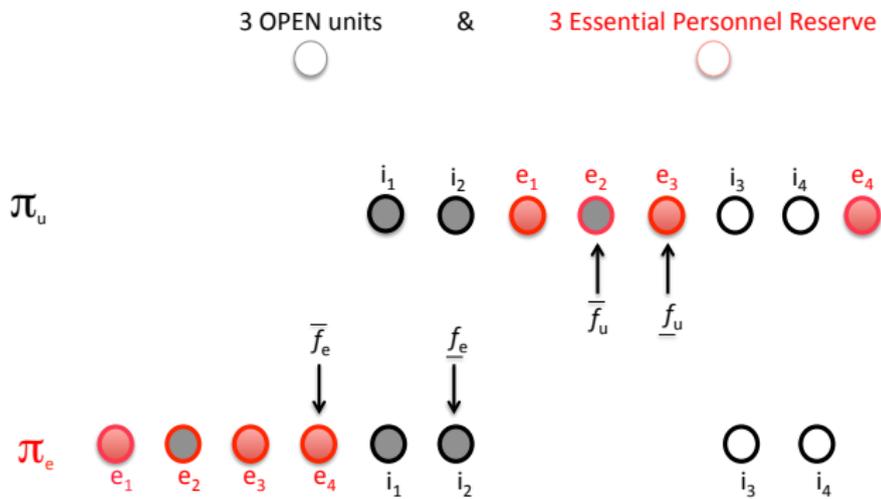


Higher Priority

# Cutoff Vector Construction



# Cutoff Vector Construction



# Cutoff Equilibria Properties

- We focus on the **maximum cutoff vector**  $\bar{f}^\mu = (\bar{f}_c^\mu)_{c \in \mathcal{C}}$ 
  - For any category  $c \in \mathcal{C}$ , it is given by the lowest  $\pi_c$ -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.

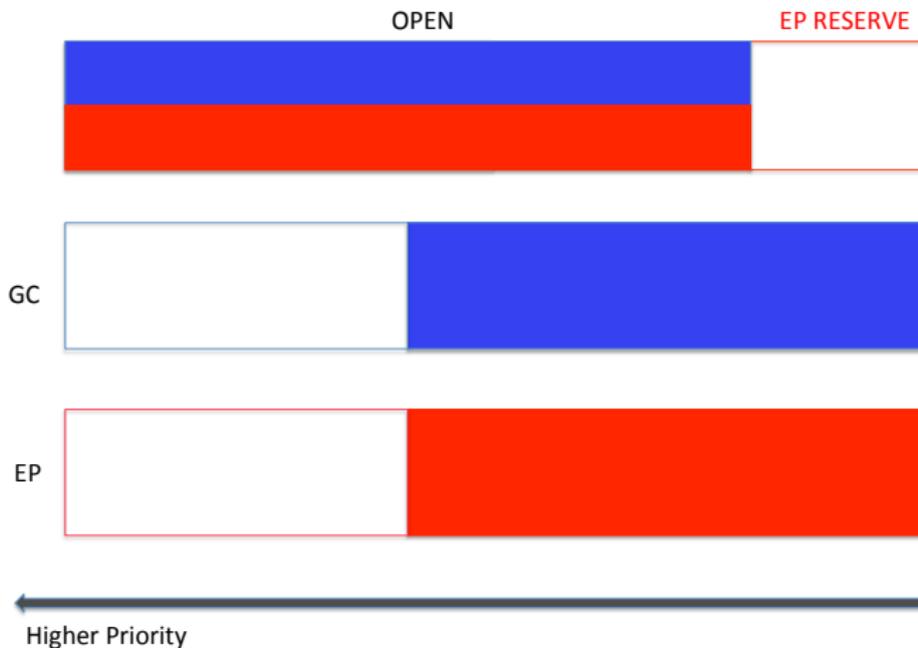
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  - Other cutoffs are **artificially** lower and without any clear interpretation.
- The maximum cutoff indicates the **selectivity** of a category.
  - The higher priority the cutoff patient is, the more competitive the category is.
- How do you find cutoff equilibrium matchings?
  - We start with a situation where we process categories sequentially.
  - Most widespread practice in real-life applications.

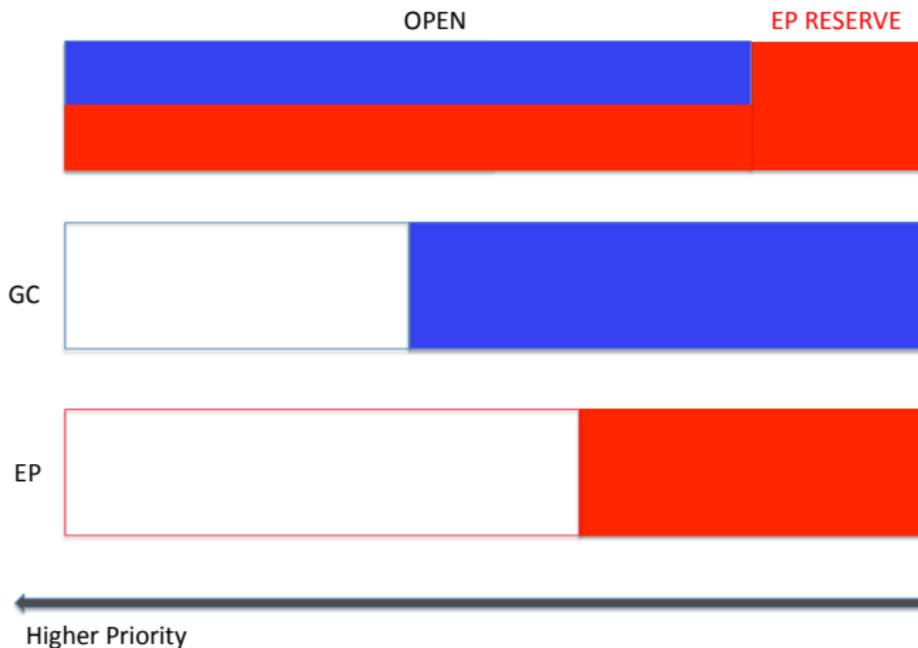
# Sequential Category Processing: Open-Reserved



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# Open First - Reserved Next = Over & Above Policy



# Sequential Category Processing: Reserved-Open



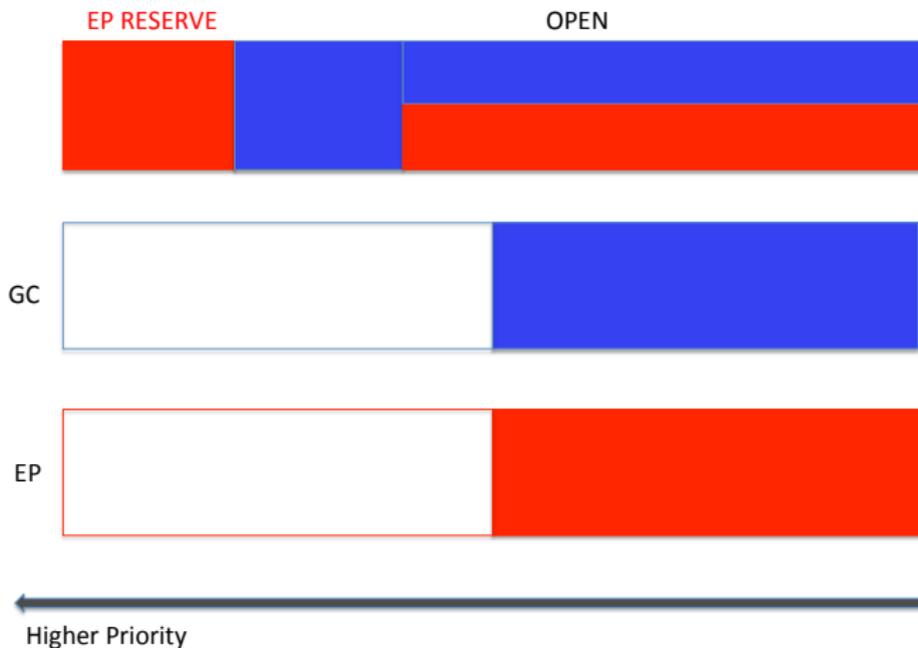
# Sequential Category Processing: Reserved-Open



# 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
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# Construction of Cutoff Equilibria

- Example shows that
  - 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  $c$
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- **Observation:** All primitives **except the student preferences** naturally follow from the primitives of the original problem.

# Individual-Proposing Deferred Acceptance Algorithm

- Step 1:
  - Each patient applies to her most preferred acceptable category.
  - Each category holds eligible applicants with highest priority up to capacity and rejects others.
- Step  $k$ :
  - Each patient who was rejected in the previous step applies to her next preferred acceptable category.
  - Considering all patients on hold and the new applicants, each category holds applicants with highest priority up to capacity and rejects others.
- The algorithm terminates when there are no rejections. All assignments on hold are finalized.

# Characterization through Deferred Acceptance Algorithm

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

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  - *respects priorities*if, and only if, it is **DA induced**.
- 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  $\succ_i$ .

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  - **Example:** Patient A can be considered first for open category and then for Essential Personnel category, whereas patient B who has similar attributes can be considered for these categories in the reverse order.

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- Critically, this sequence can differ between patients.
  - **Example:** Patient A can be considered first for open category and then for Essential Personnel category, whereas patient B who has similar attributes can be considered for these categories in the reverse order.
- Without a systematic way to construct these preferences, it may be difficult to motivate this methodology for real-life implementation.

# Sequential Reserve Matching: Processing Categories

- 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: Processing Categories

- **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  $\pi_c$ -priority patients.
  - In previous example, in the first case all open units are processed first (over & above), and in the second case all reserve units processed first (minimum guarantee).

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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  $\varphi_{\triangleright}$  is DA-induced from the preference profile  $\succ^{\triangleright}$ .

# Category Processing and 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  $c^* \in \mathcal{C} \setminus \{c, c'\}$

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

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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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$\pi_c$ : Prioritizes beneficiaries of category  $c$  over others and  $\pi_u$  is used to break ties internally within the two groups.

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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: Order of Precedence

- 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:
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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

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- **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

## Efficiency Loss

- **Example 2:** 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  $\pi_u$  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  $\pi_c$  is s.t.

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- $i_1$  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.

## Unnecessary Rejection of High-Priority Individuals

- **Example 3:** 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  $\pi_u$  is s.t.

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

Sets of beneficiaries for the two preferential-treatment categories with **soft** reserves are  $I_d = \{i_2, i_4\}$  and  $I_e = \{i_2, i_3\}$ . Hence:

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**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.

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- **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.

# 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 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.

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

Then

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

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- **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 Anti-Viral 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.**

# 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 precise recommended mechanism to prioritize members of hard-hit communities, and brought 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*

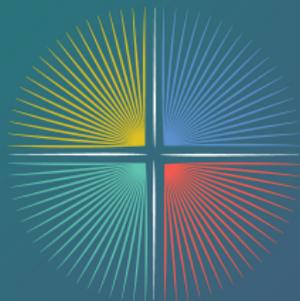
*In May 2020, an article in The New England Journal of Medicine proposed a set of ethical values to underpin recommendations for allocating scarce medical resources during the COVID-19 pandemic (Emanuel et al. NEJM 2020). Drawing on previous proposals about how to allocate resources during scenarios 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  
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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).”*

# 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.