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.
- The most widespread allocation mechanism is based on a priority system, which places patients into a single priority order and allocates all units based on this priority.

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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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  - 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 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.

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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- 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 Betsy McCaughey

July 16, 2020 | 7:38pm

At least two COVID-19 vaccines are scoring major successes in trials.

AFP 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.

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, (SOFA or mSOFA based) IN, KY, TN, KS, VT
  - 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 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 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.

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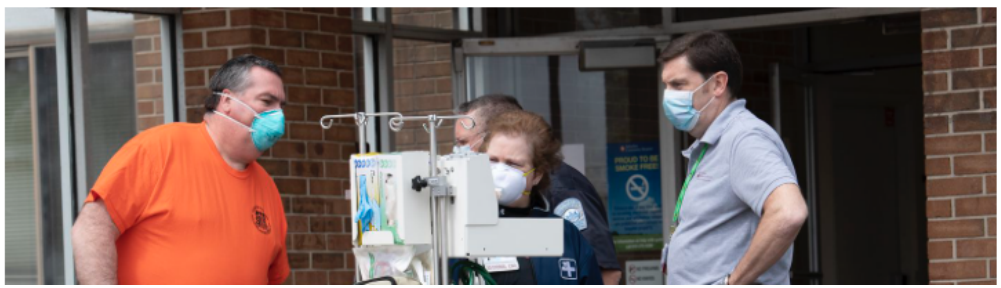
OPINION

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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- 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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- 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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  - 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.

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

- 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 and Its Properties

- A matching $\mu : I \to \mathcal{C} \cup \{\emptyset\}$ 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 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, 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
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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 **PROVISIONALITY 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
GEN	GEN	218.89
	FEM	185.22
	WD	141.80
	DV	162.31
SC	GEN	210.79
	FEM	151.73
	WD	123.68
	DV	141.94
TSP SC	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/LV		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
Brooks	Tier 1	694	729.42	804
Brooks	Tier 2	731	773.39	806
Brooks	Tier 3	759	782.61	806
Brooks	Tier 4	704	758.78	806

School	Selection Method	Min	Mean	Max
Hancock	Rank	826	848.51	890
Hancock	Tier 1	722	754.2	814
Hancock	Tier 2	776	802.4	825
Hancock	Tier 3	784	804	826
Hancock	Tier 4	700	762.95	825

School	Selection Method	Min	Mean	Max
Jones	Rank	891	895.02	900
Jones	Tier 1	799	838.11	889
Jones	Tier 2	845	868.11	890
Jones	Tier 3	855	872.53	890
Jones	Tier 4	883	886.96	890

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

School	Selection Method	Min	Mean	Max
Lane	Rank	875	885.58	900
Lane	Tier 1	747	788.16	874
Lane	Tier 2	810	836.36	875
Lane	Tier 3	838	855.8	875
Lane	Tier 4	862	869.39	875

School	Selection Method	Min	Mean	Max
Lindblom	Rank	771	813.38	895
Lindblom	Tier 1	687	717.85	769
Lindblom	Tier 2	712	734.78	769
Lindblom	Tier 3	707	733.63	769
Lindblom	Tier 4	603	669.78	771

School	Selection Method	Min	Mean	Max
Northside	Rank	894	897.61	900
Northside	Tier 1	745	817.39	894
Northside	Tier 2	843	871.14	894
Northside	Tier 3	875	884.06	894
Northside	Tier 4	888	891.63	894

School	Selection Method	Min	Mean	Max
Payton	Rank	898	899.44	900
Payton	Tier 1	803	849.11	894
Payton	Tier 2	855	882.74	898
Payton	Tier 3	882	891.13	898
Payton	Tier 4	895	896.61	898

School	Selection Method	Min	Mean	Max
South Shore	Rank	684	734.64	862
South Shore	Tier 1	602	634.69	682
South Shore	Tier 2	602	636.91	684
South Shore	Tier 3	600	633.74	682
South Shore	Tier 4	613	645	677

School	Selection Method	Min	Mean	Max
Westinghouse	Rank	796	821.27	883
Westinghouse	Tier 1	711	744.43	793
Westinghouse	Tier 2	734	765.08	795
Westinghouse	Tier 3	726	759.82	795
Westinghouse	Tier 4	601	693.78	794

School	Selection Method	Min	Mean	Max
Young	Rank	883	891.28	900
Young	Tier 1	808	841.33	883
Young	Tier 2	831	852.64	883
Young	Tier 3	854	870.1	883
Young	Tier 4	872	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.

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Characterization through Cutoff Equilibria

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

Characterization through Cutoff Equilibria

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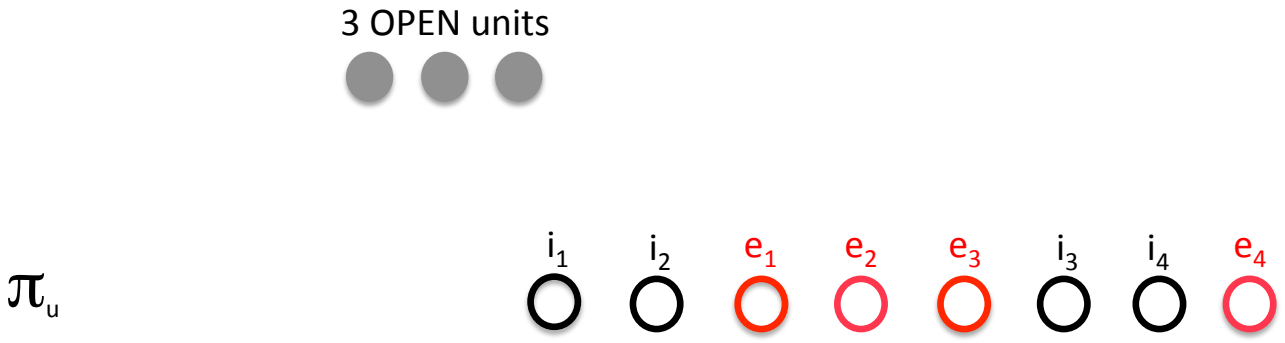
- Theorem 1. A matching
  - *complies with eligibility requirements*,
  - is *non-wasteful*, and
  - *respects priorities*

  if, and only if, it is a cutoff matching.

Cutoff Vector Construction



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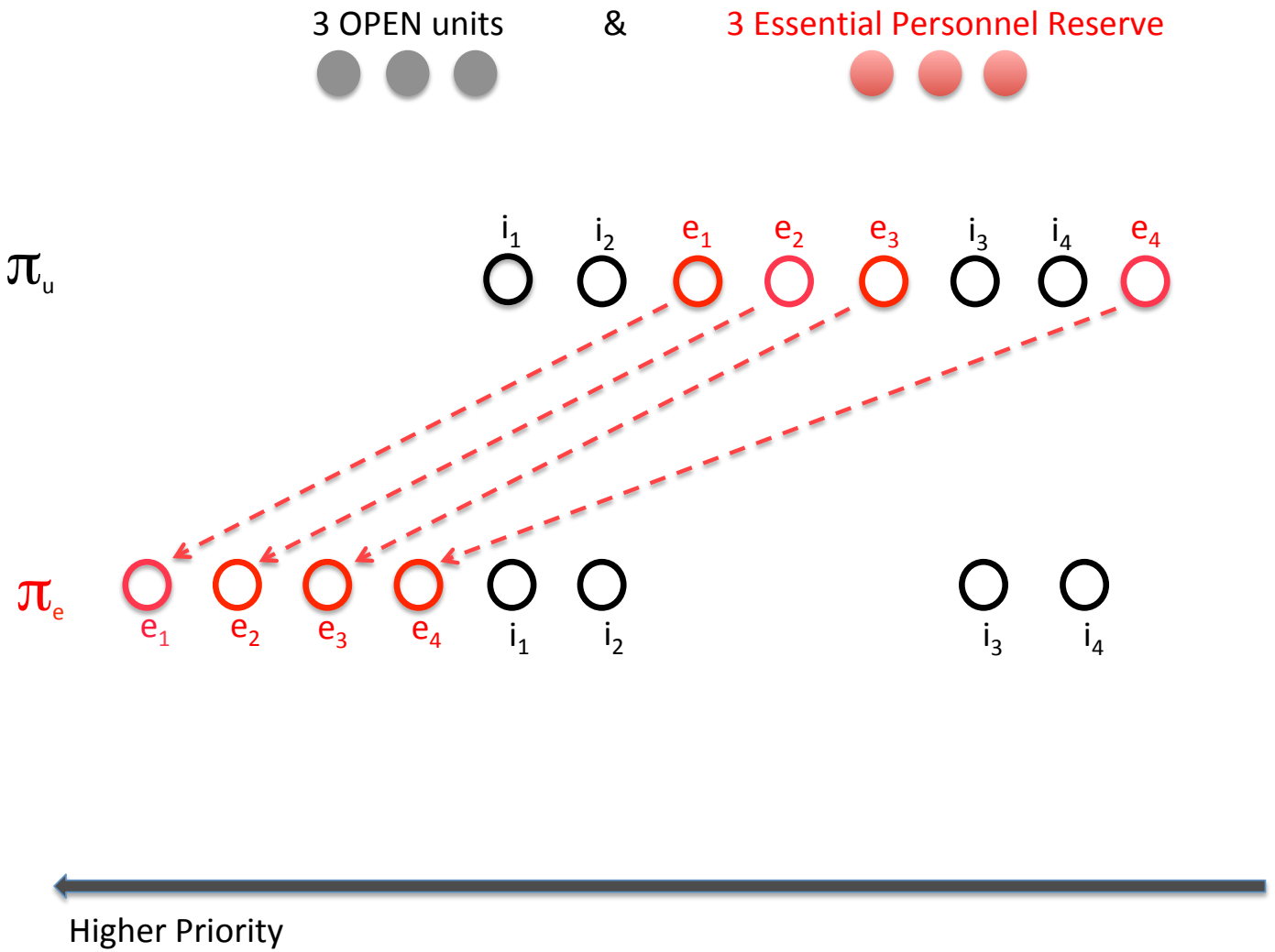

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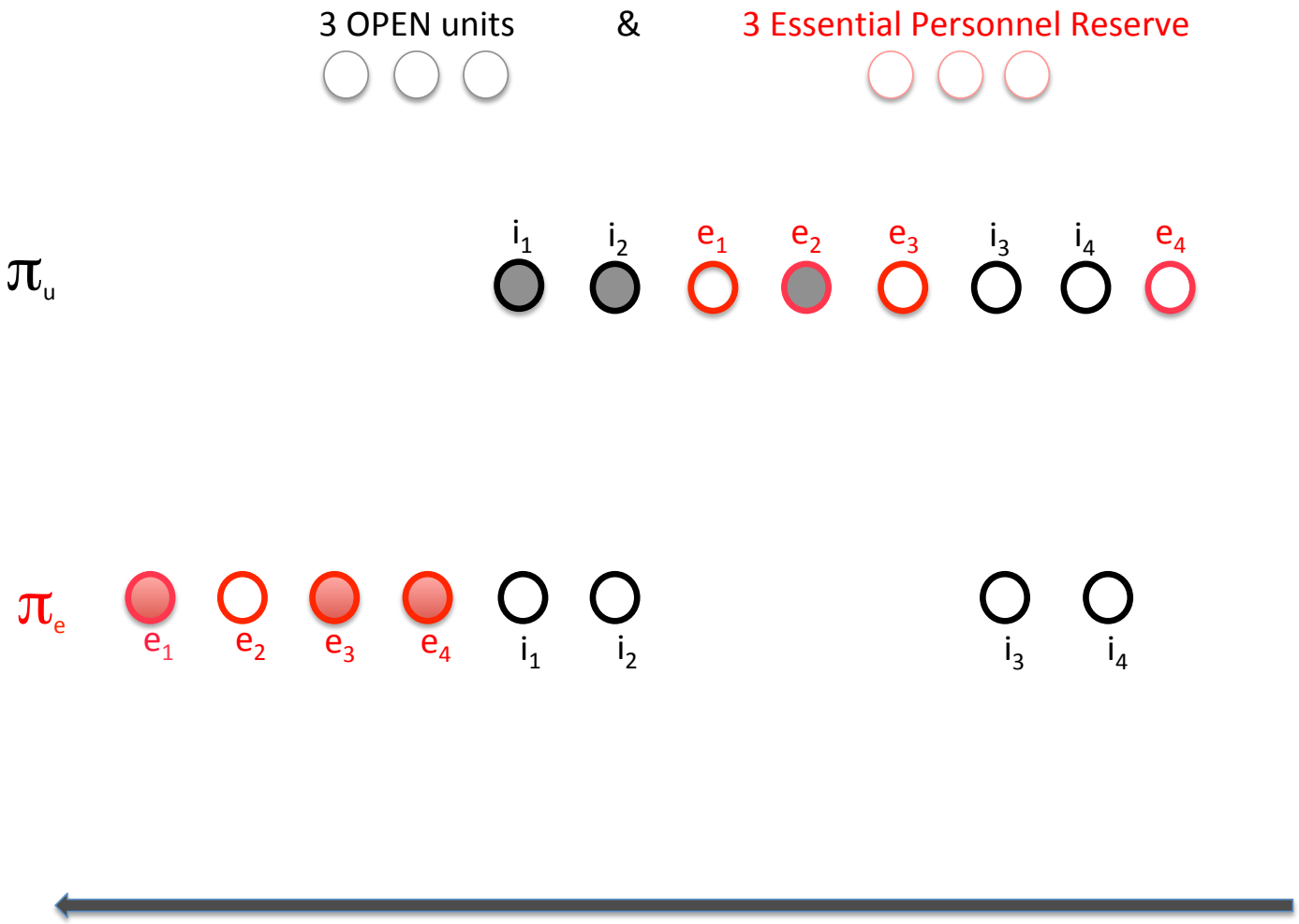

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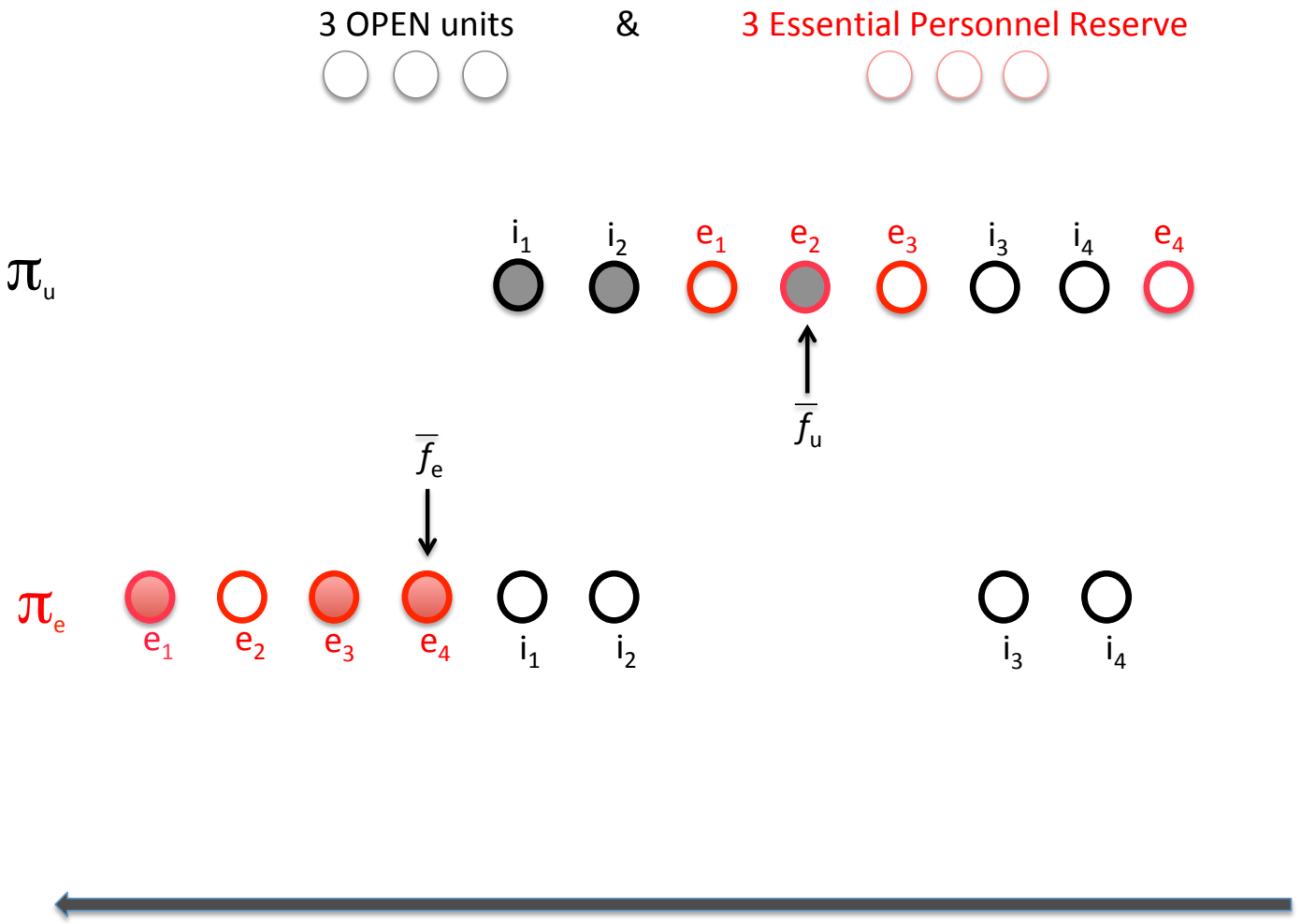

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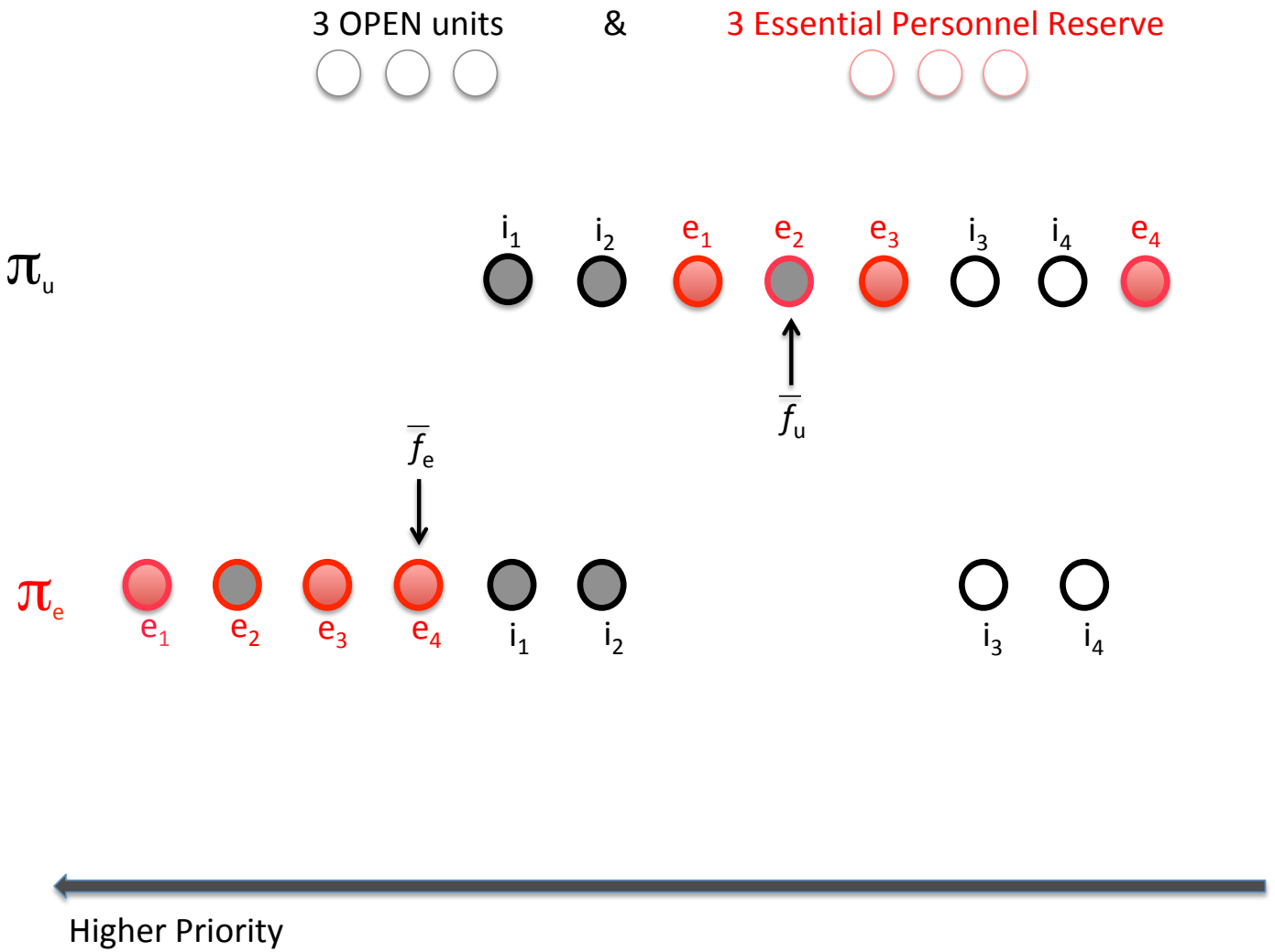

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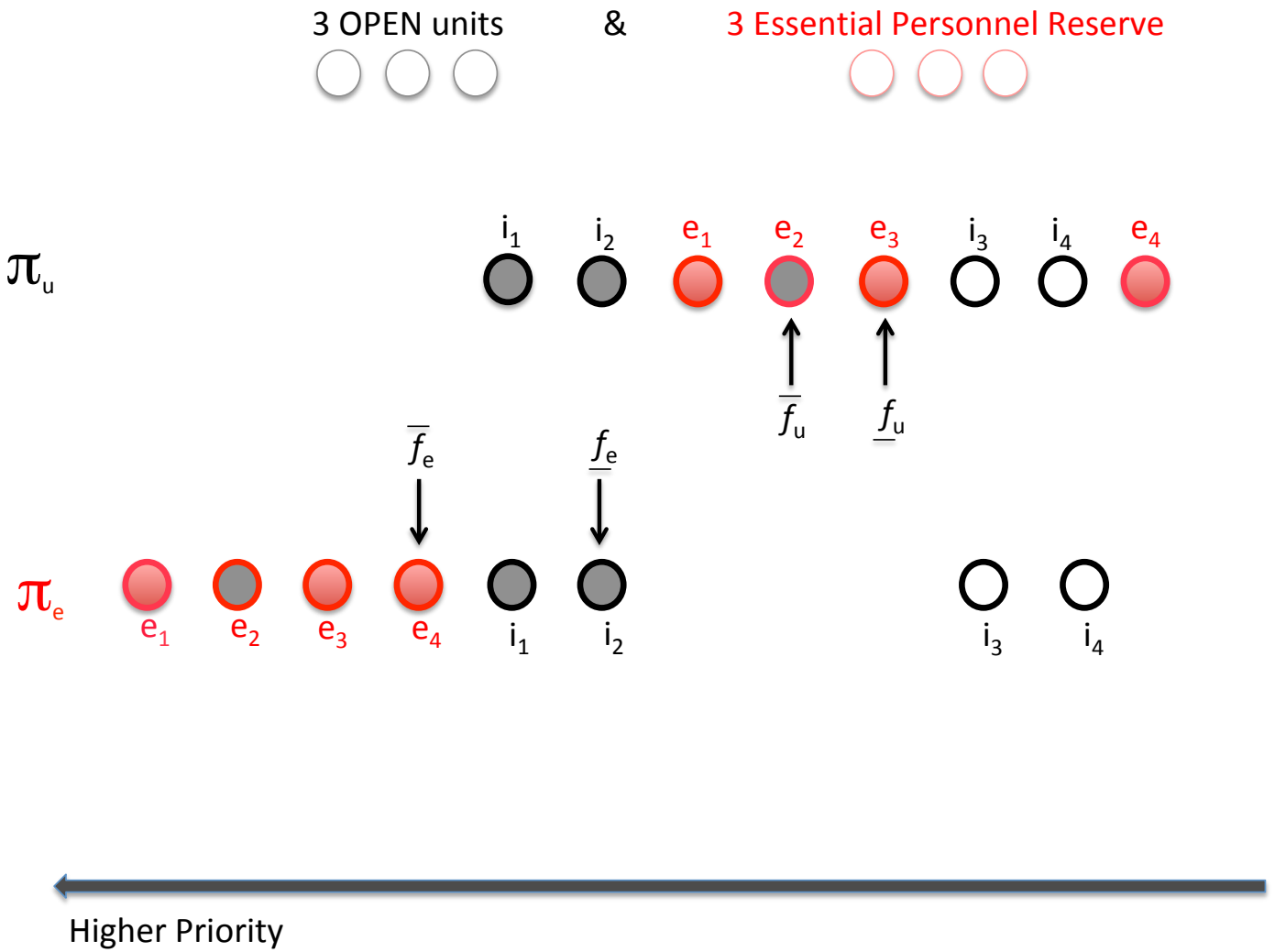

Cutoff Equilibria Properties

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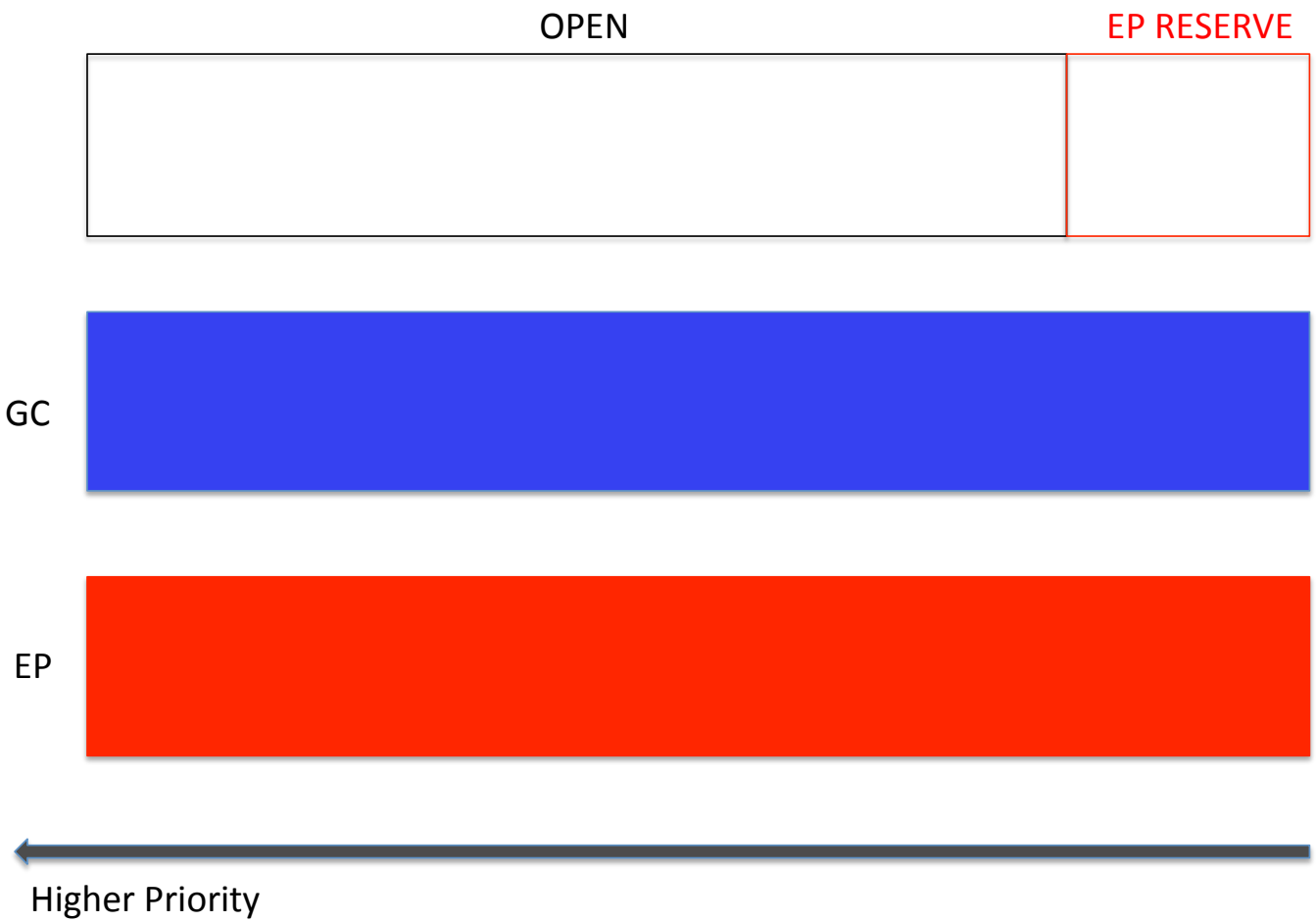
- The maximum cutoff indicates the selectivity of a category.
  - The higher priority the cutoff patient is, the more competitive the category is.
- How do you find cutoff equilibrium matchings?
  - We start with a situation where we process categories sequentially.
  - Most widespread practice in real-life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

Sequential Category Processing: Open-Reserved



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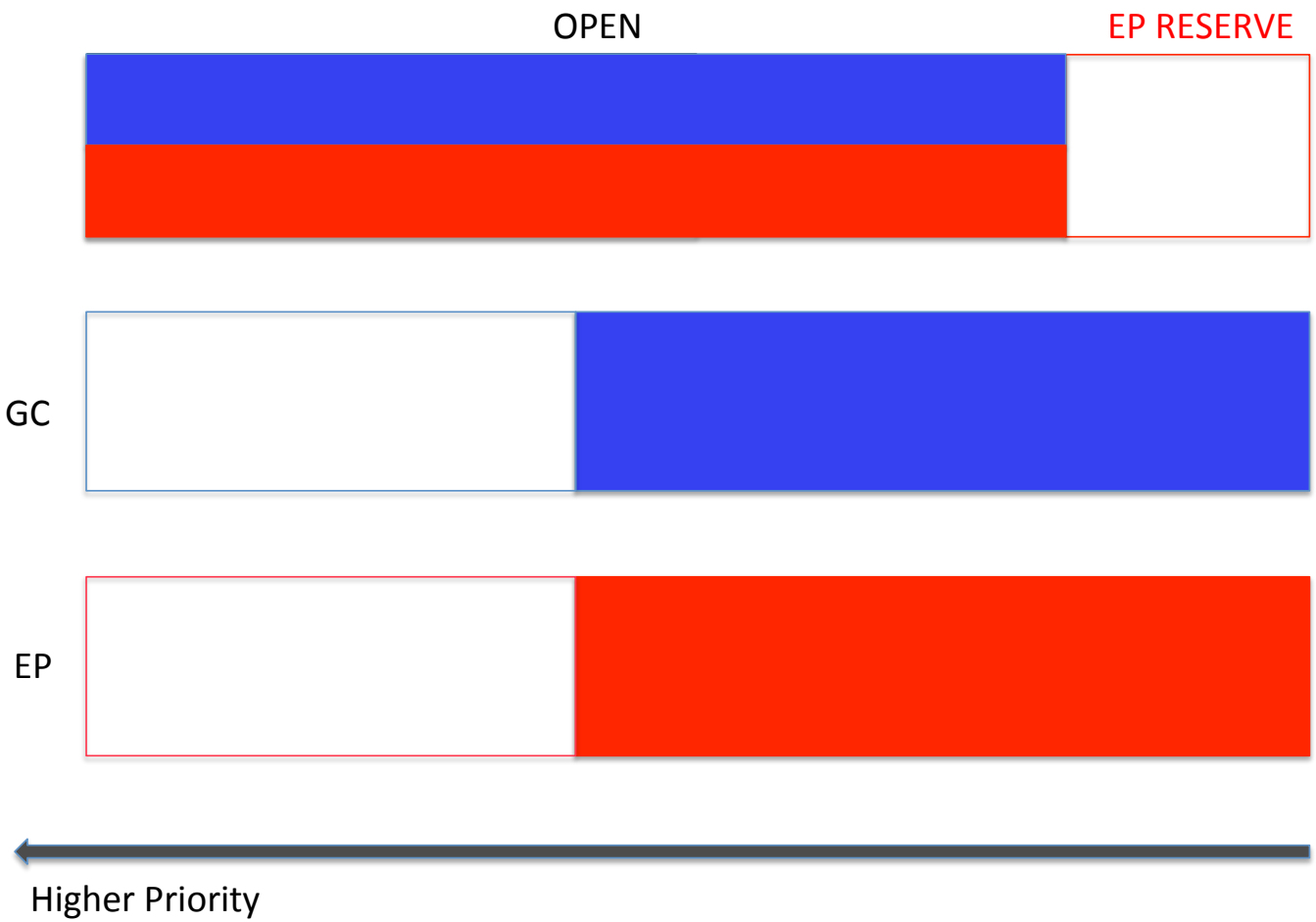
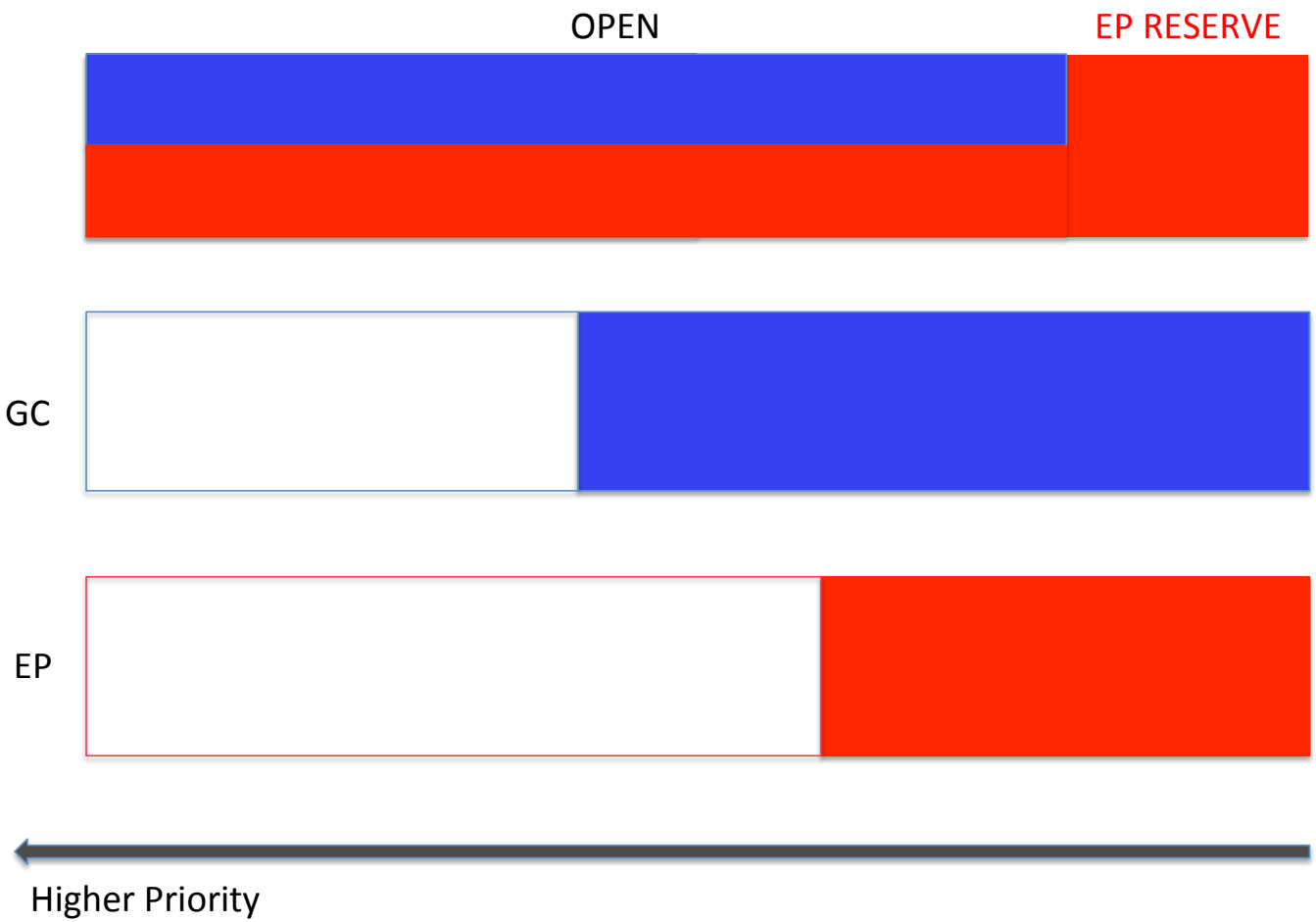


Open First - Reserved Next = Over & Above Policy



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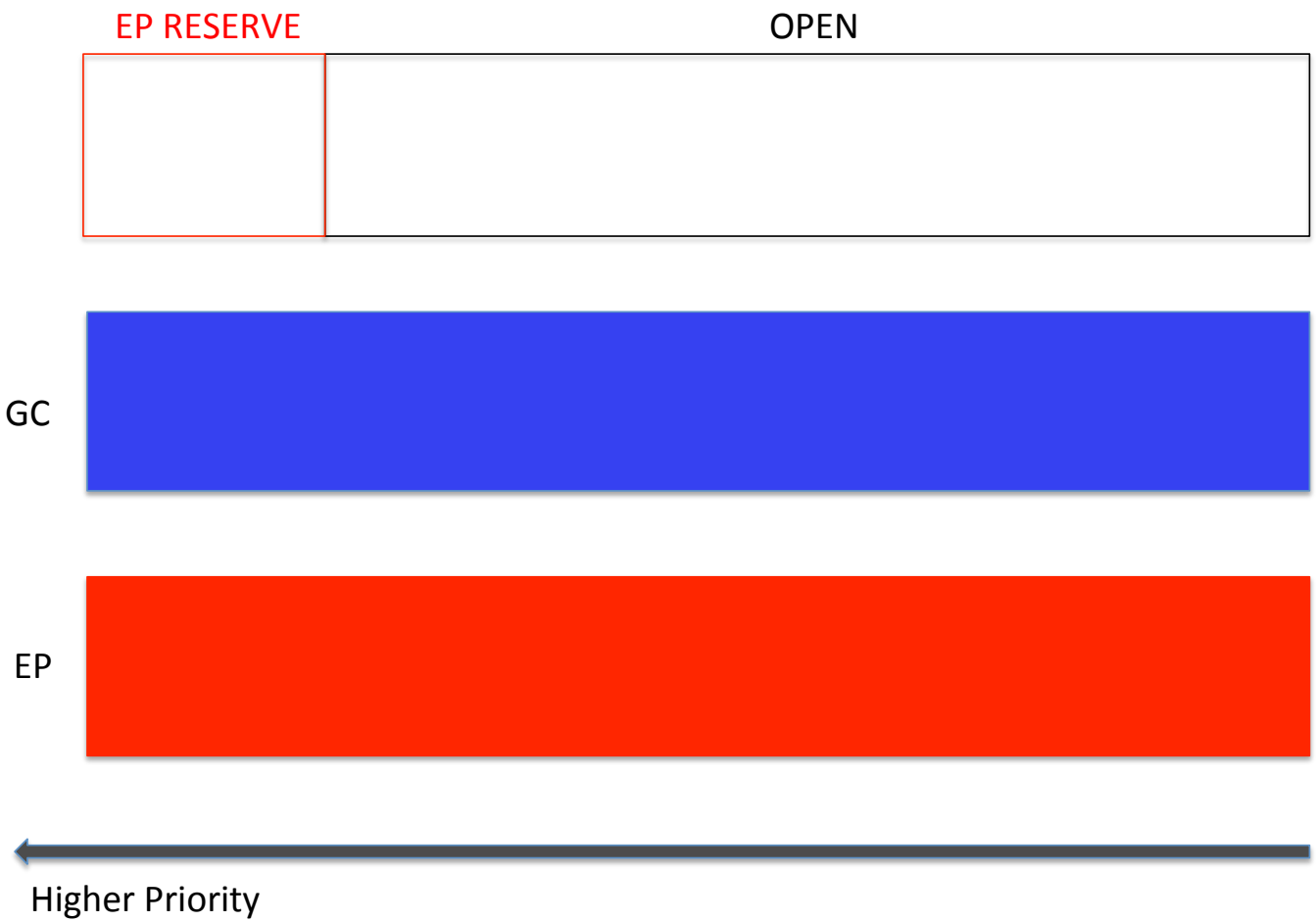

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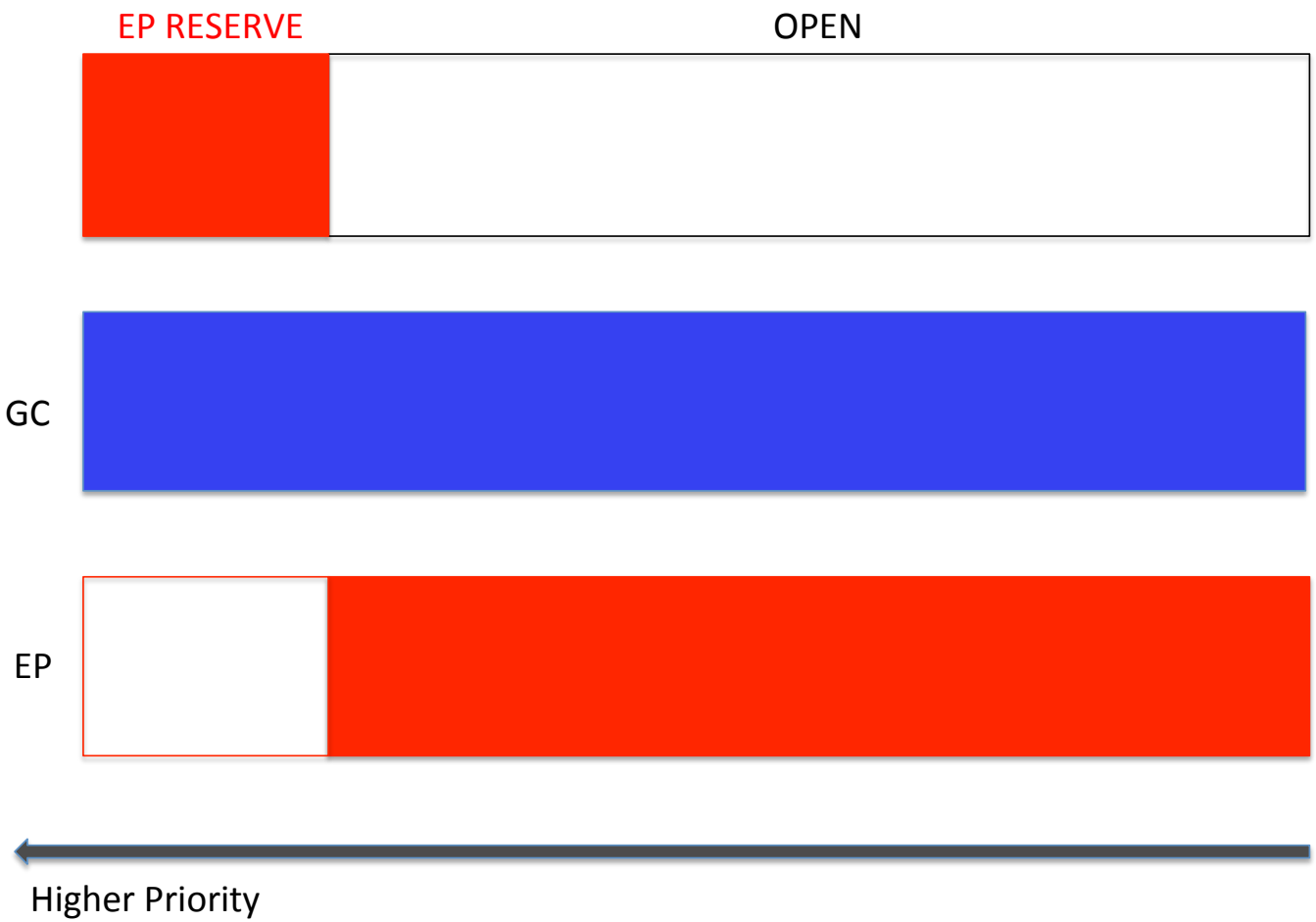

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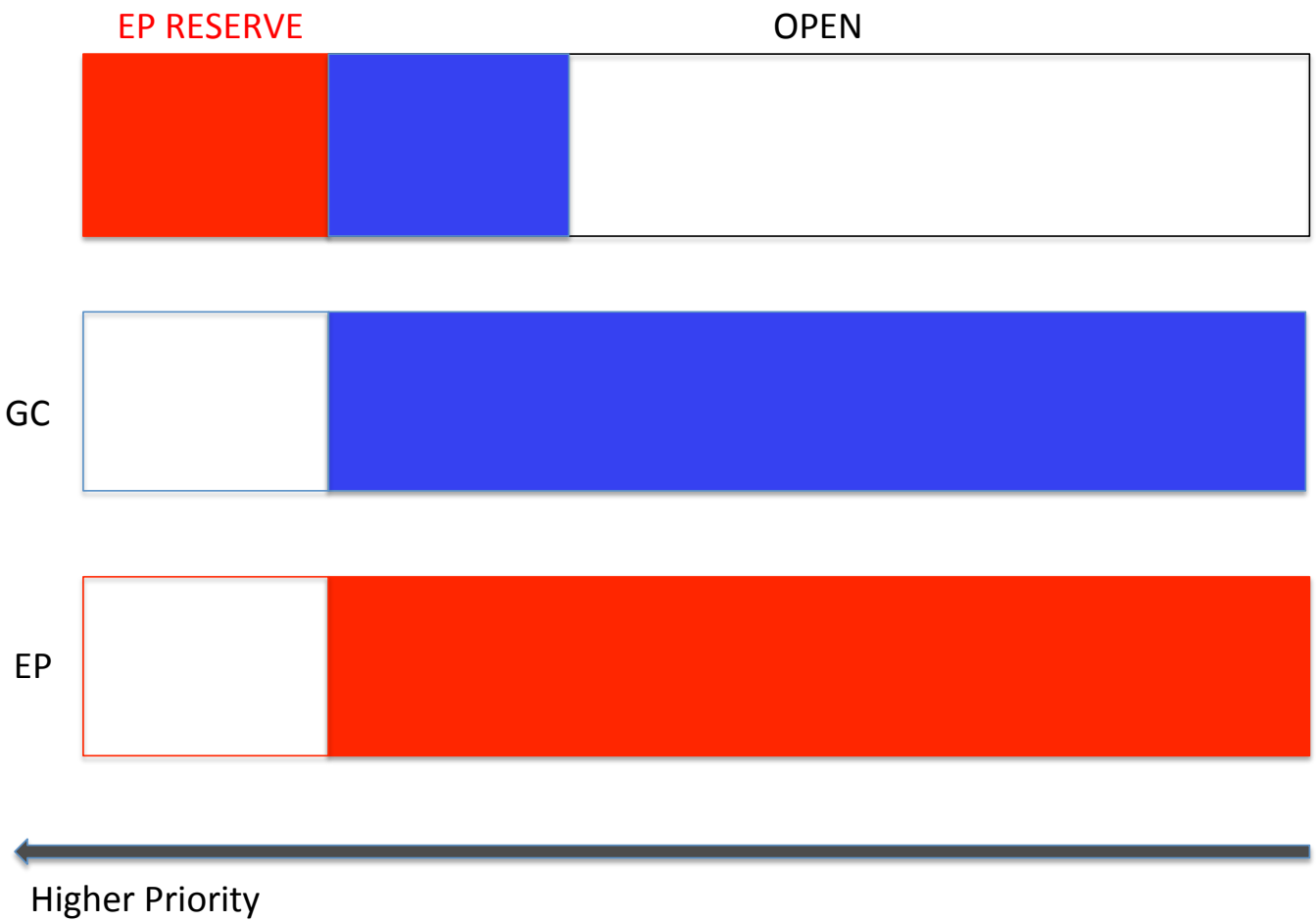
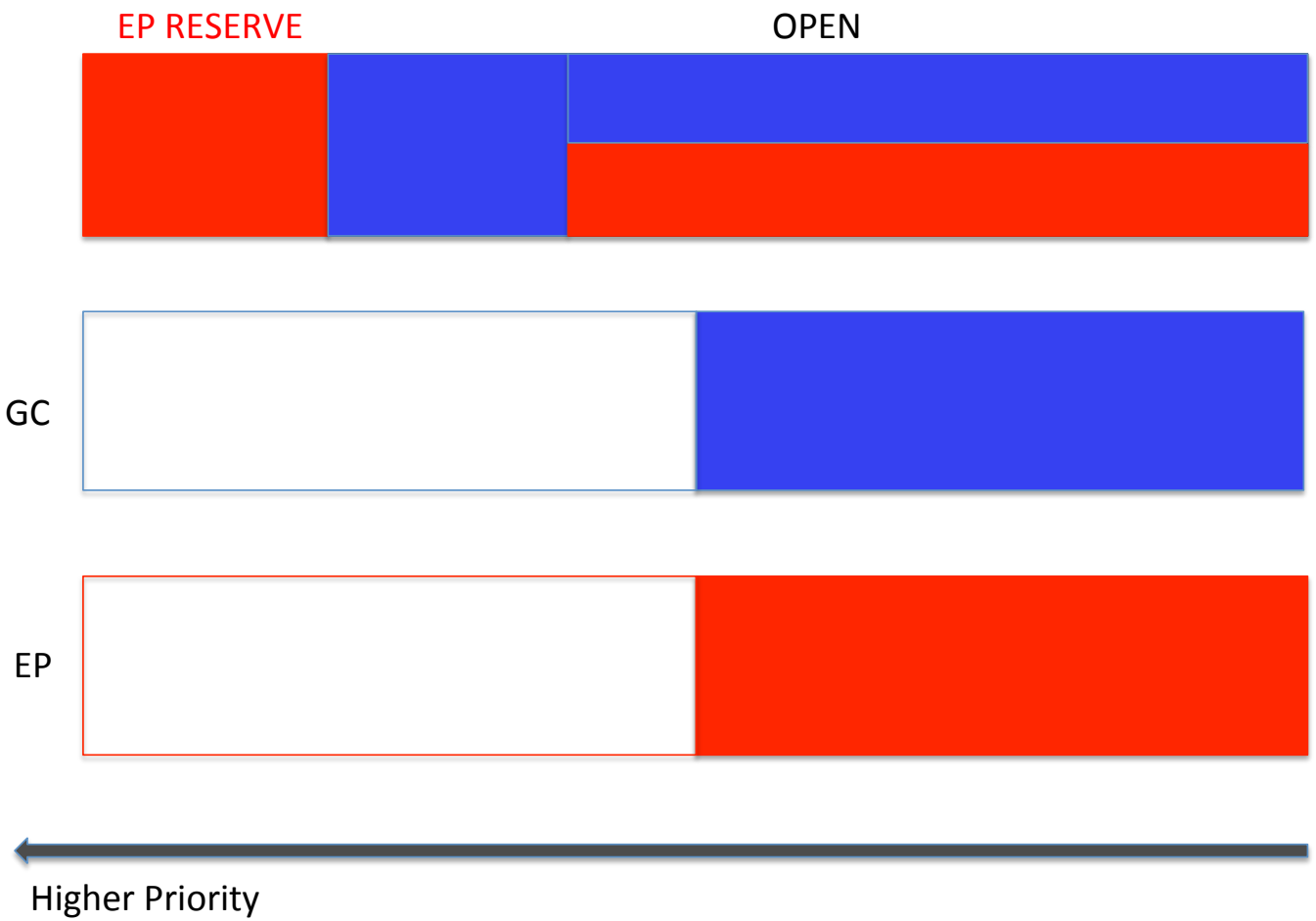


Reserved First - Open Next = Minimum Guarantee Policy



Construction of Cutoff Equilibria

- Example shows that
  - there may be several cutoff matchings, and
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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 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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- 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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  - 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 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 π_c-priority patients.

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- 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.
- 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 $\rhd, \rhd' \in \Delta$ such that:
  - $c' \rhd c$,
  - $c \rhd' c'$, and
  - for any $\hat{c} \in \mathcal{C}$ and $c^* \in \mathcal{C} \setminus \{c, c'\}$

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

That is, $\rhd'$ is obtained from $\rhd$ 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

Next, consider the following version of the problem, common in real-life applications.

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

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

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 $\rhd, \rhd' \in \Delta$ such that:
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$$\varphi_{\rhd'}(I_c) \subseteq \varphi_{\rhd}(I_c).$$

- Interpretation: The later a preferential-treatment category is processed, the better it is for its beneficiaries (set inclusion-wise).

Over & Above Reserve Processing

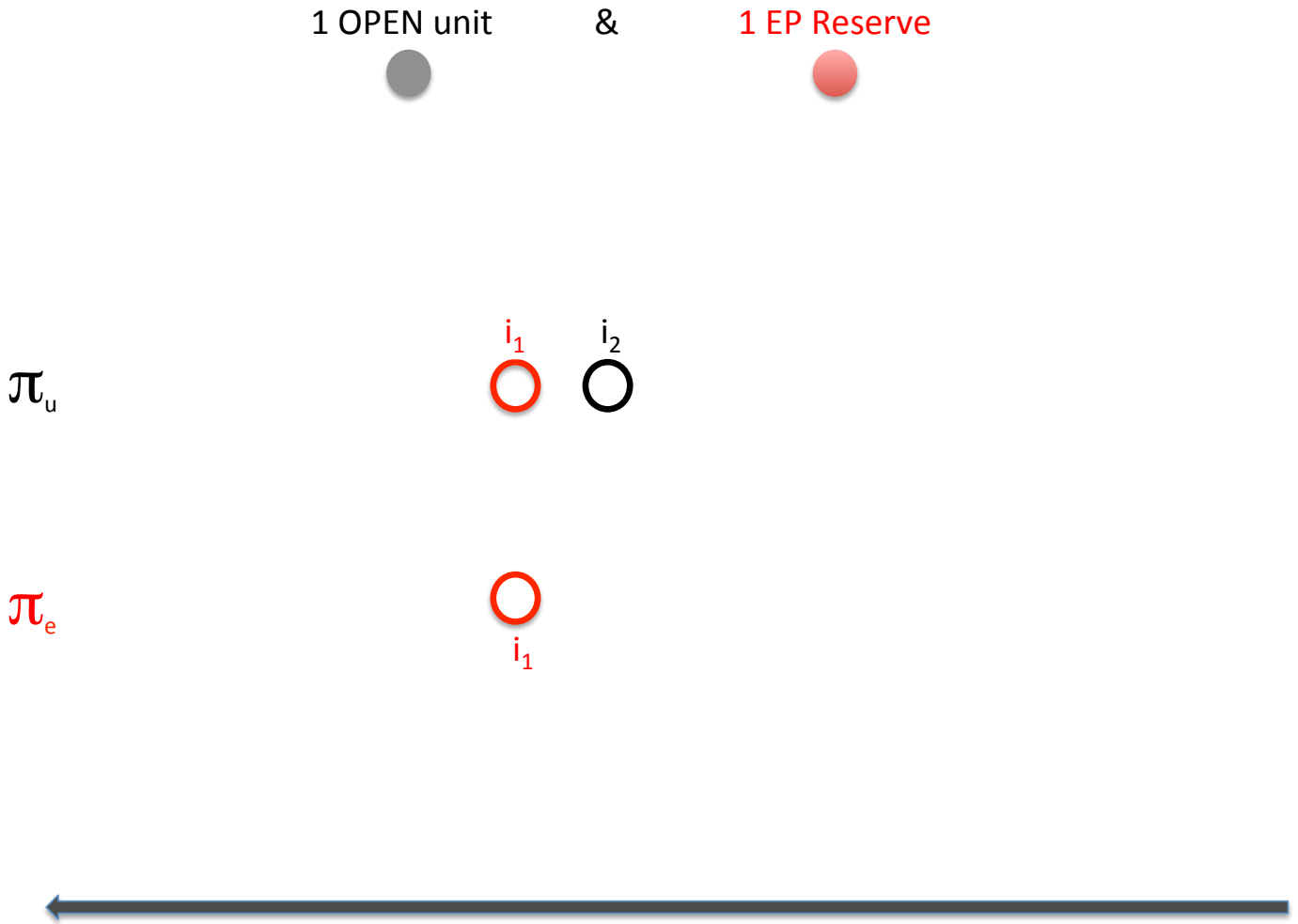
Over & Above Reserve Processing

- 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

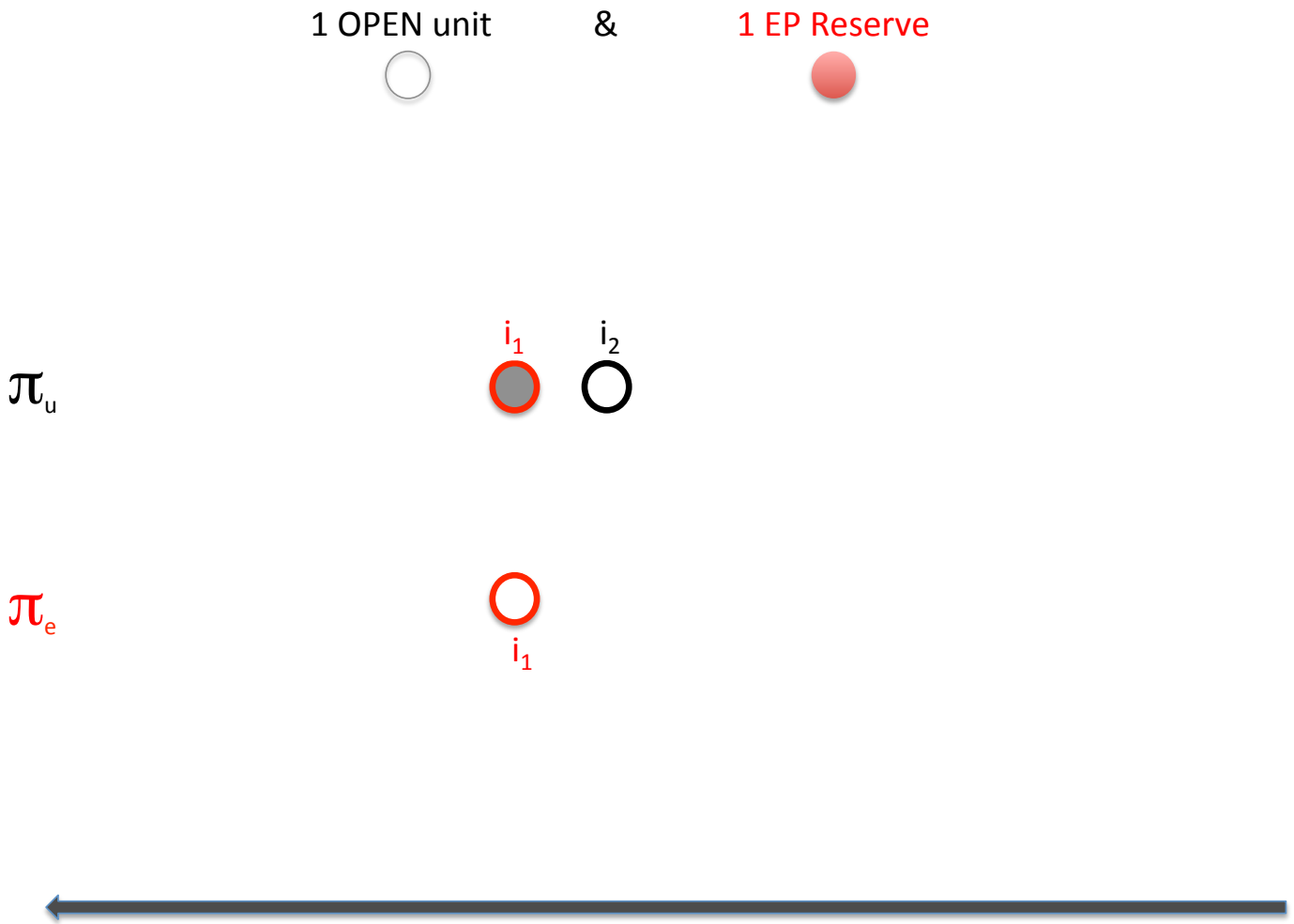
Minimum Guarantee Reserve Processing

- 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

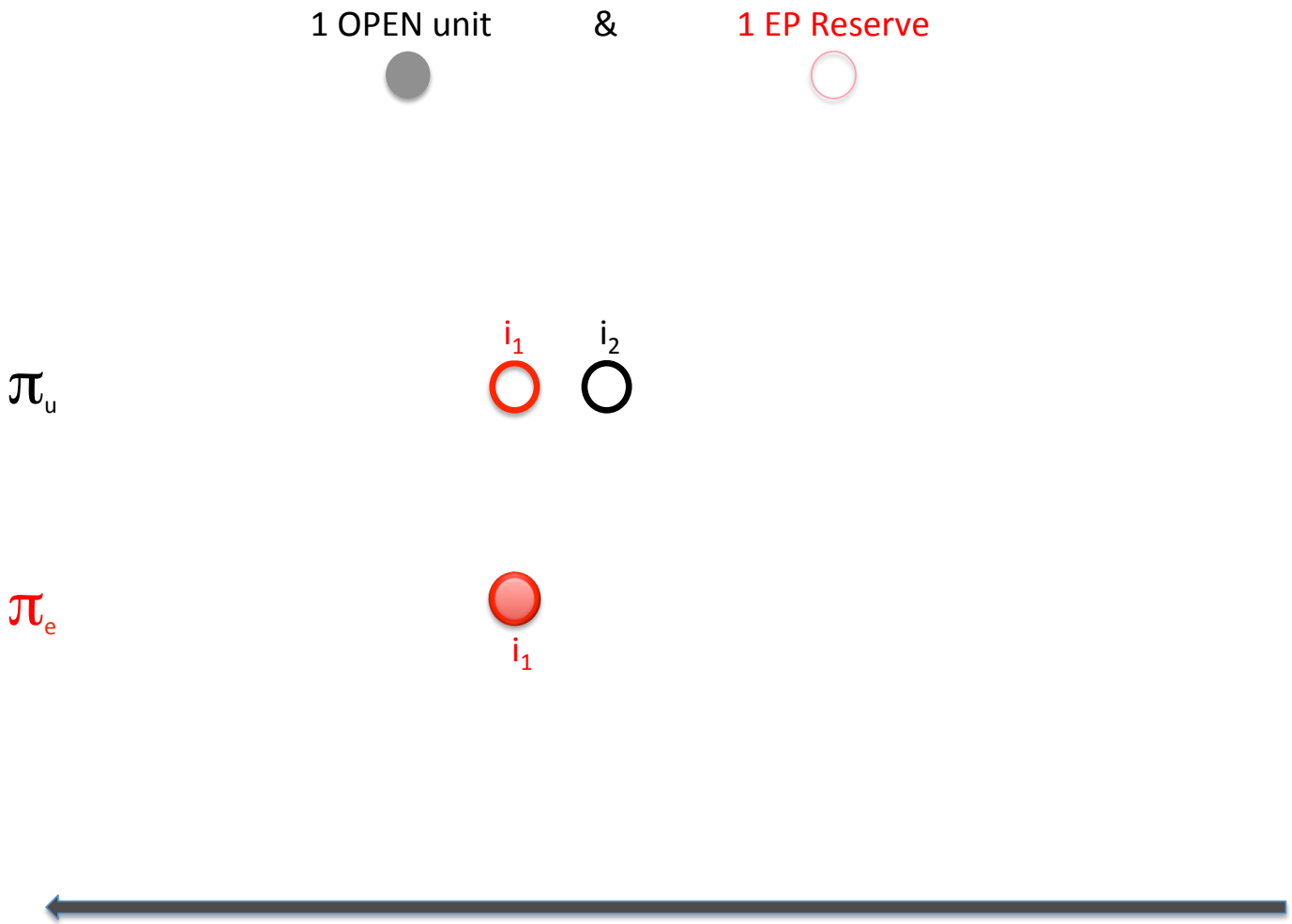
Example 2



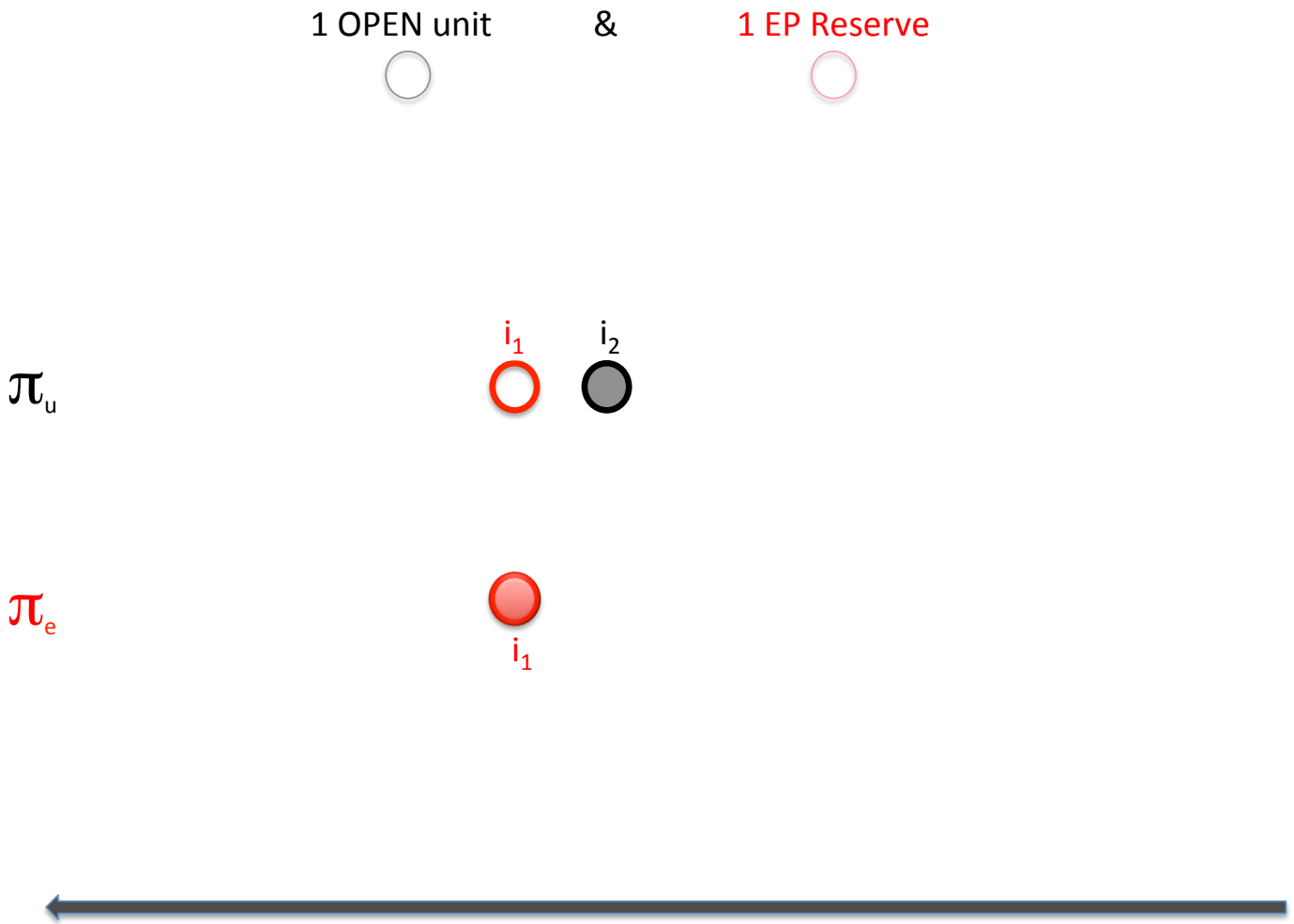
Example 2: Open ▷ Reserved $\Longrightarrow$ Idle Unit



Example 2: Reserved $\triangleright'$ Open



Example 2: Reserved $\triangleright'$ Open $\Longrightarrow$ Maximal Match



Possible 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 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.

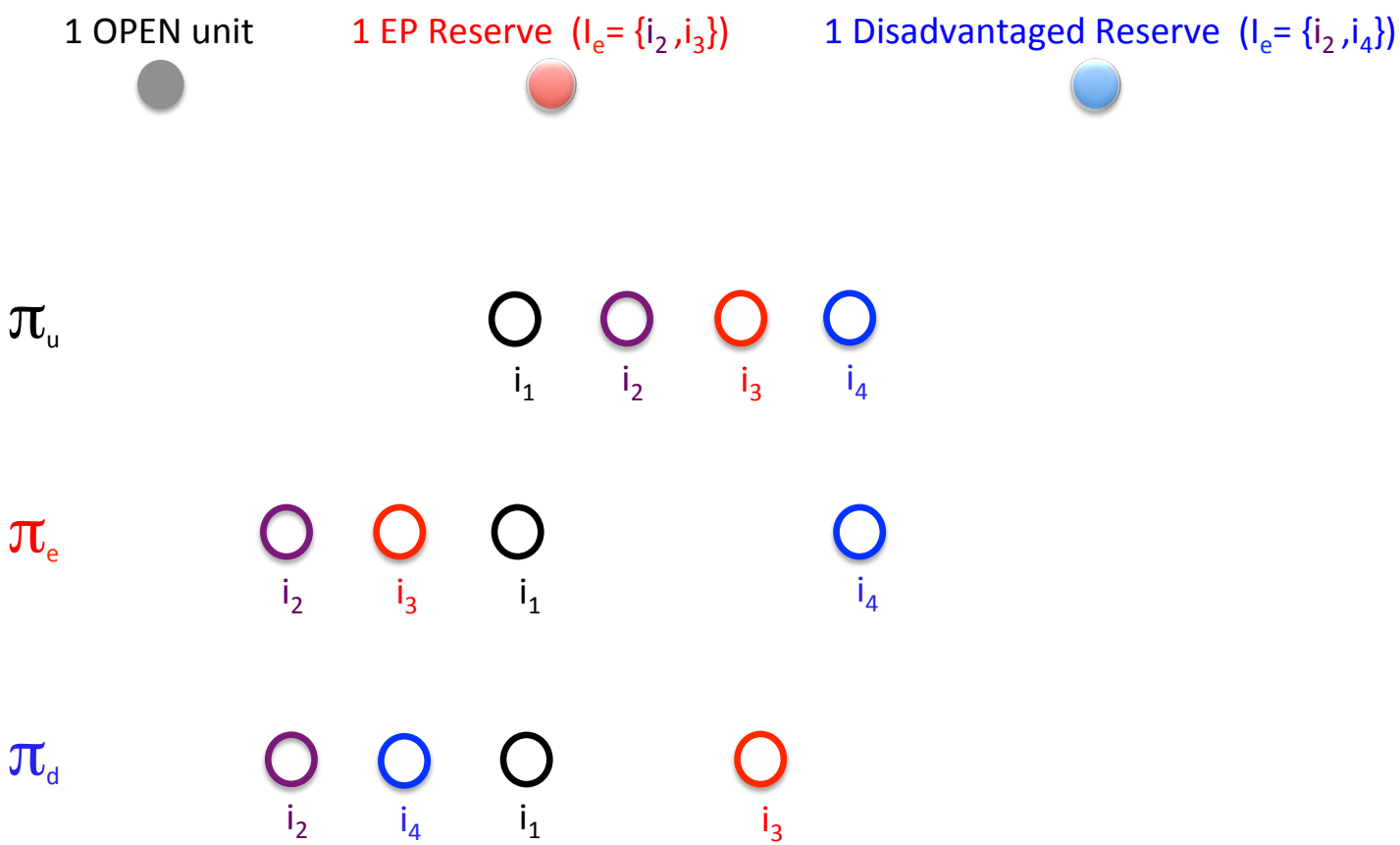
  $$i_1 \ \pi_c \ \emptyset \ \pi_c \ i_2$$

  Case 1 (Inefficient Reserve Processing): $u \triangleright c$
  - i_1 receives the unreserved unit and category-c unit is left idle.

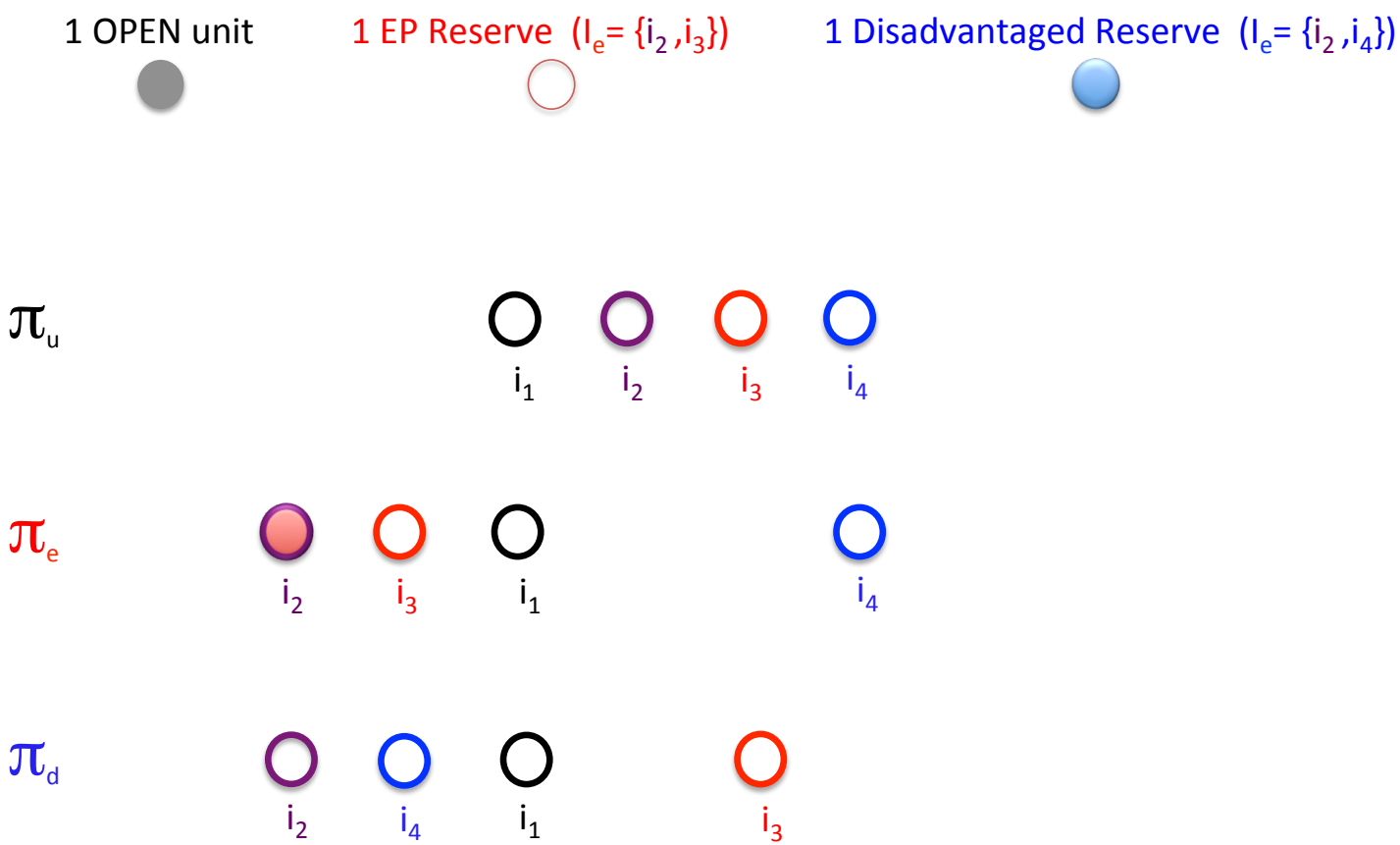
  Case 2 (Efficient Reserve Processing): $c \triangleright' u$
  - i_1 receives the category-c unit and i_2 receives the unreserved unit.

- 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


1 OPEN unit
1 EP Reserve ($I_e = \{i_2, i_3\}$)
1 Disadvantaged Reserve ($I_e = \{i_2, i_4\}$)
π_u
i_1 i_2 i_3 i_4
π_e
i_2 i_3 i_1 i_4
π_d
i_2 i_4 i_1 i_3
Higher Priority

Example 3: EP Reserve ▷ Disadvantaged Reserve ▷ Open



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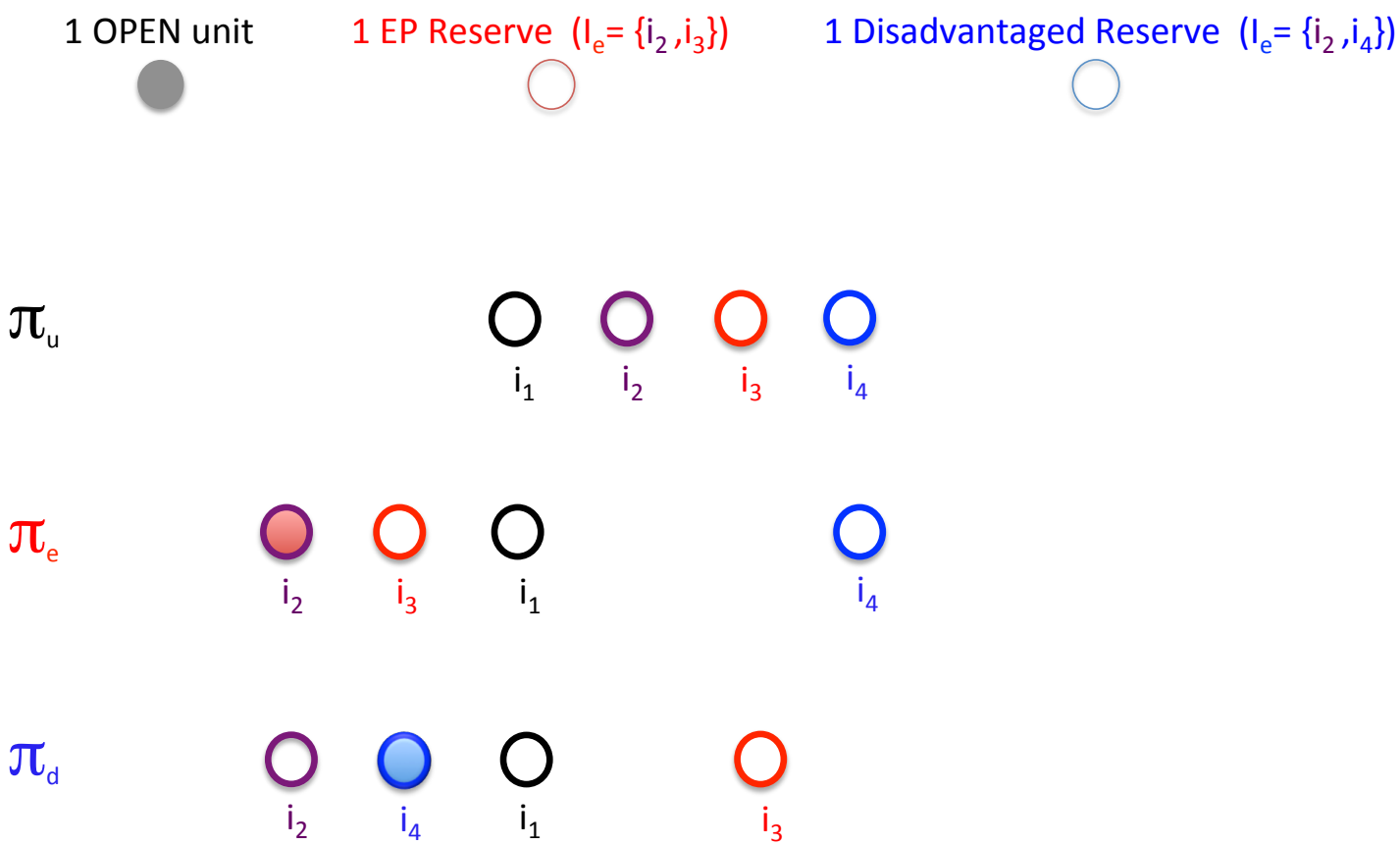

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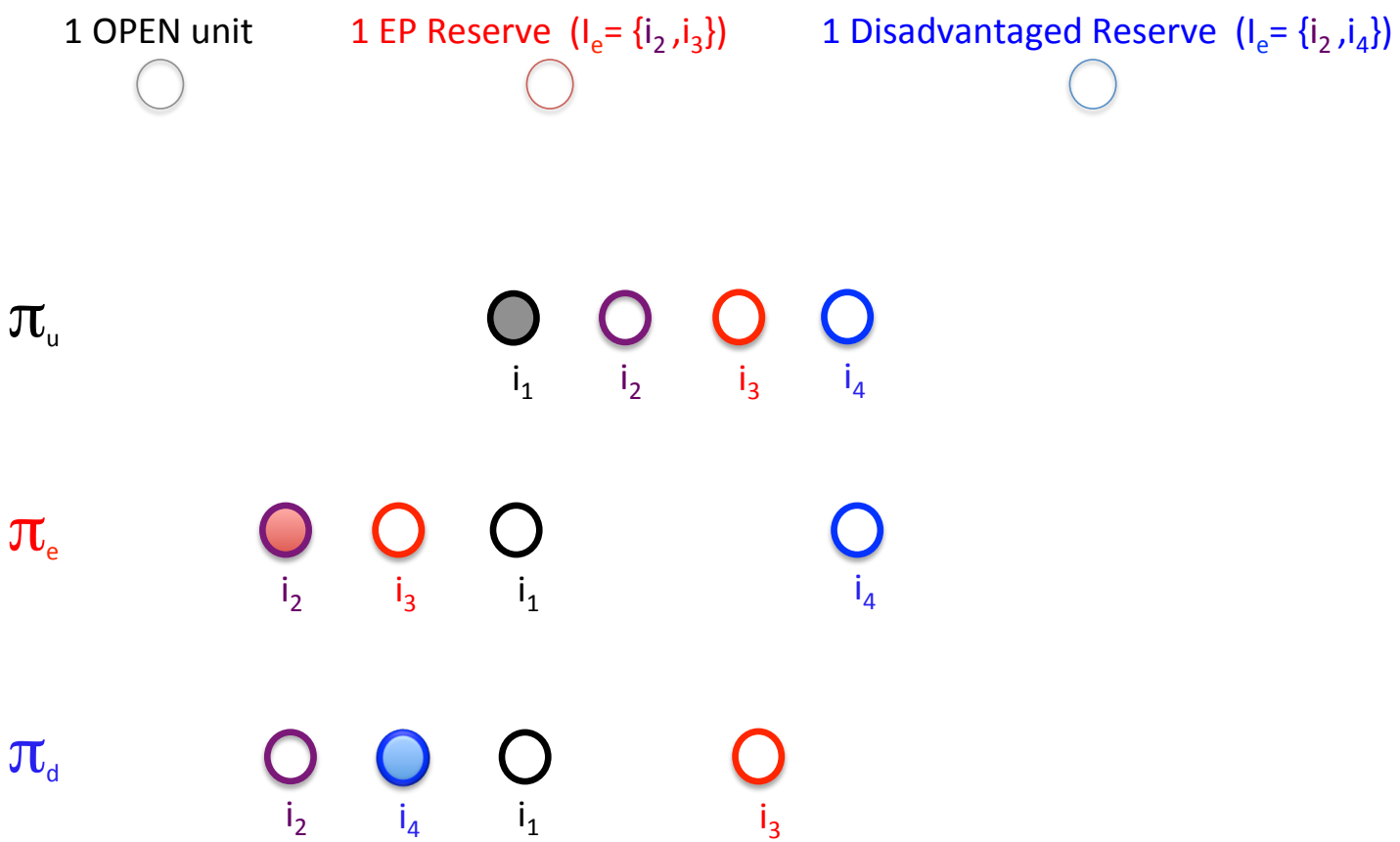
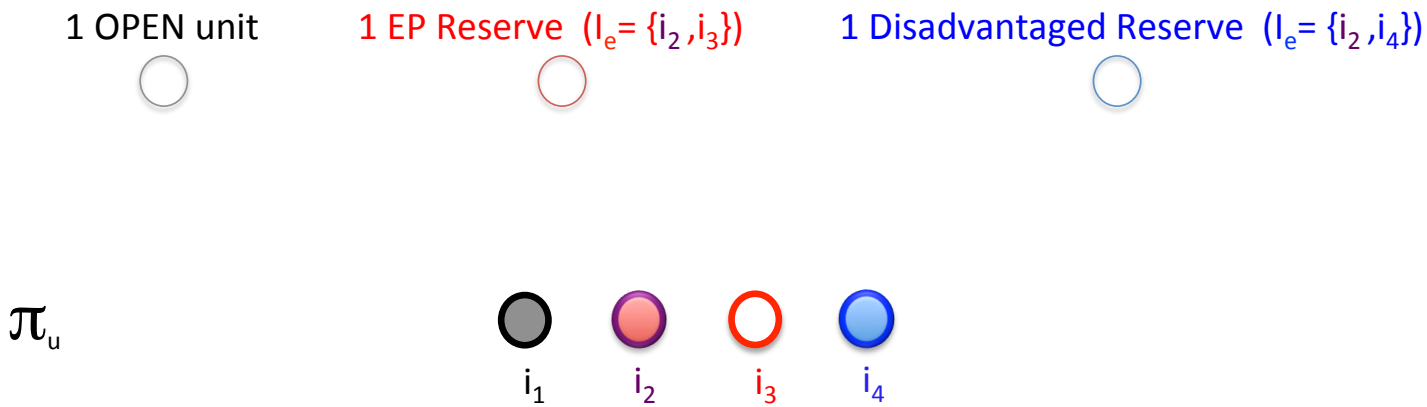
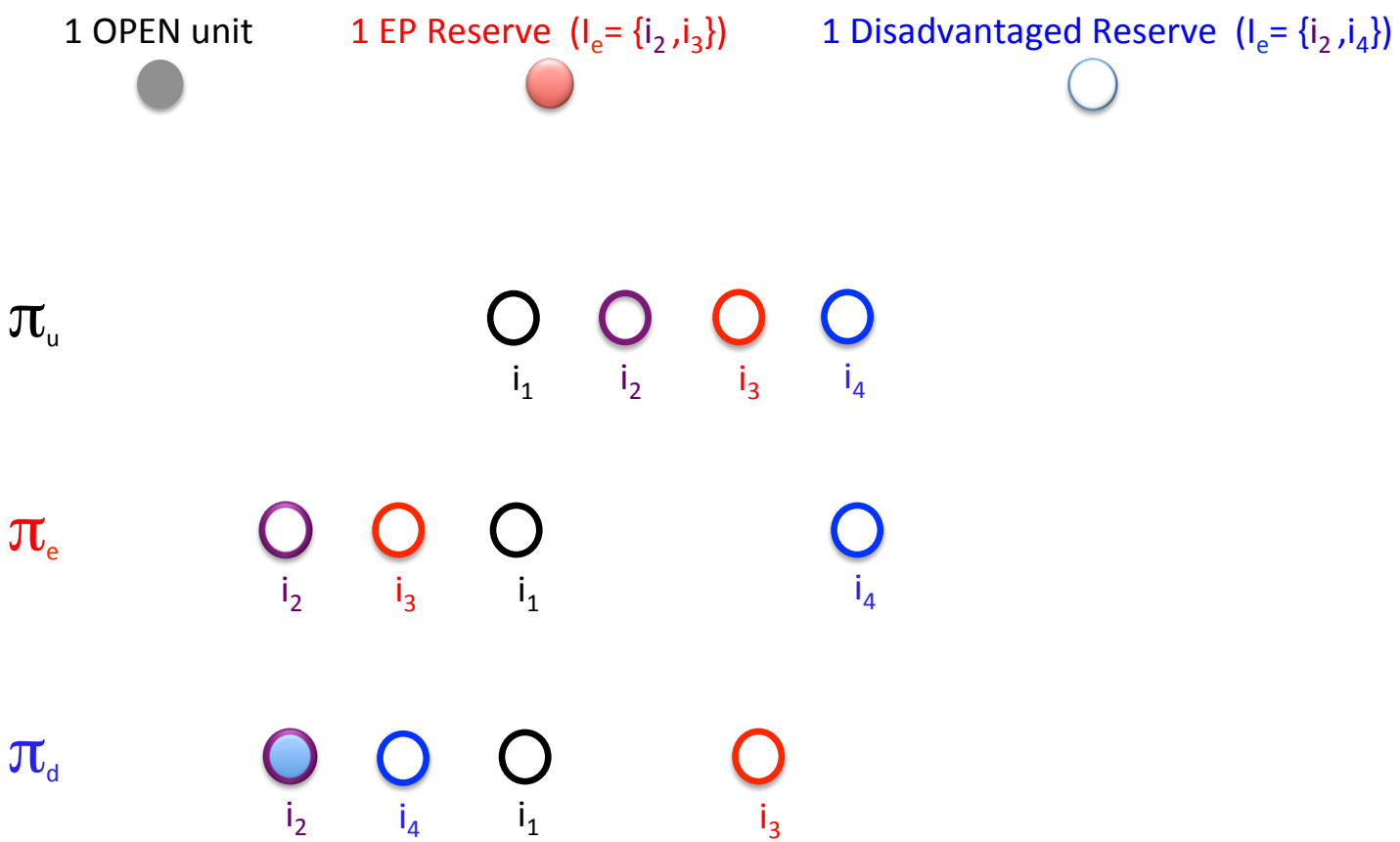


Example 3: i_4 Receives a Unit at the Expense of i_3



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



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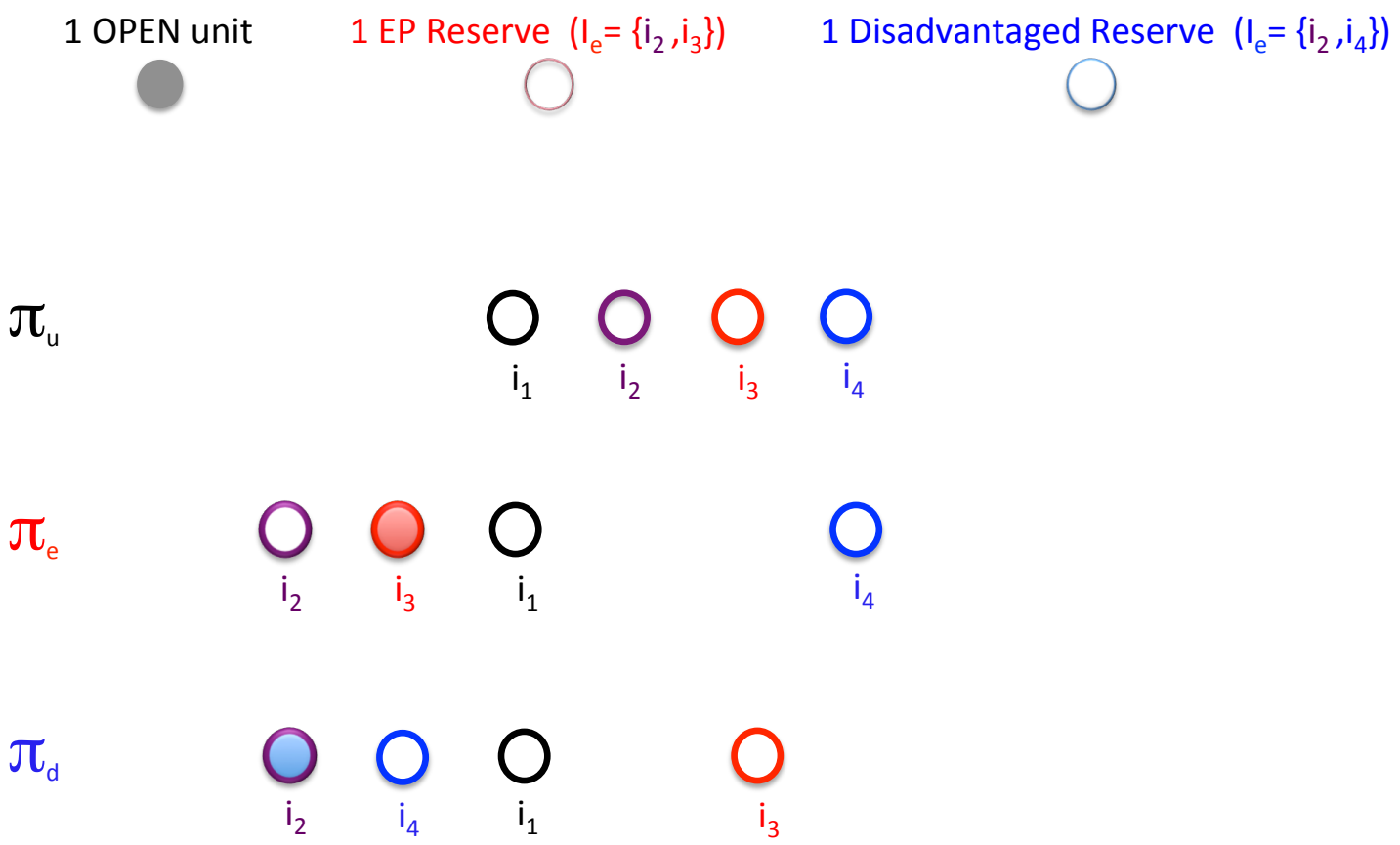

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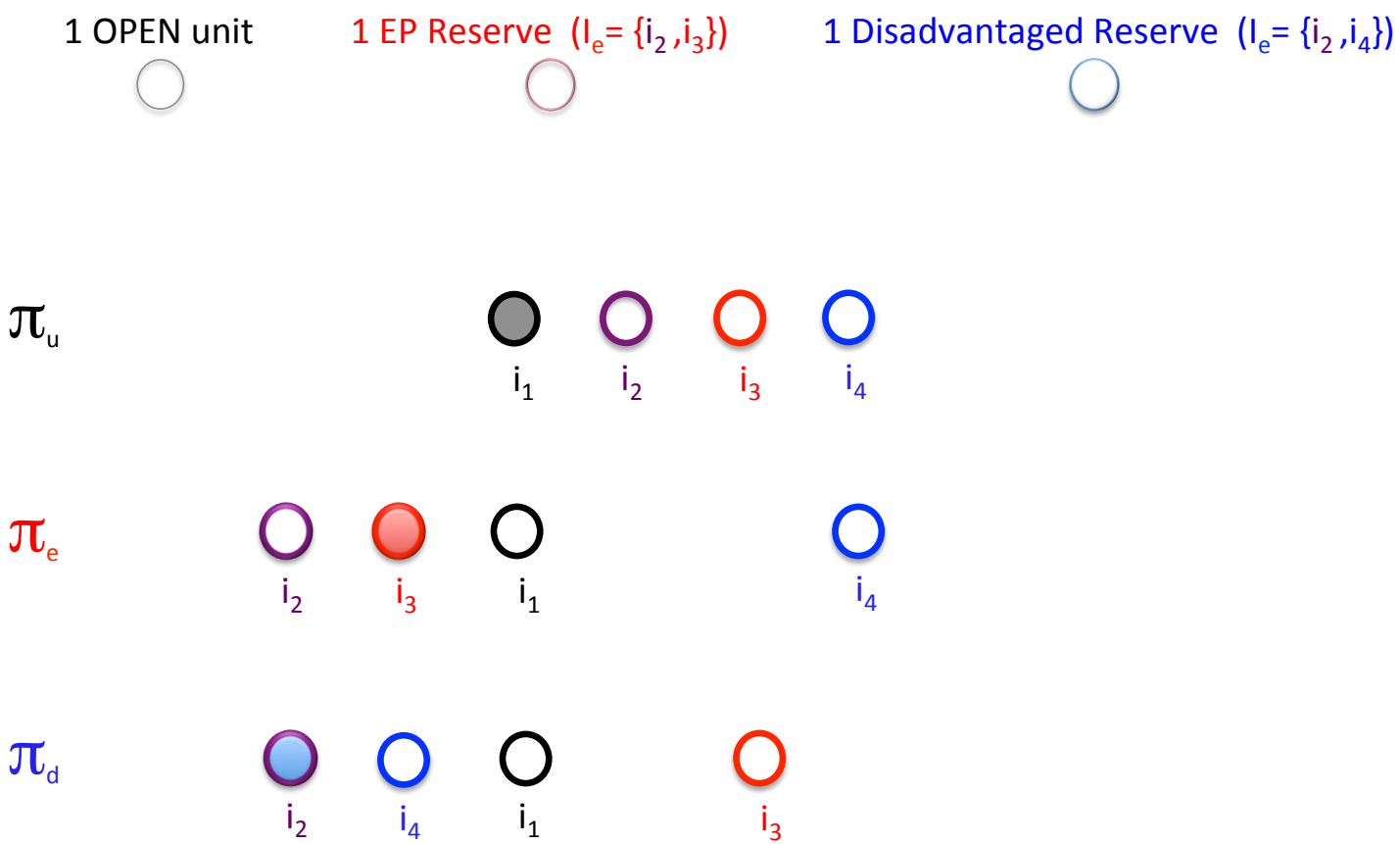
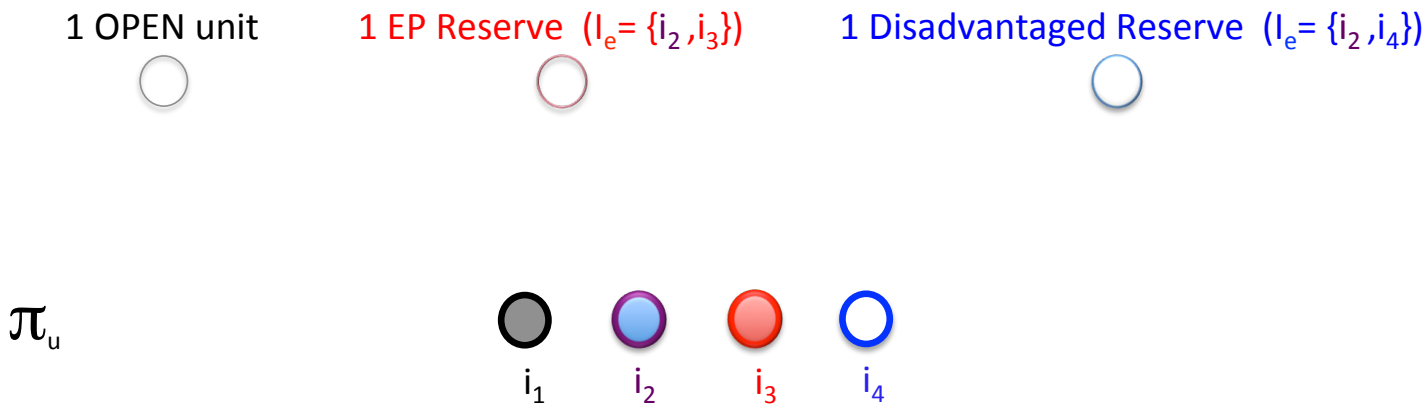


Example 3: Units Go to Highest Baseline Priority Agents



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 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.

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

$$\overline{f}_u^{\omega} \underline{\pi}_u \overline{f}_u^{\nu} \underline{\pi}_u \overline{f}_u^{\mu}$$

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  Then
  $$\overline{f}_u^{\omega} \underline{\pi}_u \overline{f}_u^{\nu} \underline{\pi}_u \overline{f}_u^{\mu}$$
- 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 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 reccommended 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

- 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).

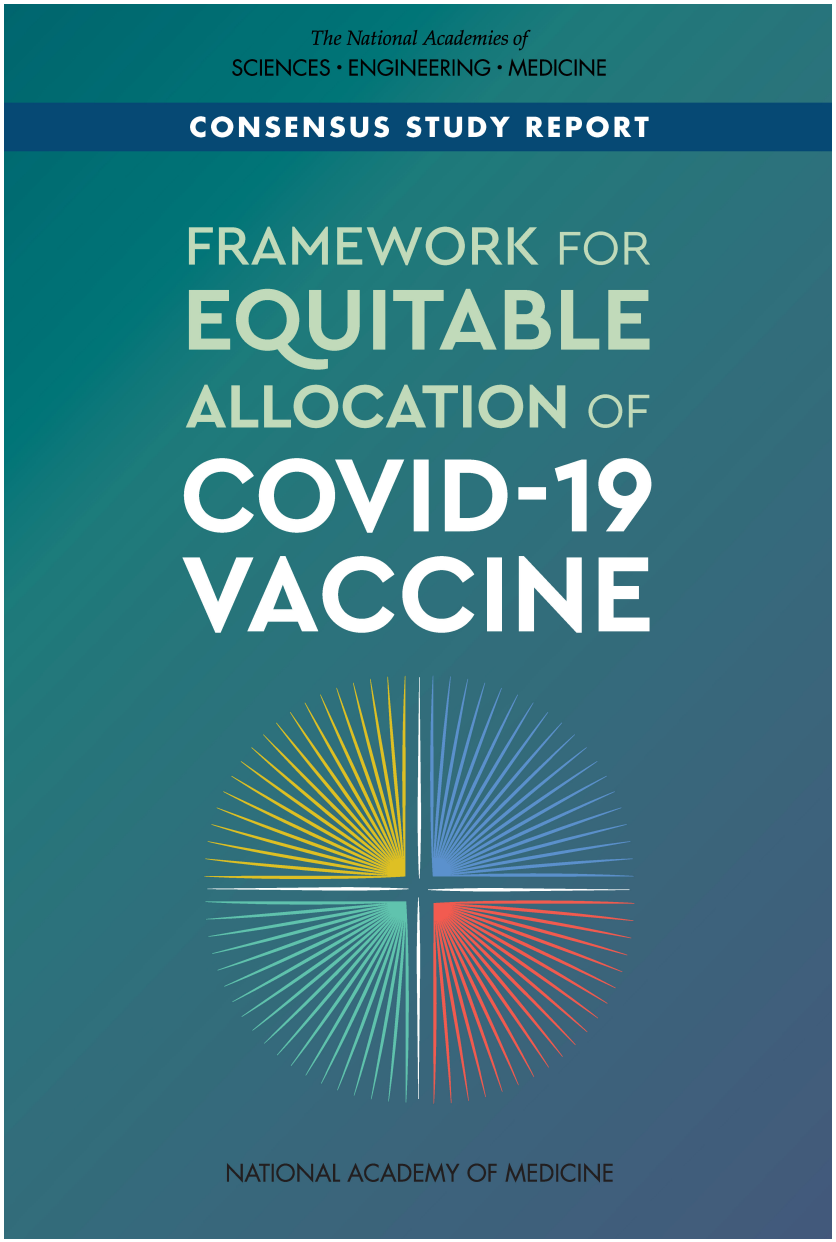
> *"Dividing the initial vaccine allotment into priority access categories and using medical criteria to prioritize within each category is a promising approach. For instance, half of the initial allotment might be prioritized for frontline health workers, a quarter for people working or living in high-risk 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 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.